A DISSOCIATIVE ANALYSIS OF SUDOMOTOR RESPONSE PATTERNS

By

© RICHARD G. MARLIN, B.A.

A Thesis

Submitted to the School of Graduate Studies

in Partial Fulfilment of the Requirements

for the Degree

Doctor of Philosophy

McMaster University

March 1984

A DISSOCIATIVE ANALYSIS OF SUDOMOTOR RESPONSE PATTERNS

DOCTOR OF PHILOSOPHY (1984)
(Psychology)

McMASTER UNIVERSITY
Hamilton, Ontario

TITLE: A Dissociative Analysis of Sudomotor Response Patterns

AUTHOR: RICHARD G. MARLIN, B.A. (Dalhousie University)

SUPERVISOR: Professor L.E. Roberts

NUMBER OF PAGES: (x), 220

Abstract

This thesis is concerned with the nature of the response patterns that accompany the learned control of autonomic responding. Specifically, the thesis examined the role of respiratory adjustments in learned increases in electrodermal responding. Experiment 1 measured the concomitants of learned electrodermal control in unconstrained subjects, and employed correlational analyses to examine relationships between autonomic and concomitant activities. The results indicated that even though several activities were altered during training, only respiratory changes showed evidence of being functionally coupled to electrodermal changes. Functional coupling refers to that class of relations in which performance of the concomitant directly contributes to the autonomic change, presumably because of the neural organization of the response systems involved.

Experiment 2 directly addressed the question of whether respiratory alterations were necessary for the production of electrodermal increases. Subjects were trained to alter both electrodermal activity and respiration (integration) and to alter electrodermal activity while maintaining a constant pattern of respiration (dissociation). This procedure allowed for an assessment of two questions. First, could significant electrodermal increases be produced in the absence of respiratory change? Second, would the magnitude of electrodermal change on dissociation trials be comparable to that seen on integration trials? An affirmative answer to the first question would establish that respiratory changes are not required for the production of learned increases in electrodermal activity. However,

a negative answer to either question would suggest that respiratory changes were functionally coupled to electrodermal performance.

It is possible that dissociation performance may be poor, not because respiratory maneuvers contribute to electrodermal performance through functional coupling, but because dissociation is a more difficult task than integration. The information-processing demands associated with learning to change two responses in different directions may be greater than the information-processing demands associated with changing two responses in the same direction. To assess this possibility, a second group of subjects was employed substituting gross body movement for respiration. Gross body movement showed no evidence of functional coupling to electrodermal change in the first experiment, and thus it was felt that this group would serve to estimate the extent of any impairment of dissociation performance due to task difficulty.

The results of Experiment 2 demonstrated that respiratory alterations were not necessary for electrodermal increases to occur. Four of five subjects showed significant electrodermal increases on both integration and dissociation trials by the end of 18 training sessions. Furthermore, three of these four subjects produced changes of comparable magnitude on the two trial types. However, subjects did not appear to produce their electrodermal changes in isolation from other ongoing behaviors. In particular, manipulations of the volar surfaces (fingers and palms) may have contributed to electrodermal responding.

The thesis concludes with a discussion of the role of functional coupling, and the learning process itself, in determining the nature of the response patterns accompanying learned autonomic control.

Acknowledgements

I am deeply indebted to my supervisor, Dr. L.E. Roberts, for his continued guidance and support throughout the thesis, and my graduate career. I wish to also thank Drs. H.M. Jenkins, A.B. Kristofferson and D. Campbell for their advice and assistance throughout the completion of the experimental work described in the thesis, and the thesis itself.

I also owe an immeasureable debt to my wife, Carolyn, for her support, patience and understanding, and to David for his inspiration and love.

Finally, thanks go to D. Imiolo, J. Lyons and Carolyn for their help in various aspects of data analysis and programming, and to B. Bardy and W. Selbie for their invaluable assistance with the manuscript.

Table of Contents

	Page
Abstract	(iii)
Acknowledgements	(v)
Table of Contents	(vi)
List of Figures	(vii)
List of Tables	(ix)
List of Appendices	(x)
CHAPTER 1: GENERAL INTRODUCTION	1
CHAPTER 2: REVIEW OF THE LITERATURE	17
I The Organization of the Electrodermal System	17
II The Concomitants of Learned Electrodermal Control	26
III The Organization of the Cardiovascular System	41
IV The Concomitants of Learned Heart-Rate Control	44
CHAPTER 3: EXPERIMENT 1	53
I Method	54
II Results	64
III Discussion	79
CHAPTER 4: EXPERIMENT 2	85
I Method	90
II Results	98
III Discussion	158
CHAPTER 5: GENERAL DISCUSSION	161
APPENDICES	170
REFERENCES	209

List of Figures

Figure		Page
1.	A comparison of electrodermal responses in two limbs of a human subject (upper panel) and from the limbs of a curarized rat (lower panel).....	20
2.	A schematic representation of the feedback display used in Experiment 1.....	57
3.	Mean changes from pretrial to trial in heart rate and skin conductance for groups SC and HR on all 5 days of training.	70
4.	Mean changes in forearm EMG and gross body movement for groups SC and HR on all 5 sessions.....	72
5.	Mean changes in respiration volume, amplitude and frequency in groups SC and HR for all 5 sessions.....	75
6.	The frequency distributions of within subject correlations between HR and the concomitant measures in the HR target group or with increase and decrease training trials.....	78
7.	The frequency distributions of within subject correlations between SC and the concomitant measures on increase training trials for the SC group.....	81
8.	A schematic representation of the feedback display used in Experiment 2.....	93
9.	The skin conductance and respiratory volume changes produced on training trials by each of the subjects in a group SC-RESP.....	101
10.	The skin conductance and respiratory volume changes produced on training trials by subject MR01.....	105
11.	The respiratory amplitude and cycle duration changes produced on training trials by subject MR01.....	108
12.	The forearm EMG, gross body movement and lB1 changes produced on training trials by subject MR01.....	111
13.	Actual polygraph records from three individual trials for subject MR01.....	114

List of Figures (cont'd)

Figure		Page
14.	Skin conductance and respiratory volume changes produced by subject MRO2 on training trials	118
15.	Forearm EMG changes produced by subject MRO2 on training trials	121
16.	Skin conductance and respiratory volume changes produced by subject MRO3 on training trials	124
17.	Skin conductance and respiratory volume changes produced by subject MRO4 on training trials	128
18.	Changes in mean respiratory cycle duration produced by subject MRO4 on training trials	131
19.	Skin conductance and respiratory volume changes produced by subject MRO5 on training trials	134
20.	The skin conductance and gross overall movement changes produced by each subject in group SC-MUT	137
21.	The skin conductance and gross overall movement changes produced by each subject MMO1 on training trials	141
22.	The skin conductance and gross overall movement changes produced by subject MMO2 on training trials	145
23.	The skin conductance and gross overall movement changes produced by subject MMO3 on training trials	149
24.	The skin conductance and gross overall movement changes produced by subject MMO4 on training trials	152
25.	The skin conductance and gross overall movement changes produced by subject MMO5 on training trials	156

