THE STIMULUS SPECIFICITY OF THE ELECTRODERMAL RECOVERY TIME: AN EXAMINATION AND REINTERPRETATION OF THE EVIDENCE

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ABSTRACT

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This research was designed to test the hypothesis that the recovery time of the skin conductance response can be (a) independent of other electrodermal measures and (b) responsive to particular stimulus manipulations when other more commonly used measures of electrodermal activity are not. Experiment I employed a reaction time task, each trial consisting of a warning tone and an execution tone. The results indicated that the recovery time discriminated the two signals only when the number of responses in the intertrial interval and preparatory interval differed. For those subjects who responded only to the signals, the recovery time was strongly correlated with the intertrial interval but did not discriminate the two signals. In experiment II each subject was presented three different stimulus conditions (mirror tracing, rest and pressor) in all possible stimulus orders. The recovery time did not discriminate between the stimulus conditions differently than any other electrodermal measure. The results of these experiments suggest that the recovery time primarily reflects the amount of previous responding and is not independent of other electrodermal measures. The relevance of these data to other research implicating a dual component electrodermal system is discussed.

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To my wife Jan

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INTRODUCTION

Researchers in virtually all areas of psychology have used electrodermal measures as dependent variables. Edelberg (1972a) estimates the electrodermal literature to encompass over 1500 articles in the English language alone, providing a convincing numerical confirmation of their relationship to psychological phenomenon. This is especially impressive in view of the fact that we do not yet fully understand the physiological mechanisms or the adaptive functions of these responses, nor have we arrived at consensus opinion of proper recording techniques (Lykken, 1968).

Regardless of the method being used to record electrodermal activity, investigators often implicitly assume that electrodermal activity most directly reflects the secretion of sweat by the sweat glands. In spite of this several investigators have suggested that there may be more than one effector system and that these systems may be independently innervated (Darrow, 1927, 1933; Davis, 1934; Edelberg, 1964, 1966, 1970, 1972a, 1972b; Edelberg & Wright, 1964; Katkin, 1965; Wilcott, 1964). If electrodermal activity does reflect the activity of two different effector systems then it should be possible to analyze electrodermal activity such that the relative influence of the two components could be determined. This is of interest to behavioral scientists because of the possibility that different components of electrodermal activity may be individually responsive to different behavioral manipulations. In general, investigators have successfully demonstrated that different electrodermal measures might be differentially responsive to different stimulus manipulations. In many cases data from these studies have been taken as evidence for a dually innervated response system. This evidence is listed below according to the electrodermal measures which have been used.

1. The positive component of the skin potential response is more likely to appear with intense stimuli than with fairly neutral stimuli (Burnstein et. al., 1965; Forbes, 1936; Forbes & Bolles, 1936; Fujumori, 1955; Raskin, Kotses & Bever, 1969; Wilcott, 1958). Raskin, Kotses and Bever (1969) argue that the positive component reflects a defensive response which is qualitatively different from an orienting response which is represented by the negative component.

2. Alerting or orienting responses are associated with relatively larger skin conductance responses on the dorsum of the hand while defensive, anxiety-like responses are typically associated with relatively larger responses on the palmar areas (Katkin, Weintraub & Yasser, 1967; Mordkoff, Edelberg & Ustick, 1967). These findings assume that one component of the response is located in the epidermis and that this component is more in evidence in areas of lesser sweat gland concentration such as the dorsum of the hand. Thus, palmar responses more accurately reflect the sweat gland component of the response since there is greater sweat gland concentration in the palmar region.

3. The correlation between skin potential level and skin conductance level may be fairly high during rest but may be near zero during periods of active motor performance (Hupka & Levinger, 1967). Lykken, Miller and Stratham (1968) have shown that the correlation is high for

subjects with a low skin conductance level. These two reports seem to be consistent since one would expect that motor performance would be accompanied by a higher skin conductance level.

4. Skin conductance level and electrodermal frequency are independently related to different psychological processes (Katkin, 1965; Kilpatrick, 1972; Miller, 1968; Miller & Schmavonian, 1965). In general it appears that electrodermal frequency is related to emotional arousal while skin conductance level is related to cognitive processing (Kilpatrick, 1972).

5. Water absorption responses are more likely for some tasks than for others although skin conductance responses are in evidence during all tasks (Edelberg, 1966). Water absorption was measured by passing saturated air over the skin surface and measuring the amount of water loss from the air.

6. The recovery time of the skin conductance response is fairly independently related to the goal orientation of the subject (Edelberg, 1970, 1972b). Slower recovery times are related to more defensive, anxiety like responses while faster recovery times are related to goal oriented activity. Axe and Bamford (1970) have shown that the recovery limb can discriminate between subtypes of schizophrenia based on biochemical analysis. Furedy (1972) has indicated that the recovery time is a highly sensitive indicator of the anticipated intensity of electrical shock.

The last two approaches are of most interest because they represent attempts to find measures directly related to hypothesized effector systems. Edelberg (1972a) has proposed an electrodermal model which can explain most data in which it appears that different measures of electrodermal activity may be relatively independent of each other. Edelberg believes that most of the data can be accounted for if sweating and reabsorption are separately controlled processes. For example, if the reabsorption process were active, the recovery times would be shorter, there would be less change in skin conductance level, and the positive component of the skin potential response would be more prominent.

Edelberg concludes that recovery time most unequivocally reflects the reabsorption response and that the recovery limb is a measure of the subject's goal orientation. On the other hand, more commonly used measures of electrodermal activity such as skin conductance level and electrodermal frequency are simply measures of general activation. These conclusions are derived from a series of experiments in which subjects are asked to perform various tasks while electrodermal measures are recorded. In the first series of experiments (Edelberg, 1970) the data indicated that the recovery time could be used to discriminate one task from another when more commonly used measures of electrodermal activity could not. However, insufficient data presentation in these experiments does not allow one to determine whether recovery time was indeed independent of skin conductance level and electrodermal frequency. For example, one cannot determine whether gross changes in electrodermal frequency or skin conductance level between tasks influenced the recovery time. If the recovery time is independent of other electrodermal activity, one would expect that responses occurring in close temporal contiguity should at least occasionally have different recovery times.

The only experiment in this series in which adjacent responses were compared involved a reaction time task. In this experiment the recovery time did differentiate between the warning and execution signals for six of the nineteen subjects. In five of these six subjects shorter recovery times were elicited by the execution signal.

Edelberg's second recovery limb report (1972b) seemed to be designed to correct some of the methodological inadequacies reported in his previous article. In this experiment each subject was put in seven different tasks and the skin conductance level, electrodermal frequency, and recovery time were measured for each of the tasks. The response pattern was similar for most tasks with lower electrodermal frequencies being associated with lower skin conductance levels and longer recovery times. The one exception to this pattern was the cold pressor task in which there was a high skin conductance level and a high electrodermal frequency but a long recovery time. Edelberg concluded that these data indicated that the recovery limb was a measure of goal orientation since the cold pressor task was not a goal oriented activity while all of the other tasks which produced faster recovery times were goal oriented.

The design of this experiment leaves several questions unanswered. For example, all subjects received the same order of task presentations. Since it is not known how previous electrodermal activity affects the recovery time of subsequent responses it could be that the long time constant associated with the cold pressor task is due to some peculiar order effect rather than due to the nature of the task. Moreover, the effects of vasomotor activity on the recovery limb are not known. It is known that vasomotor activity affects the height of the response (Edelberg, 1964). Since immersing a hand in cold water normally produces vasoconstriction in the rest of the body, it is possible that the longer recovery times are due to vasomotor activity rather than due to the effects of some effector in the epidermis.

There are solid empirical grounds for questioning Edelberg's interpretation of his data. Pilot research conducted prior to the experiments reported herein indicated that the recovery limb is strongly influenced by responses which occur prior to the response in question. Responses which closely follow other responses have faster recovery times than do responses which are not immediately preceded by a response. Thus, in a reaction time task it could be that there is some anticipatory responding in the preparatory interval which causes the recovery time of the response to the execution signal to be shorter. While this effect might be due to some central process the possibility of a peripheral effect cannot be discounted. If the recovery limb is a function of previous responding, Edelberg's finding (1972) that slow recovery times were associated with the cold pressor task could be due to an order effect. In that experiment the cold pressor task was preceded by the task which produced the lowest electrodermal frequency, the rest period.

The present study was designed to examine some of the findings reported by Edelberg (1970, 1972b). Specifically, it was designed to determine (a) whether the recovery limb might be influenced by the occurrence of previous responses and (b) whether there are some effects which might be due to the vasomotor activity arising from the use of the cold pressor task.

Experiment I was designed to replicate the reaction time experiment reported by Edelberg (1970). Experiment II was designed to examine the critical features of the second recovery limb study reported by Edelberg (1972b). In the latter study Edelberg chose three stimulus situations for special analysis; the rest period, the mirror tracing task, and the cold pressor task. Experiment II employs these three stimulus situations but unlike Edelberg's study the order was varied. Moreover, one half of the subjects received the hot pressor task rather than the cold pressor task.

Method

Subjects

The subjects were twelve males and twelve females who received extra course credit for their participation. They were recruited from introductory psychology classes at Michigan State University. Subjects who did not give scoreable responses in at least two of the three task situations in experiment II were replaced until there were a total of 24 subjects. Five subjects were replaced for this reason.

Apparatus

Skin potential and skin conductance were recorded on a Beckman type RS Dynograph with both channels operated in the DC mode. The frequency response of the channels was flat to 60Hz. All electrodes were of the silver-silver chloride type, constructed according to Venables and Martin (1967). The electrolyte was a Unibase preparation (Lykken & Venables, 1971). For the skin conductance measure a constant voltage (0.5V) bridge was used which had an output of 1.0mV per 1.0 micromho of input. The polygraph then read out directly in conductance units. Immediately before applying the electrodes, the sites were cleaned with 70% ethanol prep pads and allowed to dry. The two conductance electrodes were placed about 1.5 cm apart on the hypothenar eminence of the left hand. The active skin potential electrode was placed on the thenar eminence of the same hand. The reference electrode was placed over the ulnar bone on the left arm one fifth the distance from the elbow to the wrist.

Design and Procedure

When the subject reported for the experiment he was given a copy of the instructions and asked to read along while the experimenter read the instructions out loud. (See appendix A for a representative copy of the instructions.) After the instructions were read, the subject was asked if he had any health problems which might become a problem during the experiment because of the stressful effects of the pressor task. No subjects refused to participate for health reasons. The subject was then shown the mirror tracing apparatus and instructed in its use. The electrodes were then attached and the subject was seated in a sound resistant booth and shown the reaction time switch. After the polygraph operator confirmed that everything was operating properly, the booth was closed and the subject was told to sit quietly and relax for about five minutes until the reaction time experiment began.

Experiment I

The reaction time experiment consisted of 15 reaction time trials. The alerting and execution signals were 75 db tones delivered from a speaker and of .5 second duration. One of the signals was a 400 Hz tone while the other signal was a 1500 Hz tone. One half of the subjects received the low tone for the alerting signal and the high tone for the execution signal (the RTA condition). For the other subjects the high tone was the alerting signal and the low tone was the execution signal (the RTB condition). The intertrial interval and preparatory interval ranged from 10 to 30 seconds with a mean of 20 seconds. There were four different random sequences which are listed in appendix B. These sequences were assigned to the subjects according to the subject list in appendix C.

Experiment II

This experiment included three different tasks presented in all possible orders. Subjects were assigned to the different orders according to a predetermined list (see appendix C). The tasks were:

1. Mirror Tracing (MT)

The subject was given the mirror tracing apparatus and was told to start tracing as soon as the blue light came on and to stop the task as soon as the light went off. The light was on for two minutes.

2. Pressor; hot pressor (HP) or cold pressor (CP)

A container of water was placed in the booth and the subject was told to immerse his hand up to the wrist when the blue light came on and to remove his hand when the light went off. The light was on for 40 seconds. For one half of the subjects the water was at zero degrees centigrade and for the other subjects the water was at forty eight degrees centigrade.

3. Rest Eyes Open (REO)

The subject was told to rest with his eyes open until given further instructions. This period laster for two minutes.

Data Scoring

Experiment I

The recovery times of all scoreable stimulus elicited responses were measured using the half-time method (Edelberg, 1970). A scoreable response was defined as a response which had a pen deflection of at least 3 mm, occurred at least seven seconds after the previous response and recovered at least half its height before the next response.

Experiment II

The skin conductance level, electrodermal frequency, and time constant were determined for each task for each subject. The skin conductance level was the average of the initial and final level for each of the tasks. The electrodermal frequency was the count of all responses which produced positive going pen deflections during the task divided by the number of minutes in the task. The recovery time was measured from the first scoreable response which occurred at least 15 seconds after the start of the task. Responses were rated as being scoreable or non-scoreable according to the criteria mentioned for experiment I.