List of Tables

Table		Page
1.	Summary of F-statistics from Experiment 1.....	67

List of Appendices

Appendix		Page
A	Initial interview form used for screening all subjects in Experiments 1 and 2.....	170
B	Text of prerecorded instructions for subjects in Experiment 1.....	173
C	An explanation of the derived respiratory measures....	176
D	An explanation of the respiratory feedback algorithm..	178
E	The printed instructions provided to subjects in Experiment 2.....	182
F	Text of the prerecorded instructions provided to subjects in Experiment 2.....	191
G	The questions included in the post-experimental questionnaires used in Experiment 2.....	201
H	A summary of the t-comparisons from Experiment 2.....	206

CHAPTER ONE: GENERAL INTRODUCTION

Two procedures have been widely employed in recent years to train subjects to control their autonomic responding. In one procedure, usually referred to as operant conditioning, subjects receive exteroceptive "reinforcement" (for example, brief tones signalling monetary reward) whenever the desired pattern of autonomic responding has been produced. The development of learned control is assessed by determining whether the frequency of the desired pattern increases over that observed when reinforcement is given randomly or for a different pattern of autonomic responding. The second procedure is usually referred to as biofeedback training. In this procedure, subjects are typically given continuous exteroceptive feedback conditional upon the autonomic response that is to be altered. For example, the frequency of a tone may be altered in accordance with beat-by-beat fluctuations in heart rate. The task of the subject is to change the response in a specified manner (either increase or decrease the response) using exteroceptive feedback as a guide to success. Learning is inferred from progressive improvement in the ability of the subject to produce the required responses over the course of training. Although operant conditioning and biofeedback procedures have emerged from different traditions and differ in several ways (Brener, 1974a), they are similar in one basic respect. In each procedure a change in autonomic responding is sought by providing subjects with exteroceptive stimulation (reinforcement or feedback) conditional upon their visceral performance.

The ability of both humans and other animals to learn to control their autonomic responding through experience with reinforcement or feedback is well established. The responses that have been studied to date include electrodermal activity (Kimmel & Hill, 1960; Fowler & Kimmel, 1962; Stern & Kaplan, 1967; Lacroix & Roberts, 1978); heart rate (Engel & Chism, 1967; Blanchard & Young, 1973; Lacroix & Roberts, 1978); blood pressure (Shapiro, Tursky, Gershon & Shore, 1969; Schwartz, 1975, 1977); pulse transmit time (Steptoe, 1976; Steptoe & Johnson, 1976); regional blood flow as measured by skin temperature (reviewed by Taub, 1977); rectal sphincter control (Engel, Nikoomaresh & Schuster, 1974); penile tumescence (Barlow, Agvas, Abel, Blanchard & Young, 1975), and gastric acid secretions (Welgan, 1972). These techniques have also been extended to a variety of responses not under the direct control of the autonomic nervous system, such as electroencephalographic activity (Beatty and O'Hanlon, 1979, Zeir and Kocher, 1979), neuromuscular responding (DeBacher and Basmajian, 1977; Engel-Sittenfeld, 1977) and ocular-motor activity (Cornsweet & Crane, 1975; Provine & Enoch, 1975).

It is the case, however, that the detailed nature of the performance that is actually produced by many of these training procedures is not well documented. A sizeable body of research has demonstrated that, in the normal biological context in which they are found, specific changes in autonomic responses are well integrated within the overall activity of the autonomic nervous system and with the totality of the ongoing behavior of the organism (Canon, 1939; Obrist, 1981; Roberts, 1974). However, considerable debate has ensued in the visceral learning area about whether or not the learned changes in

visceral activity that are produced through biofeedback training also occur in an integrated fashion with other autonomic and skeletal responses, or whether these learned changes are evidenced in relative isolation.

This debate focused interest on the patterns of responding that are produced when feedback or reinforcement is provided for a given autonomic change. The examination of response patterns was seen as relevant to two general issues. The first was the question of mediation. Were the autonomic changes merely secondary to the learned control of more conventional activities such as somatomotor or respiratory changes (Katkin & Murray, 1968; Crider, Schwartz & Shnidman, 1969)? If so, then learned control of autonomic responding was not a new type of learning and, therefore, might not be of much interest (see Black, 1974; Roberts, 1978). The second and related issue was that of plasticity. How malleable was the autonomic nervous system? What degree of learned control was possible, and to what extent could response patterns be manipulated (Roberts, 1978)? Some investigators went so far as to suggest that operant conditioning of the internal milieu might be a mechanism of homeostatic regulation (Miller, 1969; Miller & Dworkin, 1980).

At one point about ten years ago, a definitive statement about the potential for learning procedures to produce very specific autonomic changes seemed to be provided by the research of Neal Miller and his colleagues (DiCara & Miller, 1969; Miller, 1969). Using the neuromuscular blocking agent curare, in animals, these studies reported the ability of operant contingencies to produce autonomic changes that

were completely independent of other autonomic or skeletal changes. There are however, two major difficulties with these data. First, a number of individuals including the original investigators have been unable to replicate the original findings (see Roberts, 1978 for a review). Second, even if the data were valid, a number of investigators have pointed out that curare produces paralysis through competitive blocking of the neuromuscular junction. Motor activity could still be centrally integrated with learned autonomic changes (see Black, 1974; Roberts, 1978). That is, the animals may have learned to emit a response consisting of motor commands and visceral adjustments that are organized centrally. The action of curare merely prevented the observation of the motor events at the periphery.

The decade that has followed has yet to elucidate the nature of learned visceral performance. At the time the research for this thesis was undertaken, relatively little had been done except to document the presence of concomitant activities. A sizeable number of correlational studies have indicated that learned autonomic changes tend not to be specific (e.g. McCanne & Sandman, 1975; Lacroix & Roberts, 1978; Obrist, 1982). The majority of such studies, however, did not address whether the concomitant changes seen under these conditions contribute in some way to the production of the target changes, or whether training procedures requiring more specific autonomic changes might be successful. Techniques such as dissociative training are available to address such questions, and their use has been urged by a number of investigators (Black, 1974; Schwartz, 1974, 1975, 1976, 1977; Roberts, 1978). In spite of this, only a handful of studies have attempted to

systematically examine learned visceral performance through these methods.

This thesis begins an investigation of the nature of the response patterns associated with the learned control of electrodermal responding in human subjects. Electrodermal activity is usually measured from the palmar or digital surface as either skin conductance, skin resistance, or skin potential. In all cases the electrical changes measured appear to reflect changes in the hydration of the skin caused by the activity of the sweat glands (Edelberg, 1972). In this thesis electrodermal responding was measured as changes in skin conductance.

Electrodermal activity is of interest for a number of reasons. Historically it was one of the first autonomic responses to be controlled through operant conditioning (Kimmel & Hill, 1960; Fowler & Kimmel, 1962; Kimmel & Kimmel, 1963; Crider, Shapiro & Tursky, 1966). It has been implicated in a number of behavioral and psychological processes including locomotion, tactile perception, digital manipulation, "fight or flight" responding, orienting, emotional arousal, deception, and a variety of psychopathologies (see Edelberg, 1972; Lykken, 1981; Kimmel, Van Olst & Orlebeke, 1979; Roberts, 1974). The sweat glands appear to be innervated only by the sympathetic branch of the autonomic nervous system (Wang, 1964; Edelberg, 1972), unlike most cardiovascular measures which are influenced by both parasympathetic and sympathetic innervations. It remains to be seen if this simplifies the relationships between electrodermal responding and the rest of the organism's ongoing behavior. Finally, in spite of its historical prominence and putative role in such a variety of behavioral

processes, the response patterns accompanying learned electrodermal control have received even less attention than other autonomic responses.

Concomitant activities may accompany learned changes in autonomic responding for a number of reasons. It is possible to divide such reasons into two classes. The first class includes those instances where a functional relationship or coupling exists between the target activity and the concomitant. Such functional relations may take a number of forms. It may be that a visceral response system is organized within the nervous system so that a particular concomitant activity is necessary for a change in the target to occur. An alternative functional relation is that a particular concomitant contributes to the magnitude or ease of target changes, although target change in the absence of the concomitant is possible. Several patterns of neural organization that might produce functional coupling between an autonomic response and concomitant activities have been discussed by Miller and Dworkin (1972).

The second class of reasons concerns the nature of visceral learning rather than funtional systemic relations. It is possible that target changes can occur without concomitant activities. However, when a given training procedure is employed, the learning processes involved may be unable to gain control over such specific visceral responding. The response pattern that emerges in such situations is determined by properties of the learning process as well as by functional relationships involving visceral activity.

One goal of the present research was to examine more fully than has previously been attempted the concomitants of learned changes in electrodermal activity. A second goal was to determine whether selected concomitants are present because they actually contribute to target change (functional coupling between these concomitants and target change). For reasons that will become apparent later, the focus of the research was upon the role of functional coupling between sudomotor action and respiratory behavior. The possibility that selected concomitants may occur because of the nature of the learning process was not specifically investigated in this thesis, although the results call attention to this issue.

There are obviously a variety of ways in which concomitant activities may be functionally related to learned electrodermal change. The nature of these possible relationships, and the procedures designed to discriminate between them, are discussed next.

The Investigation of Response Patterns

The study of response patterns may be conceptualized in three stages. First, it is necessary to measure concomitant behavior during the development of learned control to determine which changes in responding accompany changes in target activity. Concomitants that are either necessary for, or contribute to, target change may be expected to occur with the target response during the training procedure. Second, relationships between the concomitants and the target are assessed. Some form of covariation is expected in the case where concomitant change contributes to production of the target. On the other hand, the absence of such relationships points to the necessity of some other

explanation for the presence of concomitant behavior. Finally, experimental manipulation of the response pattern may be attempted to order to determine the necessity of concomitant behavior for target control. The first two steps were taken in Experiment 1 of this thesis, which followed what will be termed herein a "correlational" approach (after Black, 1974; see also Schwartz, 1977; Fetz, 1974). The third step of direct experimental manipulation was taken by Experiment 2 of the thesis which analyzed sudomotor-respiratory coupling through the application of a dissociative feedback training procedure.

Correlational Approaches

As Black (1972, 1974) has pointed out, a number of non-specific factors may reliably vary between periods when subjects are producing, or attempting to produce, changes in target behavior and when they are not. Factors related to attention, stimulus processing, and so forth are examples of activities that may be required for learning and give rise to concomitant actions although these actions may not themselves be coupled with changes in target behavior that occur. There are a number of techniques for isolating such factors.

One of these is the bidirectional control procedure. This procedure, when employed in a within-subject design, requires the subject to increase the target activity on one type of trial and to decrease it on another. Concomitant activities that fail to track the direction of target change but instead show similar changes on both types of trials are likely to reflect non-specific factors such as attention or sensory processing and not specific mechanisms of target change (Black, 1972; Fetz, 1974).

Concomitant activities that do track the direction of target change however, may still not contribute to performance of the target. It is possible that some concomitants may be non-specific factors that nonetheless are differentially active, dependent, for example, on the trial cues employed. A common biofeedback procedure is to instruct subjects to increase the target response on some trials and to decrease it on other trials. Even though the exact physiological response may not be mentioned, the instructions "increase" and "decrease" are often explicit. It is not unreasonable to suppose that such instructions themselves elicit somewhat different activities (see Brener, 1974) which may or may not contribute to target change. At this point it is necessary to examine the relationship of target behavior to concomitant activity within a specific trial type.

One approach to the study of within-trial relationships is to examine the correlation between magnitude of target change and magnitude of the concomitant (eg. Fetz, 1974). It is reasonable to suppose that stronger functional relations between concomitant and target activities should give rise to larger correlations. These should be assessed within subjects, as a variety of factors including response lability, initial baseline levels of responding, and differences in electrode placement, may artifactually affect between-subject analyses.

Experiment 1 examined within-subject correlations on a trial-to-trial basis. That is, target change on trial n was correlated with concomitant change on trial n. If a given concomitant, for example respiration, is functionally coupled to the target autonomic change, then one would anticipate that on those trials where the largest

respiratory alterations occur the largest autonomic changes should also occur, thus producing a sizeable within-subject, between-trial correlation.

However, a correlation between target responding and a concomitant does not establish the role of the concomitant in the performance of target change. For example, the presence of the concomitant may not be necessary for target change to occur. Rather, it may be the easiest means of producing target change, or it may be a purely adventitious response whose magnitude is influenced in the same fashion as is the target response by some additional factor such as motivation or general effort. Furthermore, such a correlation may not be necessary under all conditions where functional coupling is important. For example, it may be that a concomitant is necessary for target change but that the magnitude of the concomitant, in excess of some threshold value, is unrelated to the magnitude of the target.

Within-subject correlations do, however, permit assessment of the following. First, a failure to observe significant within-subject correlations excludes the simple case of functional coupling (or "mediation") where there is an intimate relationship between both the direction and magnitude of target and concomitant change. Second, the presence of within-subject correlations do permit an identification of those instances where a concomitant activity and an autonomic target covary. Such concomitants are likely candidates to be involved in the production of target change. This heuristic value is considerable when one contemplates the large number of potential concomitant responses that might accompany learned autonomic control. It narrows the field

initially, so as to focus the application of more involved procedures designed to directly assess the role of concomitant responding. Schwartz (1977) has pointed out the complexity involved in multiple response analyses of the autonomic nervous system, and the need to avoid the "shotgun" approach.

The direct manipulation of response patterns.

While a correlational approach to the investigation of response patterns is of heuristic value and a necessary first step, a complete analysis of the nature of learned visceral performance must extend to the direct experimental manipulation of the relations evidenced between the target response and concomitant activities.