Results and Discussion

Experiment I

Since Edelberg's original report (Edelberg, 1970) indicated that the recovery time could discriminate between the warning and execution signals only for some subjects, a group analysis was not performed on the reaction time data. The data for individual subjects is summarized in Table 1. The subjects are ordered according to the ratio of the average recovery time of the execution signal response to the average recovery time of the warning signal response. The heights of

TABLE 1

Summary of individual data for total height (TH) and average recovery time (T) for experiment I arranged according to the ratio of execution recovery time to warning recovery time (ET/WT)

		Spontaneous Responses, Intertrial Interval		Warning Signal Elicited Responses			Spontaneous Responses, Preparatory Interval		Execution Signal Elicited Responses		
Subj. #	ET/WT	TH	N	T	TH	N	TH	N	T	TH	N
16	1.52	19.9	14	3.71	29.1	11	29.9	14	2.44	26.4	14
12	1.27	25.4	14	1.81	23.8	13	42.9	15	1.42	26.5	14
21	1.14	1.2	8	4.33	15.6	9	1.1	8	3.81	17.5	13
8	1.13	5.2	13	1.64	8.9	9	15.7	15	1.45	24.8	15
2	1.08	10.4	12	1.66	24.9	13	20.6	15	1.54	34.3	15
14	1.05	0.1	5	9.32	6.0	5	0.3	4	8.84	17.2	14
23	1.02	3.5	12	5.82	20.5	13	6.9	11	5.69	24.1	12
11	1.01	0.4	2	4.40	5.5	3	0.5	3	4.37	12.4	4
1	.98	1.0	3	10.50	2.8	3	0.3	3	10.70	9.3	11
18	.95	2.0	8	3.04	4.6	5	7.1	15	3.19	15.3	14
9	.94	0.1	2	3.11	13.2	11	0.3	2	3.29	28.6	14
17	.91	3.5	9	4.50	8.5	8	1.9	13	4.95	10.1	12
7	.89	1.8	9	3.11	9.4	7	5.0	11	3.50	26.9	14
5	.88	8.1	10	1.98	19.9	11	6.7	14	2.23	29.6	14
3	.86	0.2	2	6.87	3.4	3	0.2	3	7.97	7.7	11
24	.77	0.5	6	5.14	11.4	13	0.7	7	6.70	19.2	12
22	.76	1.6	5	3.82	16.0	13	7.2	11	5.05	29.0	14
6	.74	5.3	10	2.78	20.2	13	7.3	14	3.77	30.3	15
19	.74	2.7	5	5.17	8.0	11	0.0	2	6.94	18.0	11
15	.68	1.7	10	5.37	3.5	3	1.1	11	7.90	3.5	4
13	.58	0.6	5	2.96	6.1	5	12.2	12	5.12	13.9	5
4	.58	4.2	12	2.49	7.1	9	4.9	15	4.26	22.6	13
10	.55	0.2	2	5.98	8.7	5	0.1	2	10.91	18.7	12
20	—	1.1	3	—	0.0	0	1.1	3	15.41	11.1	7

the responses which occurred between the stimuli were added together to determine the total height for the intertrial and preparatory intervals. The "N" is the total number of trials from which responses were recorded. For example; if, as in subject 3, there were a total of two responses each with a height of 0.1 micromho, then in all of the 15 intertrial intervals the total height would be 0.2 for the intertrial interval. The total height for the warning and execution responses is the sum of the heights of all of the signal elicited responses.

Only 8 of the 24 subjects had shorter recovery times to the execution signal than the warning signal and only in subject 12 ($t=2.55$, $p<.02$) and subject 16 ($t=2.40$, $p<.05$) did this relationship reach statistical significance. This is considerably less than in Edelberg's experiment in which 5 of 18 subjects evidenced significantly faster recovery times to the execution signals than to the warning signals.

The 2 subjects who did show significangly faster recovery times to execution signals showed a response pattern distinctly different from the patterns of other subjects. These 2 subjects responded more in the intertrial and preparatory intervals, gave responses to most of the stimuli, and tended to give responses of about equal height to the warning and execution signals. The fact that these subjects gave more responses in the preparatory interval than in the intertrial interval is consistent with the hypothesis that it is the greater number of responses in the preparatory interval which cause the recovery times of execution responses to be faster. A typical skin conductance record from a reaction time experiment is shown in Figure 1. Note the spontaneous responses which occur before the execution signal and which apparently cause the recovery times of the execution response to be

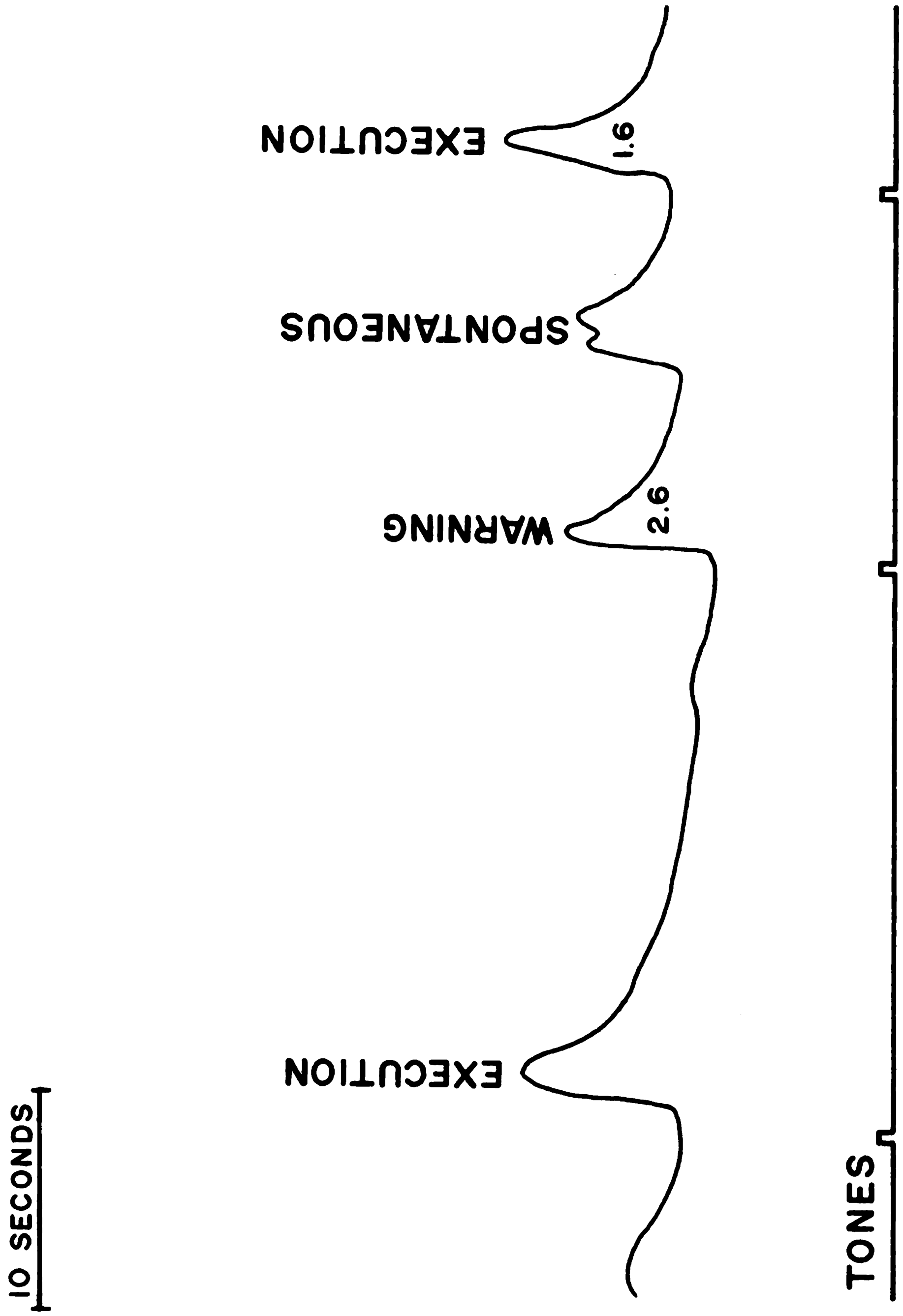

Figure 1. Recovery times of skin conductance responses to signals with spontaneous responses in the preparatory interval.

faster.

Although special emphasis has been placed on the role of these spontaneous responses there is no reason to believe that stimulus elicited responses have different effects on the recovery time than do spontaneous responses. Figure 2 shows a polygraph record in which all of the responses are stimulus elicited. In this case the responses which closely follow other responses have faster recovery times. In addition, the effect seems to be cumulative in that the last response in the series has the fastest recovery time.

The data also suggest that there might be effects due to response height. For most subjects the average recovery time of the execution responses was longer than that of the warning responses. In nearly all of these subjects the total height of the execution responses were larger than the total height of the warning responses. This could mean that the recovery time and response height co-vary such that most subjects have longer recovery times for the execution responses. It could also mean that the height of the previous response has some effect on the recovery time. Because the response to the execution signal usually follows a relatively small response, the time constant of the execution response might be longer.

Since the data in Table 1 are either sums or averages across 15 trials the actual relationships between the response intervals and the response heights are obscured. To examine these relationships more carefully the data from 5 subjects were selected for individual analysis. These particular subjects were selected because they emitted relatively few spontaneous responses and they tended to respond to nearly all of the stimuli. This assured that there would be a

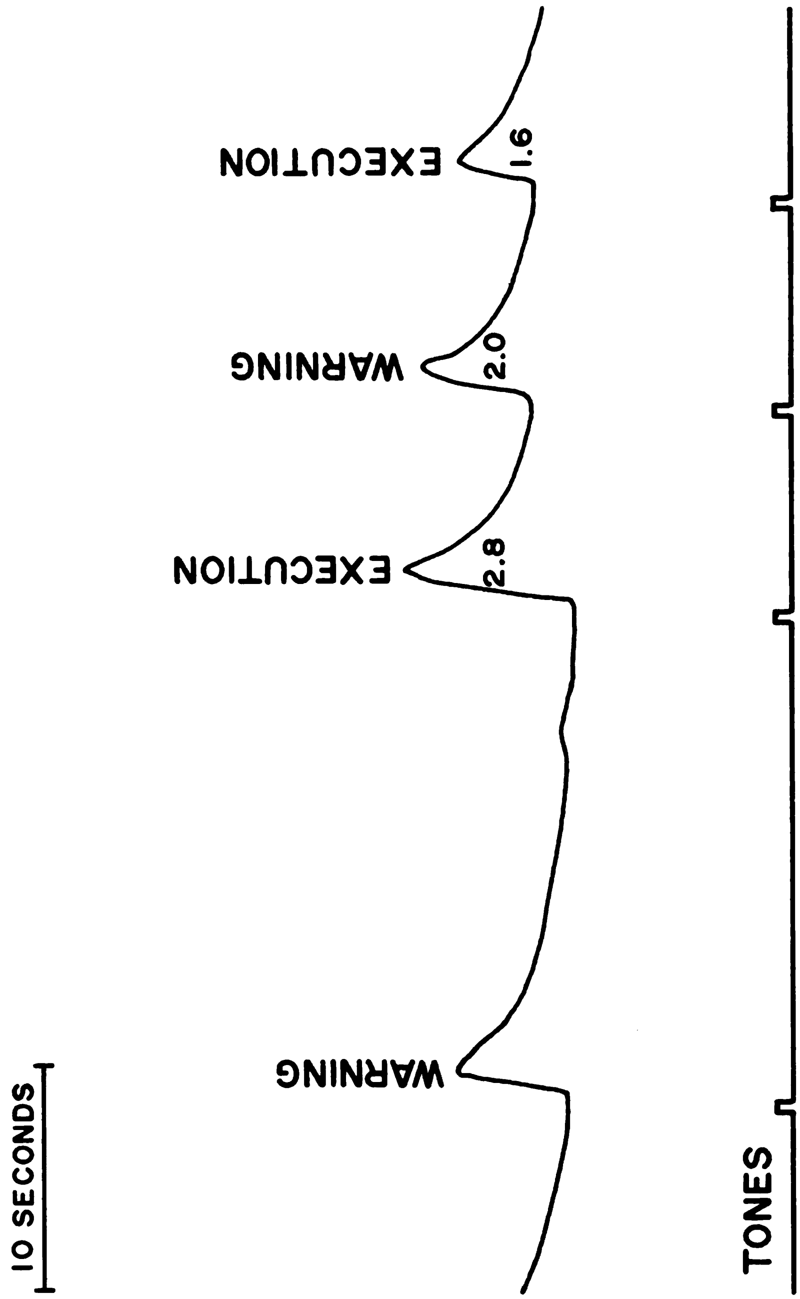

Figure 2. Recovery times of skin conductance responses to signals only.

sufficient number of responses from each subject to perform a meaningful analysis and that the time between the responses would be within the range of the intertrial and preparatory intervals. Subjects 6, 9, 19, 21, and 24 were selected for this analysis.

First a Pearson product moment correlation was computed between the recovery times and the time since the previous response (r_{TF}). These correlations are shown in Table 2. A scatter plot of subject 9's data is shown in Figure 3. These correlations take into account only the time since the previous response and do not take into account the effects of the size of the previous response or the existence of other responses just prior to the response in question.