There are a variety of techniques that experimentally attempt to directly examine the target concomitant relation. One approach suggested by Fetz (1974) is to reverse the training arrangement so as to make the concomitant the target. If production of the concomitant is a sufficient condition for target change, then the changes seen in the original target activity should persist. If they do not persist, then we can conclude that production of the concomitant alone was not sufficient to effect target change. However, the absence of original target changes when the concomitant is brought under learned control does not necessarily rule out a contribution of that concomitant to the target change. The continued presence of target responding, however, does suggest an important, although not necessarily invariant, link between the target and that concomitant.

Let us examine respiration as a possible example. Suppose that subjects adopt, under conditions of feedback for electrodermal

responding, a particular and somewhat complex pattern of breathing that is sufficient for the production of electrodermal change. If, however, feedback is provided directly for respiration, subjects may learn a different pattern of breathing that alters respiration feedback but is not sufficient for altering electrodermal activity. In order to train subjects to produce the particular respiratory pattern sufficient to alter electrodermal responding, it would be necessary to know the requisite pattern in advance. If this pattern were constant across subjects, and if it could be measured so that feedback could be provided for it, then its sufficiency could be tested in this manner. However, there would seem to be considerable room for experimental error in replicating the necessary pattern.

A second approach suggested by Fetz (1974) is to train subjects to produce a second, unrelated target response. The response patterns generated by the two different targets can then be compared. If all other factors have been held constant, then differences in the concomitants that are seen must reflect differences in the organization of visceral performance. However, this situation is somewhat different from the bidirectional procedure reviewed earlier. In the bidirectional procedure where subjects are taught to change the same target response in opposite directions, the two changes are considered to be mutually exclusive. Any concomitants that are shared between the two conditions can reasonably be attributed to non-specific factors such as perceptual or attentional variables. This is not the case when two different targets are used. Such targets may share certain components of their response patterns because of functional coupling to both responses and

not because of attentional or perceptual factors. Thus, when two different targets are employed, differences must reflect differences in functional coupling but commonalities may reflect either non-specific factors or common functional elements.

Perhaps the most powerful technique for directly examining the strength of the relation between a target response and concomitant activity is to directly attempt to dissociate the two (Black, 1972; 1974; Fetz, 1974). Dissociative training involves procedures designed to alter the target response while holding the concomitant activity constant. If a subject is able to dissociate a particular concomitant from the target, then it is clear that the measurable occurrence of that concomitant is not necessary for the production of target change.

The second experiment of this thesis was a study of this type. Specifically, the goal was to determine whether subjects could be trained to dissociate the learned control of electrodermal activity from any changes in respiration. If subjects succeed then it is clear that respiratory change is not necessary for learned electrodermal changes to occur. However, if subjects are unable to produce target changes in the absence of the concomitant activity, it cannot be concluded that the concomitant is necessary for target change to occur. A number of alternative possibilities need to be dealt with.

First, the information-processing demands of any multiple response procedure, where the subject must pay attention not only to the control of the target response but also to the concomitant activity, are likely to be greater than the information-processing demands of a procedure in which subjects are trained to produce a single target

response. Hence it must be shown that the inability to dissociate the two activities does not stem from the increased difficulty of the dissociative task. One step towards addressing this issue is to compare performance on "dissociation trials" where the subject alters the target while holding the concomitant constant to performance on "integration trials" where the subject is altering both responses in the same direction. Since both trial types now involve the simultaneous control of two responses, differences in target success between them would appear to suggest functional coupling rather than a difficulty factor.

However, even when dissociation performance is compared to integration performance, one must be careful about interpreting a superiority of integration performance as evidence of functional coupling. It may be that it is easier to alter any two responses in the same direction than in opposite or orthogonal directions. For example, Hassett and Schwartz (1975) reported that it was easier to alter electroencephalic activity and heart rate in the same rather than opposite directions. They suggested that this provided evidence of coupling between the two responses. An alternative explanation is one of unequal task difficulty between integration and differentiation conditions.

Additional steps are necessary to address this aspect of task difficulty. Specifically, it must be shown that the inability to dissociate a particular concomitant from an autonomic target does not stem from the increased difficulty of any dissociative task relative to integration, but rather is attributable to functional coupling between that particular concomitant and the target. One means of demonstrating

this is to show that subjects are capable of dissociating a second concomitant from the same autonomic target. If subjects succeed at that dissociation, then failure of the first dissociation must be due to the relationship between target and concomitant. The second experiment of this thesis followed this approach. One group of subjects was trained to dissociate increases in electrodermal responding from concomitant changes in respiratory behavior. Respiration showed evidence of being functionally related to electrodermal activity in the first experiment and thus was expected to pose a difficult dissociation task. The second group was trained with gross body movement as the concomitant. This concomitant showed no evidence of functional coupling to electrodermal activity in the first study, and therefore was expected to be readily dissociated from electrodermal responding.

It is possible that neither complete dissociation nor a total inability to produce target change without concomitant activity is the outcome of a dissociative experiment. Fetz (1974) has suggested that the degree of difficulty of the dissociation may be an index of the strength of the coupling between the target and concomitant. For example, if the constraint of holding respiration constant reduces the magnitude of electrodermal change but does not eliminate target change completely, it can be argued that the production of changes in respiratory activity contributes to the performance of electrodermal changes but is not a necessary component.

In summary, the investigation of response patterns may begin with a correlational examination of potential concomitant activities. It must however procede to the direct manipulation of response patterns

in order to assess functional relationships between target autonomic responses and concomitant activities. Dissociative training is perhaps the most direct way to approach this problem. However, it is important to address the additional task demands of a multiple target control procedure. Specifically, it must be shown that poor performance on a dissociative task is due to a specific functional relationship between the targets, rather than the difficulty of altering any two responses, simultaneously, in opposite directions.

Plan of the Thesis

The next chapter of this thesis reviews the literature concerning the response patterns produced by operant conditioning or biofeedback training for changes in electrodermal activity. The first experiment, a correlational analysis of electrodermal response patterns, is detailed in Chapter 3. The second and principal experiment of the thesis, an attempted dissociation of electrodermal increases from changes in respiration or gross body movement, is presented in Chapter 4. Finally Chapter 5 constitutes a general discussion of the work to date, and an examination of the questions raised by these data.

CHAPTER TWO: A REVIEW OF THE LITERATURE

This review is divided into four sections. The first summarizes evidence concerning the functional organization of the electrodermal system. It is intended to provide the background with which to approach the study of mechanisms involved in the performance of learned sudomotor control. The second section reviews the current state of knowledge with respect to the concomitants of learned sudomotor control, and the role(s) that such concomitants may play in the production of the learned changes.

The remaining two sections parallel the first two except that they deal with the cardiovascular system, and learned heart rate control. This review is less detailed than the first since heart rate control is not the major focus of the thesis. However, a brief review is necessary because a group given feedback training for heart rate was included in the first experiment so as to assist identification of concomitant activities related uniquely to electrodermal performance (after Fetz, 1974).