TABLE 2

Individual correlations between recovery time (T), response interval (I), height and distance of previous responses (X), and response height (H)

Subject#	6	9	19	21	24
r_{TI}	.56	.87	.13	.71	.59
r_{TX}	.64	.91	.52	.84	.73
r_{TH}	.43	.05	.77	.03	.53
$r_{T.HX}$	.69	.91	.93	.83	.94

In order to account for these other factors a simple formula was employed which weighted the sizes and distances of the two previous responses. This formula, which is shown in Figure 4, is probably not the best formula but only one which seemed to fit the data. A scatter plot of this transformed data is shown in Figure 4. The correlations between this transformed data (X) and the recovery times for the subjects selected for special analysis is shown in Table 2. In all

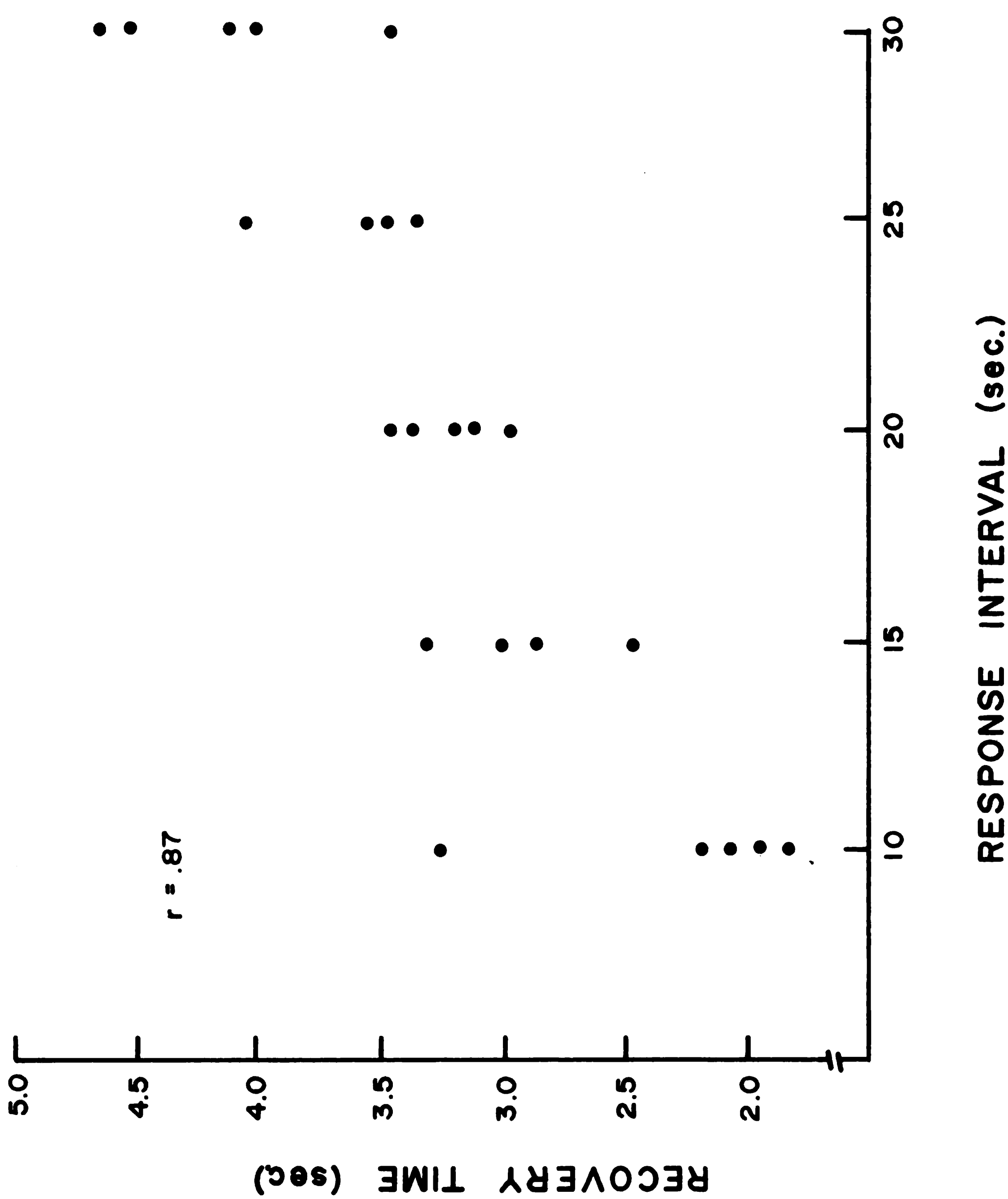

Figure 3. Skin conductance response recovery time as a function of response interval.

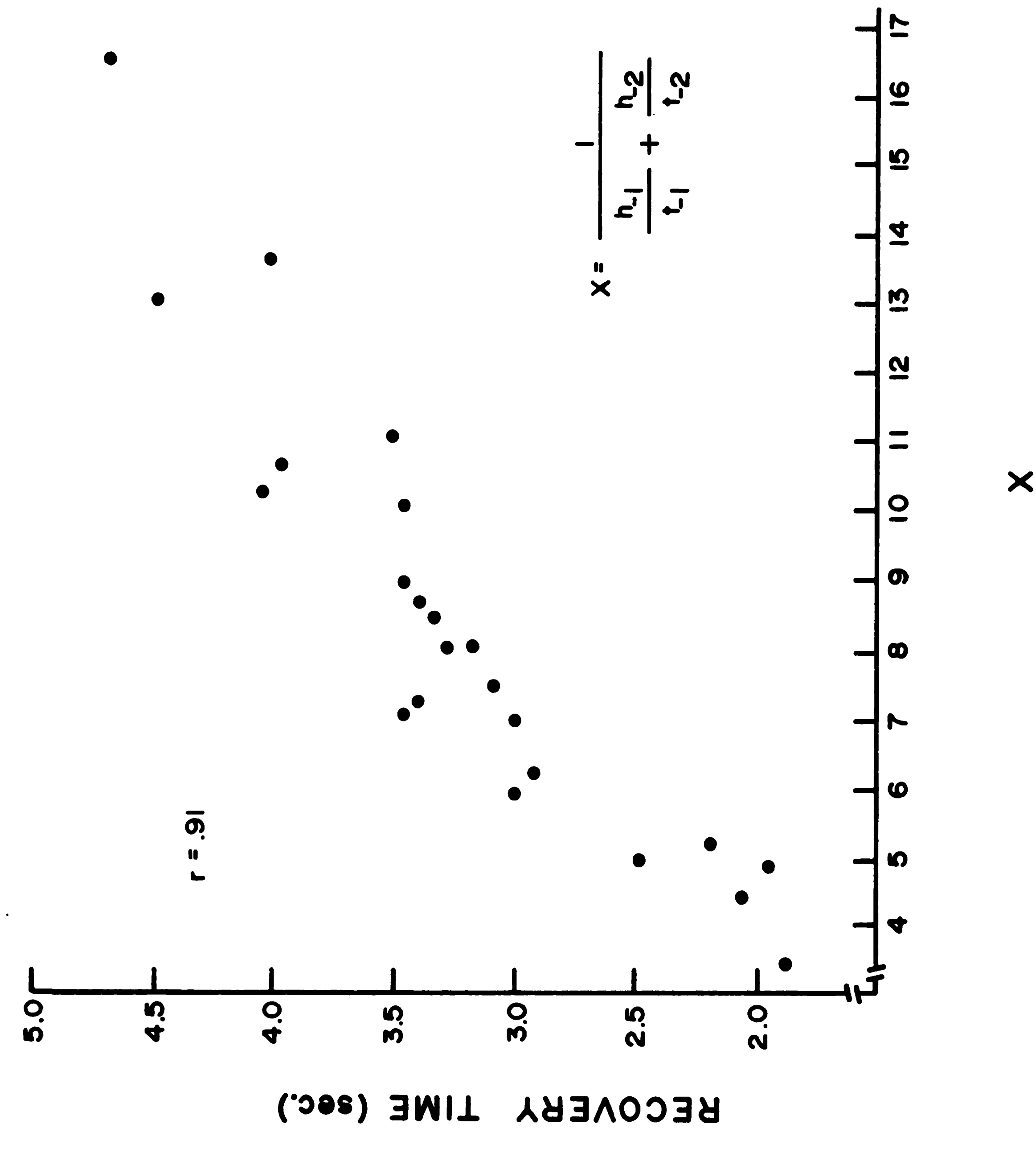

Figure 4. Skin conductance response recovery time as a function of the height and distance of previous responses (X).

cases the transformed data gave improved predictive power for the recovery time but the improvement was much greater for some subjects than for others.

Although Edelberg (1970) has suggested that the recovery time and the response height are independent, he did at times obtain fairly large correlations (>.50) between response height and recovery time. For this reason a correlation was performed between the response height and the recovery time for all of the subjects selected for special analysis. These correlations (r_{TH}) are shown in Table 2. Finally a multiple correlation was performed between the transformed data, the height of the response and the recovery time. These correlations also are shown in Table 2.

In all cases a large portion of the variance can be accounted for by knowing the amount of previous responding and the height of the response. While the multiple correlations are very high, one cannot completely discount the possibility that the recovery limb is somehow modified by some neural effector which can operate independently of the sweat gland innervation.

It could be argued that since all of the correlations were below 1.00 that the remaining variance is due to the actions of the other effector system. Even with the highest correlation, .94, it is possible that another variable could correlate as high as .34 with recovery time. Many experiments reach statistical significance with correlations of that magnitude or less. While this explanation is logically possible it seems quite unlikely. In the first place some of the remaining variance is due to measurement error. There is a considerable amount of visual estimation involved in scoring the polygraph record and some fairly subjective judgments in determining whether a response is scoreable or not. Edelberg (1970) has reported an inter-scorer reliability of .93 while Lockhart (1972) has reported an inter-scorer reliability of .94. The within scorer reliability is probably somewhat higher but it is certainly not perfectly reliable. Also, the correlations are only a measure of the strength of relationship of the linear components of two variables. The mathematical relationships of the variables used in this study have not been determined. The equation used to weight the sizes and distances of the previous responses is probably not the most appropriate mathematical model and perhaps another equation would yield better correlations. Finally there is some unpublished evidence suggesting that the recovery limb becomes longer over a period of time, probably due to the effects of the electrolyte on the skin surface. Given all of the factors which might account for the remaining variance in the data it seems quite unlikely that there is much variance which could be accounted for by the effects of another effector system.

It could also be argued that although the hypothesized second effector system is independently innervated, it is normally highly correlated with sweat gland activity through some centrally mediated process. In view of the notoriously low correlations between the various autonomic measures this explanation also seems quite unlikely. For example, Lucio, Wenger and Cullen (1967) obtained intercorrelations of 19 different measures of autonomic activity from 166 subjects. The highest correlation obtained between independently innervated response systems was .25.

Experiment II

Analyses of variance were performed on the three dependent variables; electrodermal frequency, skin conductance level, and recovery time. The independent variables for the analyses were sex, pressor (hot or cold) and task (mirror tracing, pressor and rest). The task variable was a within subjects factor while the other variables were across subjects.

The summary table of the analysis of variance for electrodermal frequency is shown in Table A3 of Appendix E. The only variables reaching statistical significance were pressor and task. Although the pressor variable only reached minimal significance ($p<.1$) the data bear looking into since the effects of temperature of the pressor task on electrodermal activity might be of interest. The effects of the cold pressor task are usually assumed to be a result of induced stress rather than thermoregulatory activity. If the different pressor tasks affected only the pressor task itself but did not affect the other tasks, one would expect that the task by pressor interaction would also be significant. The fact that this interaction did not approach significance indicates that those subjects who were in the cold pressor task gave different electrodermal frequencies on the other tasks as well. Table 3 shows this relationship. The means for all of the tasks are higher when they are associated with the hot pressor task than when they are associated with the cold pressor task, even though the pressor task was the only one being manipulated. Since all of the subjects were informed of the type of pressor task before entering the experiment, it is possible that the effect is due to an instructional variable. The thought of immersing the hand in hot water may be more anxiety provoking than immersing the hand in cold water. It is also quite possible that this effect is simply due to sampling error and could not be replicated. This is reasonably likely since the finding is only minimally significant.

TABLE 3

Electrodermal frequency means for hot pressor and cold pressor groups

	Rest	Pressor	Mirror tracing
Cold Pressor	2.0	6.1	7.0
Hot Pressor	5.0	9.8	11.5

The task effect was highly significant. The relationship between the task means are shown in Table 7. Both the pressor and mirror tracing tasks produced relatively high electrodermal frequencies while the rest period produced lower electrodermal frequencies. T tests for related measures were performed to determine the degree to which the electrodermal frequency measure discriminated between the different tasks. The t values and the levels of significance for these tests are shown in Table 4. These data replicate those of Edelberg (1972) who found that the electrodermal frequency measure discriminated the rest task from the pressor and mirror tracing task but did not discriminate between the mirror tracing and the pressor tasks.

The summary table for the analysis of variance performed on skin conductance level data is shown in Table A4 of Appendix E. Task was the only variable reaching significance. The pressor variable did not reach significance but did reach a higher F value than any of the other nonsignificant variables and in this respect seemed to parallel the electrodermal frequency data.