The Organization of the Electrodermal System.

Electrodermal activity is commonly recorded from one of the volar surfaces, typically the palm. An active recording electrode is placed over the desired site and a reference electrode is placed over an abraded site, usually on the wrist. The reference site is abraded to reduce epidermal resistance and thus insure that recorded changes are due to changes at the active site. A small current, usually about 10

$\mu a/cm^2$, is then passed between the two electrodes and conductivity (or its reciprocal, resistance), is measured. Alternatively, the endogenous skin potential may be recorded. This measure is normally about 10 to 20 mv negative at the surface of the active site for the typical subject (Martin & Venables, 1980). In the alert conscious subject, skin conductance and potential show highly correlated phasic fluctuations which are superimposed upon a slow tonic component. Phasic responding is highly synchronized across the volar surfaces. Two examples of this synchronization are shown in Figure 1, one taken from the palm and foot of a human subject (Edelberg, 1973) and the other from the limbs of a curarized rat (Roberts, 1970, unpublished observations).

Changes in electrodermal activity are produced by the activity of the sweat glands. Phasic responding appears to represent active secretion, while the tonic level corresponds to the state of hydration of the epidermis (Edelberg, 1974). The sweat glands are innervated only by the sympathetic branch of the autonomic nervous system. However, the post-ganglionic neurotransmitter is acetylcholine. Consequently, the sweat glands do not respond directly to the release of epinephrine and norepinephrine by the adrenal medulla. Sudorific changes are also dissociable from adrenergically mediated changes in vascular activity in the palm, which have been found to have little effect upon skin conductance or potential (Lader & Montagu, 1962). Volar sweating, unlike sweating on the other areas of the body, contributes very little to thermoregulation (Kuno, 1956; Wilcott, 1963).

Our understanding of the neural organization of the electrodermal system comes primarily from the study of the cat (Wang,

Figure 1. The synchronization of electrodermal responding as evidenced by recording from two limbs of a human subject in the upper panel (from Edelberg, 1973) and from the four limbs (LF, left front; RF, right front; LR left rear; RR right rear) of a curarized rat. Point A indicates where the record was electronically limited. (from Roberts, 1970, unpublished observations).

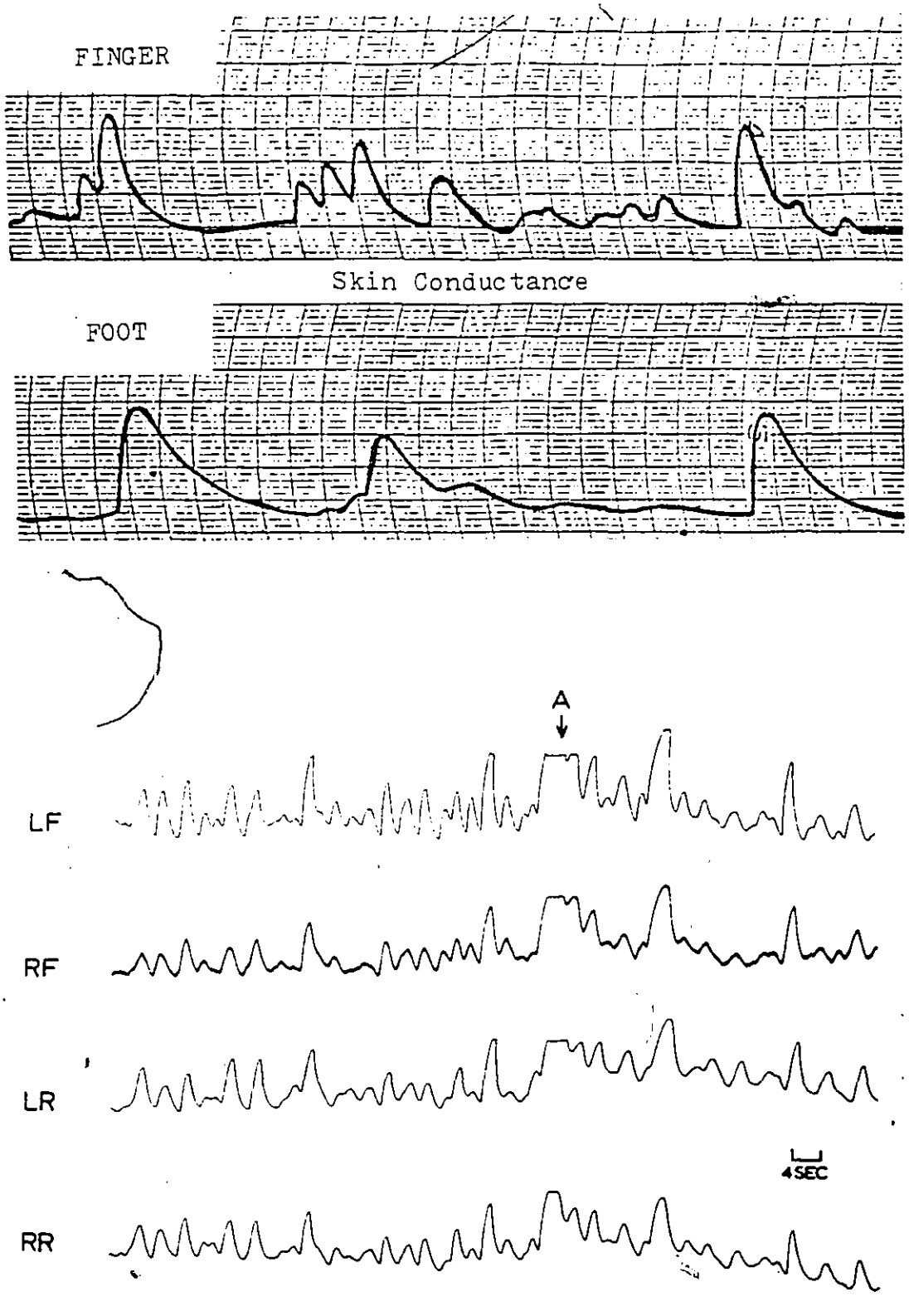

FINGER
Skin Conductance
FOOT
A
LF
RF
LR
4SEC
RR
SP: INTERDIGITAL PADS

Figure 1

1964). However, data available from humans are consistent with that found in this species (Edelberg, 1974). Briefly, five excitatory areas have been identified in the central nervous system. These include areas in the sensorimotor cortex, in the anteriolimbic and infralimbic areas of the cortex, a region in the dorsal thalamus, in the hypothalamus, and in the lateral region of reticular formation. A number of inhibitory centres have also been located including areas in the frontal lobe, the hippocampus, the caudate nucleus, the cerebellum and in the ventromedial portion of the reticular activity system. Wang (1964) also refers to an area of the striopallidum which acts directly upon both inhibitory and excitatory areas in the CNS. Ablation of this "regulatory" center desynchronizes electrodermal activity across the four volar surfaces.

There is also a considerable body of research examining the role of electrodermal responding in ongoing behaviour. For convenience these studies may be divided into two broad groups. The first group consists of studies that have explored relationships between electrodermal activation and striate muscular activity (Roberts, 1974). These studies have shown that substantial increases in electrodermal activation are elicited by cues that set the occasion for subsequent somatomotor acts. The fact that the electrodermal change frequently anticipates somatomotor responding suggests control of the sudomotor system by mechanisms concerned with the potentiation and preparation of motor behaviour rather than by mechanisms responsible for the execution of such behavior. Control by such mechanisms may explain electrodermal changes that occur under conditions of threat which appear to bear little relation to ongoing or subsequent somatomotor action (Roberts &

Young, 1971). However, effects of motor execution also appear demonstrable in the electrodermal system. For example, localized movement of a limb elicits greater electrodermal responding at recording sites ipsilateral to the movement than are seen at contralateral locations (Culp & Edelberg, 1966; Roberts, 1978). Lateralized tactile stimulation without lateralized movement, however, does not have this effect (Edelberg and Beaver, 1972).

The second group of studies concerns the relationship of electrodermal responding to arousal processes. Systematic changes in the tonic level of skin conductance and potential and in the frequency of phasic responding have been shown to covary with behavioral and electrocortical activation over the course of 24 hours (Landis, 1932; Edelberg, 1972). This pattern presumably reflects the influence of the reticular activating system on these functions. More recently, electrodermal activity has been shown to respond to differential activation of the two cerebral hemispheres (Lacroix & Comper, 1979; Comper & Lacroix, 1980). In one experiment, subjects showed larger skin conductance responses on the left hand than on the right, when instructed to engage in a verbal task such as explaining a proverb (e.g., A bird in the hand is worth two in the bush). When subjects were engaged in a spatial task, for example, describing where Calgary is relative to Toronto on the map of Canada, conductance increases on the right hand were larger (Lacroix & Comper, 1979).

Data on electrodermal-behavioural relations permit some tentative inferences regarding the adaptive significance of volar sweating in performance. The significance of motor-related changes was

discussed by Edelberg (1972), who presented evidence that intermediate levels of hydration of the skin may improve the efficiency of behaviors such as locomotion or grasping by enhancing contact with the environment. On the other hand, the non-motor or arousal processes to which electrodermal activation has been linked may play a role in perception and defense. Edelberg (1961) provided evidence that tactile perception and sensitivity are modulated by spontaneous changes in the level of hydration of volar skin. Fully hydrated skin is also more difficult to puncture or abrade, and more difficult for an opponent to grasp (Edelberg, 1973). All of these functions would seem to be facilitated by the tendency of electrodermal activation to occur in anticipation of, as well as concurrently with, overt behavioural responding.

Of special interest in this thesis is the relationship of electrodermal activity to respiratory functioning (ie. Stern & Anschel, 1968). The fact that alterations in the pattern of breathing tend to elicit phasic electrodermal responses has long been known (Landis, 1930). However, the neural basis and adaptive nature of this sudomotor-respiratory relationship are not clear. Wang (1930) suggested that respiratory-related electrodermal activation may be mediated through motor mechanisms. "The galvanic skin responses caused by deep breathing," he wrote, ..."are evidently due to the stimulation of proprioceptors in the muscles" (Wang, 1930, p. 25). Another suggestion is that the two may be somehow linked neurally and adaptively by virtue of the thermoregulatory system. Respiration may contribute to evaporative cooling dependent upon the ambient air temperature and

hydration. However, Jarrett and Morimoto (1978) concluded that respiratory cooling does not significantly contribute to thermoregulation in man. Furthermore, volar sweating does not appear to contribute significantly to evaporative water loss except perhaps in extreme circumstances (Wilcott, 1963).

An alternative hypothesis is that the two responses may be linked in the service of some form of aforementioned "arousal" mechanism. Traditionally sudomotor activity on the palmar and plantar surfaces has been considered emotional sweating (Kuno, 1956). Klinge (1972) reported that instructions to "think emotional thoughts" resulted in increased electrodermal activity relative to instructions to think relaxing thoughts. There is some suggestion that altered respiratory activity might also be a component of such a "flight or fight" response. Monnier (1968) reports that stimulation of the ventral posterior hypothalamic area elicits an ergotropic reaction in which sympathetic activity is increased and respiratory frequency and amplitude are augmented. Willer (1980) reported that the anticipation of strong pain produced significant increases in respiratory frequency and heart rate. Unfortunately electrodermal activity was not measured.

Suess, Alexander, Smith, Sweeney and Marion (1980) measured respiration while subjects were required to make difficult perceptual judgements under the threat of electric shock. They measured both respiration rate and end-tidal CO_2 (lowered end-tidal CO_2 indicates hyperventilation). Heart rate, but not electrodermal responding was also measured for all subjects. They report that increased heart rate, respiration rate and lowered end-tidal CO_2 accompanied the imposition of

stressful conditions. Suess et al. (1980) also reported that the three measures were not always perfectly correlated. At times lowered end-tidal CO_2 was accompanied by increased heart rate but not by increased respiration rate. They argued that respiration rate alone may not always capture stress-induced changes in respiratory behavior. They suggested that the elevated heart rate reflected increased autonomic responding, although the absence of electrodermal measures make it impossible to definitively conclude that electrodermal responding would also have been elevated. Levenson, Jaffe and McFall (1980) reported that heart rate and skin conductance exhibited significant increases in subjects stressed by the anticipation of public speaking. However, Levenson et al. did not measure respiratory activity.

There would seem to be sufficient converging evidence to, at the very least, not rule out the possibility that respiratory changes and electrodermal increases may be linked through a common response to aversive or stressful situations.

In summary, there appears to be a considerable amount of evidence to support the view that the electrodermal system may be involved with a number of different neurobehavioral systems, and thus electrodermal responding may be multiply-determined (Edelberg, 1973; Roberts, 1974). Thus in the context of the learned control of electrodermal responding through biofeedback, it may be possible to anticipate any one or more of a variety of concomitant activities accompanying electrodermal changes, or perhaps none at all.

The Concomitants of Learned Electrodermal Control.

The evidence reviewed to this point gives reason to expect that learned changes in electrodermal responding are likely to be associated with changes in other behaviour as well. This section reviews existing evidence concerning the concomitants which occur when electrodermal responding is controlled through experience with feedback. Specifically, do certain concomitants occur and contribute to electrodermal control, and if so, which ones and what is their role in sudomotor performance?