TABLE 4

T values and significance levels of t tests performed on the electrodermal frequency data

	Mirror tracing	Pressor
Rest	t=6.87 p<.001	t=3.98 p<.001
Pressor	t=0.90 p>.1	

The skin conductance levels for the mirror tracing and pressor tasks were higher than for the rest task (see Table 7). T tests for related measures were performed to determine the degree to which the skin conductance measure discriminated between the three tasks. The t values and the levels of significance are shown in Table 5. These data again replicate those of Edelberg who found that the skin conductance measure discriminated the rest task from the mirror tracing and pressor tasks. Thus, the skin conductance level and electrodermal frequency measures display the same pattern of discriminability among the three tasks.

TABLE 5

T values and significance levels of t tests performed on skin conductance level data

	Mirror tracing	Pressor
Rest	t=3.72 p<.002	t=3.69 p<.002
Pressor	t=0.05 p>.1	

The summary table for the analysis of variance performed on the recovery time data is shown in Table A5 of Appendix E. Because the recovery time measure could only be taken from scoreable responses there were a total of 9 tasks in which there were no scoreable responses. To perform the analysis of variance on the recovery time data the missing points were estimated according to the procedure outlined by Winer (1971, pp 487-490). The mean squares and the levels of significance were determined using the adjusted degrees of freedom. The only significant effect was the task variable. As with the other dependent measures tests performed comparing the three tasks revealed that the rest task could be differentiated from the other two tasks but the mirror tracing and pressor tasks could not be differentiated from each other. The results of these tests are shown in Table 6.

TABLE 6

T values and significance levels of t tests performed on recovery time data

	Mirror tracing	Pressor
Rest	$t=3.58$ $p<.001$	$t=3.04$ $p<.01$
Pressor	$t=0.52$ $p>.1$	

Except for the electrodermal frequency during the pressor task the only significant variable for all of the dependent measures was the task variable. For all of the dependent measures the rest task was different from the mirror tracing and pressor tasks. None of the dependent measures could discriminate between the mirror tracing and the pressor tasks. The means and standard deviations of the three tasks using the three dependent variables is shown in Table 7. The data indicate that the mirror tracing and pressor tasks are associated with

TABLE 7

Means and standard deviations of electrodermal measures during three different tasks

Electrodermal Frequency, Responses/Minute

	X	σ	N
Rest	3.50	3.13	24
Pressor	7.98	6.77	24
Mirror tracing	9.06	5.85	24

Skin Conductance Level, Micromho/cm^2

	X	σ	N
Rest	12.15	7.77	24
Pressor	13.95	8.72	24
Mirror tracing	13.92	8.31	24

Recovery Time, Seconds

	X	σ	N
Rest	5.67	5.21	23
Pressor	1.80	1.09	16
Mirror tracing	2.03	1.40	24

higher electrodermal frequencies, higher skin conductances and shorter recovery times. The rest period is associated with relatively lower electrodermal frequencies, lower skin conductances and longer recovery times. All of these data essentially replicate Edelberg's (1972) except for one critical feature. That is, in the present experiment the recovery times of the pressor task were more similar to those of the mirror tracing task than to those of the rest period as reported by Edelberg.

Since Edelberg's experiment differed from the present experiment in a number of respects the differences could be due to a number of factors. In any case the generality of Edelberg's most important finding suffers considerably. Since the data from experiment I indicated that responses prior to the response being measured might affect the recovery time, it could be that Edelberg's finding is due to some order effect. Edelberg ran all of his subjects in the same order with the pressor task directly following the rest period. It could be that the presence of the rest period prior to the pressor task caused the recovery times of the pressor task to be fairly long. There are normally very few responses during the rest period. The data from this experiment do not allow a direct test of this hypothesis since those subjects which had the rest period just prior to the pressor task also had a short period between the two tasks in which the experimenter opened the door to the booth, placed the bucket of water in the booth and told each subject to wait until the blue light came on before placing his hand in the water. In Edelberg's experiment the pressor task immediately followed the rest period since the bucket of ice water was sitting beside the subject during the rest period (Edelberg, personal communication).

Conclusion

The data from these two experiments seriously question the assumption that the recovery limb can operate independently of other electrodermal measures. Obviously, a single recovery limb study such as this one cannot explain all the results of experiments which have been used to support the dual effector hypothesis. However, the results of the present experiment do provide clues as to possible alternative explanations which could be tested by further experiments.

The data which show the independence of the conductance level from electrodermal frequency is of most interest because it has attracted the most attention in recent years (Kilpatrick, 1972). It should be remembered that even though there might be only one effector system it is still quite possible that these two measures could appear to be independent in certain situations. Increased sweat gland activity (a high electrodermal frequency) presumably causes the conductance level to rise as well. The conductance level normally falls fairly slowly even in the absence of responses during a particular measurement period. For example, Stombaugh and Adams (1971) have stimulated the sciatic nerve of an anesthetized cat and observed the skin conductance of the cat's footpad. They reported that after cessation of the stimuli, the conductance level remained at a fairly high level for several minutes and did not reach the previous resting level even after an hour of observation. This independence of electrodermal frequency and skin conductance level becomes apparent only if one neglects the temporal relationship between the two measures. Skin conductance level, then, is quite likely a function of the height and distance of the previous responses much as the recovery limb seems to be.

Several investigators have noticed that conductance level increases for the first few trials of an habituation series but that the level decreases in later trials. The height of the responses, however, generally decreases from the first trial to the last trial (Coombs, 1938; Germana, 1968; Lader, 1964; Raskin, Kotses & Bever, 1969; Scholander, 1961). This change in conductance level has been taken as support for the Thompson and Spencer model of habituation (Thompson & Spencer, 1966; see also Graham, 1973). If skin conductance level were a direct manifestation of some neural activity independent of sweat gland activity then this evidence might provide some support for the Groves and Thompson model. Nevertheless, one would expect the same results on the basis of a single effector system since the first few responses, being relatively large, would cause a general increase in conductance level and the next few responses, being relatively smaller, would not be of sufficient height to maintain the conductance level at that high level. This does not imply that the Groves and Thompson model of habituation is incorrect. It only implies that the use of skin conductance level as a dependent measure is an inappropriate test of the model.

Data which show that the positive and negative components of skin potential response are somewhat independent are probably also susceptible to similar arguments. Edelberg (1970) believes that the effector that produces the positive component of the potential response also produces faster recovery times. Skin potential responses are somewhat more difficult to analyze because the positive and negative components partially cancel each other out and it is difficult to infer the relative contributions of the two components in any given response

(Edelberg, 1964). It does appear that the positive component occurs most often when it is closely preceded by several other responses. Fowles and Johnson (1972), for example, have subjects generate skin potential responses with a positive component by having them take successive deep breaths until a positive component appears.