To assess existing evidence on these questions, it will be helpful to organize the available operant conditioning and biofeedback literature into three relatively discrete categories. The first category contains experiments which have followed what I will call cryptic operant conditioning procedures. Studies of this type employed training conditions that were designed to conceal the presence of a response-reinforcement contingency. For example, subjects were misled as to the purpose of the study or were tested under conditions of low incentive that reduced the possibility that the response-reinforcement contingency was detected. Hence there was little about the procedure or the experimental environment in these studies to indicate that the procedure was a learning experiment. Control of electrodermal responding was assessed in these studies by comparing response rate between response-contingent and explicitly unpaired groups. Although the point has been questioned (Roberts, Williams, Marlin, Farrell, and Imilolo, in press; Schwartz, 1979), a difference between these groups was widely interpreted to indicate that learning had occurred.

A second group of studies employed what I shall call biofeedback or instructed operant procedures. Subjects in these experiments were informed that their task was to produce a specific response upon which exteroceptive feedback was conditional. Thus, the procedure was defined as a learning experiment. In some studies the feedback stimulus was given only when the desired pattern was produced (an operant procedure) whereas in others feedback was provided continuously and subjects were instructed to produce a change in a particular direction (traditional biofeedback training). In the majority of studies in this group explicit incentives such as monetary bonuses were also provided to increase the motivation to learn. Learning was inferred from differential performance between groups given feedback or reinforcement for different manipulations of the response.

The last group of experiments will be referred to as intervention studies. In most instances, the training conditions in these studies were such as to give reason to believe that subjects were aware of the opportunity to learn. However, explicit manipulations were introduced in an effort to dissociate changes in electrodermal responding from concomitant changes in somatomotor and respiratory behavior. The nature of these manipulations varied across the experiments reviewed in this group. The major experiment of this thesis, Experiment 2, is an extension of this approach.

Cryptic Operant Conditioning Studies

The earliest studies of operant conditioning of electrodermal activity used cryptic procedures (Kimmel & Hill, 1960; Fowler & Kimmel, 1962; Kimmel & Kimmel, 1963; Johnson & Schwartz, 1967). Subjects were

not informed that the experiment was a learning task. In addition, in the studies by Kimmel and his colleagues (Kimmel & Hill, 1960; Fowler-Kimmel, 1962; Kimmel & Kimmel, 1963) subjects were eliminated from analysis if, as a result of responses to reinforcement, they verbalized an awareness of response-reinforcer contingencies. These studies did not measure any other autonomic or skeletal responses and therefore provide no information concerning the behaviours that may have contributed to learned changes in electrodermal activity. Mandler, Preven and Kuhlman (1962), on the other hand, measured respiration with a pneumograph "to check unusual or abnormal breathing". They indicated that "...the GSR and breathing did not appear correlated" (p. 317). No mention was made of how the data were analysed to arrive at this conclusion.

Van Twyver and Kimmel (1966) subsequently employed a cryptic conditioning paradigm, and compared the rate of electrodermal responses between two groups of subjects receiving either response contingent or noncontingent (explicitly unpaired) reinforcement for electrodermal responses. Respiration and forearm EMG were also recorded. Electrodermal responding was shown to diverge in the two groups during training, while respiration rate and EMG activity did not. Van Twyver and Kimmel concluded that operant conditioning of electrodermal activity had occurred and was independent of respiration and EMG activity. However, it is possible to question the adequacy of the measurement and analysis of the concomitant measures in this experiment. While respiration was recorded with chest bellows, the only measure reported was respiration rate. Changes in the depth or pattern of breathing may

have gone unnoticed. Furthermore, the procedure of averaging concomitants across subjects may have served to mask relationships that could have been seen at the individual subject level.

Schwartz and Johnson (1969) also employed a procedure that appears to be closer to a cryptic operant conditioning approach than instructed operant learning. Slides of nude females were presented to male undergraduates either contingently upon the emission of electrodermal responses (Group C) or explicitly unpaired with electrodermal responses (Group NC). Subjects were not told that the task involved learning, but were instructed that the experimenters would be recording their physiological responses to pictures. Heart rate and respiration were recorded as well as skin resistance. A significant effect of the contingency was seen for skin resistance but not for heart rate or respiration rate. Schwartz and Johnson concluded that they had demonstrated operant conditioning of electrodermal responding, and that this was independent of respiration rate and heart rate changes. Once again only respiration rate and not other parameters of respiration was analyzed. Furthermore, changes were averaged across subjects possibly obscuring individual relationships. Direct measures of somatomotor responding were not taken.

Although concomitant measurement was not extensive in this group of studies, these findings suggest that changes in electrodermal responding observed during cryptic operant conditioning may be specific to this response. A reservation should be noted, however. The extent to which the electrodermal phenomena revealed in these studies were a product of learning can be questioned. Roberts, Lacroix, and Wright

(1974) presented evidence indicating that the electrodermal system may be more readily activated by stimulus events that occur during a response than by events that occur at other times. If this is so, it is possible that the electrodermal changes observed during cryptic operant conditioning reflected stimulus-driven activation of the electrodermal system by response-contingent tones rather than learning about this response. The fact that subjects in these studies typically denied attempting to control reinforcement and were unaware that they were altering their responding suggests that learning about the response may not have taken place. Hence the bearing of these studies on the concomitants of learned electrodermal control is unclear.

Instructed Operant and Biofeedback Procedures

The procedures employed in experiments reviewed in this section were described to the subjects as learning problems. Measures of concomitant behavior were included in all studies.

Shapiro, Crider and Tursky (1964) examined the effects of response-contingent reinforcement on the rate of emission of spontaneous skin-potential responses. This study is typical of studies employing "instructed operant" procedures. Two groups of 9 subjects each were employed. All subjects were told that the purpose of the study was "...to study the effectiveness of various devices for measuring thought processes." They were asked to think actively about emotional experiences and were told that they would hear a tone each time the equipment detected their emotional thinking, and that the tone signalled a five cent reward. The experimental group received tones that were contingent upon each criterion skin-potential response. Control

subjects were yoked to experimental subjects and received the same number of tones. However, tones were not allowed to occur within ten seconds of any skin-potential response. A five minute baseline period was followed by thirty minutes of reinforcement and then by a ten minute extinction period. The session was repeated several days later. Heart rate and respiration were measured concurrently with skin potential.

Shapiro et al. (1964) reported that the frequency of skin-potential responding remained constant for the experimental group throughout training and extinction. However, responding in the control group declined sharply through the reinforcement period, but then recovered during the extinction phase. Shapiro et al. attributed recovery of skin-potential responding during extinction by the yoked group to orienting responses caused by omission of the tone. They reported that neither heart rate nor respiration rate showed this pattern, but rather that both measures declined throughout the session. Shapiro et al. concluded that operant conditioning of the skin-potential response had occurred, and that the operant electrodermal responses were independent of respiratory and cardiac concomitants.

It is again possible to question the adequacy of the measurement and analysis of the concomitant measures in this early study. Although the procedures of Shapiro et al. (1964) were a clear advance in that heart rate and respiration were recorded, no measure of somatomotor activity was taken. As in the Van Twyver and Kimmel (1966) study, respiration was recorded, but the only measure analysed was respiration rate, and concomitant responses were averaged across subjects. Heart rate was sampled only every 20 seconds. Phasic changes in this

response, which could have signified somatomotor or respiratory manoeuvers associated with phasic skin-potential responses, might have been missed. In this connection Shapiro et al. (1964) acknowledged that:

> "There were slightly more skin responses associated with breathing irregularities in the experimental group than in the control group" (p. 148).