Finally, there are many problems with electrodermal measurement which have not been solved and make it difficult to reach definite conclusions about the independence of the various measures. For example, it is not known how the placement of a liquid electrolyte on the skin surface affects the skin conductance over a period of time. If there are changes in electrodermal activity over a period of time which are not due to sweat gland activity but rather to a measurement artifact, then the results of many experiments are cast into doubt. Preliminary experiments by this investigator suggest that over a period of time, the presence of an electrolyte on the skin surface causes a general increase in skin conductance level, a decrease in the positive component of the potential response and longer skin conductance response recovery time.

Given the difficulties in electrodermal measurement and the possible existence of two different effector systems it is not surprising that many investigators reported that they had given up on electrodermal measurement because of the many difficulties which they had encountered (see Tursky & O'Connel, 1966). If the measurement problems are solved and if further research provides support for the existence of only one effector system, then the utility of electrodermal measurement would be greatly enhanced and the data would be easier to interpret. The existence of only one effector system would imply that all electrodermal measures are related to each other across time. If the relationships between the various electrodermal measures were known, there might be some objective basis for choosing one measure over another. As things now stand, these more general conclusions are speculations which can only be tested by further research.

APPENDICES

APPENDIX A

Representative Copy of the Experiment Instructions

This is a study which is examining the relationship between human behavior and sweat gland activity. Electrodes will be attached to your hand and arm and you will be given the following tasks to perform:

1. After the electrodes are connected and a few checks are made to assure that everything is operating properly the door to the booth will be closed and you will be given a few minutes to relax so that we can calibrate our apparatus before the actual tasks begin.

2. You will then be asked to pick up the reaction time switch and listen for tones that will be played over the speaker. The first tone that you hear will be a LOW tone. This is a warning that any time up to 30 seconds after this tone there will be a HIGH reaction tone. As soon as you hear this tone press the button as quickly as possible. There will be a short period before the next LOW warning signal. This sequence will continue for about ten minutes. Remember that the LOW tone is a warning signal only. Do not push the button for this signal. You are to press the button as quickly as possible when you hear the HIGH tone. The HIGH tone will always follow the LOW tone so that you will always know in advance whether you are to react to the next tone or not.

3. After the last reaction time trial you will be given the mirror tracing apparatus. Place the pencil at the start but do not begin tracing until the blue light at the bottom of the screen comes on. Continue tracing until you are told to stop which will be about two minutes after the light goes on.

4. A container of ice water will then be placed in the booth. When the blue light on the panel goes on you are to immerse your hand in the water up to your wrist. The light will be on for about a minute. Take your hand out of the water when the light goes off.

5. The bucket of water will then be taken out of the room and you will be given a couple minutes to relax. Please keep your eyes open during this period. The experimenter will then come to remove the electrodes and you will be shown the results if you wish to see them.

There is an intercom from the booth to the next room but we cannot answer any questions while the experiment is in progress. If you have any questions please ask them now or wait until the experiment is finished.

Some people find the cold and hot water to be quite stressful which is, of course, the intent of the task so that we can measure your sweat gland activity during stress. If, however, you feel that you are not able to keep your hand in the water any longer by all means take your hand out of the water and inform the experimenter. Also it is important that you move as little as possible during the tasks because movements can affect the recording process.

Thank you for your cooperation.

APPENDIX B

TABLE A1

Experiment I Timing Chart

Trial	1	2	3	4
1. ITI	30 sec.	25 sec.	15 sec.	15 sec.
ISI	30	30	25	20
2. ITI	25	10	15	15
ISI	30	30	10	20
3.	25	15	15	20
	25	15	10	25
4.	30	15	20	20
	10	20	10	15
5.	20	25	30	30
	25	10	20	30
6.	10	10	30	30
	10	30	25	15
7.	20	20	25	15
	25	25	15	30
8.	15	25	10	25
	15	25	15	20
9.	25	10	30	10
	20	15	15	25
10.	20	30	15	10
	20	20	25	30
11.	10	20	25	30
	30	20	30	10
12.	10	30	10	25
	15	10	20	25
13.	15	15	20	20
	10	10	15	10
14.	15	30	25	25
	20	15	30	10
15.	30	20	10	10
	15	25	30	15

APPENDIX C

TABLE A2

Subject List

Subject #	Sex	RT sequence	Task order			
1	M	1	RTA	REO	CP	MT
2	M	2	RTA	REO	HP	MT
3	M	3	RTB	REO	MT	CP
4	M	4	RTB	REO	MT	HP
5	M	4	RTA	MT	REO	CP
6	M	3	RTA	MT	REO	HP
7	M	2	REB	MT	CP	REO
8	M	1	RTB	MT	HP	REO
9	M	1	RTA	CP	REO	MT
10	M	2	RTA	HP	REO	MT
11	M	3	RTB	CP	MT	REO
12	M	4	RTB	HP	MT	REO
13	F	1	RTA	REO	CP	MT
14	F	2	RTA	REO	HP	MT
15	F	3	RTB	REO	MT	CP
16	F	4	RTB	REO	MT	HP
17	F	4	RTA	MT	REO	CP
18	F	3	RTA	MT	REO	HP
19	F	2	RTB	MT	CP	REO
20	F	1	RTB	MT	HP	REO
21	F	1	RTA	CP	REO	MT
22	F	2	RTA	HP	REO	MT
23	F	3	RTB	CP	MT	REO
24	F	4	RTB	HP	MT	REO

APPENDIX D

Experiment I Analyses of Variance

TABLE A3

Analysis of variance for electrodermal frequency

Source	df	MS	F	p
Between	71			
Sex (S)	1	38.3	1	
Pressor (P)	1	247.5	4.13	.1
S x P	1	4.8	1	
Ss within groups	20	57.8		
Within	48			
Task (T)	2	209.8	14.6	.0005
T x S	2	8.5	1	
T x P	2	3.8	1	
T x S x P	2	4.4	1	
T x Ss within groups	40	14.4		

TABLE A4

Analysis of variance for skin conductance level

Source	df	MS	F	p
Between	71			
Sex (S)	1	39.8	1.34	
Pressor (P)	1	76.2	2.62	
S x P	1	0.2	1	
Ss within groups	20	29.0		
Within	48			
Task (T)	2	3.82	8.69	.001
T x S	2	0.61	1	
T x P	2	0.12	1	
T x S x P	2	0.36	1	
T x Ss within groups	40	0.44		

TABLE A5

Analysis of variance for recovery time

Source	*df*	*MS*	*F*	*p*
Between	20			
Sex (S)	1	12.8	1	
Pressor (P)	1	6.8	1	
S x P	1	0.6	1	
Ss within groups	17	17.2		
Within	39			
Task (T)	2	94.3	7.26	.005
T x S	2	22.1	1.7	
T x P	2	1.7	1	
T x S x P	2	2.9	1	
T x Ss within groups	31	13.0		

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