However, they noted that when such responses were eliminated, statistically significant differences were still present. An examination of their data (p. 148) also suggests that respiration frequency tended to be faster in the experimental group on both days of training. Shapiro et al. reported that this trend failed to reach significance.

Shean (1969) employed a shock avoidance paradigm, with avoidance contingent upon bidirectional changes in the frequency of electrodermal responses. One group was explicitly instructed that a response-shock contingency existed and that shocks could be avoided by "fear responses." A second group was simply told that lights and shocks would be presented. Since only the first group showed evidence of operant control, this experiment is best considered in the present group of studies rather than as a cryptic operant procedure. Shean recorded respiration and forearm EMG as well as electrodermal responding. Shean reported that the frequency of electrodermal responding was appropriately increased and decreased in compliance with the instrumental contingencies in the group instructed that shocks could be avoided. However, Shean reported that respiration rate also changed with the instrumental contingencies in those subjects. He concluded

that electrodermal responding was affected by instrumental contingencies only when respiratory and "cognitive" mediators were present.

Klinge (1972) examined the effects of instructions to subjects to "relax" or to "think emotional thoughts". These instructions were also combined with exteroceptive feedback for electrodermal responding. Electrodermal responding, heart rate and respiration were recorded from all subjects. Klinge found significant differences in electrodermal activity between "relax" and "think" conditions. She also reported that respiration frequency and heart rate differed significantly between these conditions. However, when between-subject correlations were computed between electrodermal responding and the two concomitant measures, no significant correlations emerged. Klinge did not indicate whether within-subject correlations were computed in order to examine individual relationships. Within-subject relationships may have existed but varied from subject to subject, thus obscuring between-subject correlations.

Lacroix and Roberts (1978) compared the effect of verbal instructions to produce bidirectional changes in either electrodermal activity or heart rate with the effect of similar instructions plus feedback for the response. Those subjects receiving feedback were also tested for their ability to perform in the absence of feedback. Electrodermal activity, heart rate, respiration frequency and amplitude, body movement and eye movements were recorded from all subjects. Subjects simply instructed to increase or decrease their "finger sweating" showed no significant bidirectional difference in electrodermal activity, but did show significant bidirectional

differences in heart rate, body movement, and respiration amplitude. However, the provision of exteroceptive feedback significantly augmented the bidirectional change in electrodermal activity, but did not augment any of the concomitant measures.

The failure of the concomitant responses to increase when electrodermal activity was augmented by feedback in the Lacroix and Roberts study suggests that the concomitant activities were not important to the production of learned electrodermal change. However, it is not possible to completely rule out their involvement either. It is possible that the procedure of averaging across subjects may have masked some relationships between electrodermal responding and one or more of the concomitant activities. Lacroix and Roberts (1978) also acknowledged that "electrodermal activation may have been associated with a localized augmentation of motor activity in the target limb that failed to have significant impact on movement as it was recorded in this study". They also acknowledged that subtle respiratory manoeuvers "that escaped detection with the present methods cannot be ruled out" (Lacroix and Roberts, 1978, p. 129).

Stern and Kaplan (1967) employed a continuous feedback procedure. Experimental subjects were allowed to watch the needle of an ammeter which was wired in parallel to the dermohmeter measuring their electrodermal activity. These subjects were instructed to move the needle to the left as much as possible. They were informed that the meter measured "their reactions". Control subjects were informed that the electrodes that had been attached measured their reactions, and that they should try and think of emotional events. However, feedback was

not provided. All subjects were instructed to "avoid unnecessary movements and deep breaths". Stern and Kaplan (1967) found that experimental subjects who were provided with feedback produced significantly more responses during periods when they were instructed to "respond" than did control subjects who were instructed to think of emotional events but were not provided with feedback. However, while respiration was recorded, no results with regard to this measure were reported.

Intervention Studies

With the exception of Stern and Kaplan (1967), the studies reviewed in the previous section reported evidence of concomitant behavior during learned electrodermal control. However, the role of these concomitants in performance was not clear. The studies reviewed in this section were undertaken to address this problem more directly.

Birk, Crider, Shapiro and Tursky (1966) partially curarized a human subject in an attempt to rule out somatomotor responding. The subject was exposed to a procedure similar to that used by Shapiro et al. (1964). Unfortunately, as described earlier the use of a neuromuscular blocking agent such as d-tubocurarine may only serve to block the occurrence of motor responses that might otherwise occur because of a central linkage between the motor and autonomic control systems (see Black, 1967, 1974 and Roberts 1978 for a more complete discussion). However, Birk et al. did measure heart rate and respiration rate and found that both measures declined during operant conditioning under curare. The electrodermal performance during the curare session was compared to performance during a pre-curare session.

Response rate was slightly lower during the curare session, even though the sessions had been matched for operant baseline levels. Birk et al. did not compare heart rate or respiration data between sessions, nor did they measure any other somatomotor variables even though they failed to completely block the neuromuscular junction. They acknowledged that deviation in respiratory pattern could not be ruled out. The subject was not so deeply curarized as to require mechanical respiration.

Rice (1966) attempted to dissociate electrodermal responding from forearm EMG in the following manner. Four groups of subjects were used. Electrodermal responding and EMG measurements sensitive to movements of the hand and fingers were recorded from all subjects. Two experimental groups, Group GSR_E and Group $GSR\text{-}EMG_E$, received contingent reinforcement for criterion electrodermal response. Subjects in Group GSR_E were reinforced for all spontaneous GSRs whereas subjects in Group $GSR\text{-}EMG_E$ were only reinforced for criterion electrodermal changes that occurred in the absence of any forearm EMG activity. Two control groups (GSR_C and $GSR\text{-}EMG_C$) were yoked to the respective experimental groups. Group GSR_C received an equivalent number of reinforcements as Group GSR_E but only at times of no electrodermal responding. Group $GSR\text{-}EMG_C$ received the same number of reinforcements as group GSR_E but at times of no electrodermal responding and no EMG activity (even if the EMG activity was unaccompanied by an electrodermal response). Reinforcement consisted of a one-second presentation of a light. Subjects were also instructed to breathe in synchrony with a standardized tape of breathing sounds in an attempt to eliminate respiratory irregularities. Respiration was not measured, however.

Rice (1966) found an effect of the reinforcement contingency in subjects classified as having "high operant levels" in the GSR groups. GSR_E subjects showed higher response rates than GSR_C subjects. In the GSR-EMG groups the results were difficult to interpret. No significant group effects were found. However, a Duncan range test indicated that, for the high operant level subjects, the experimental group showed a higher group mean than the control group. No significant effect was seen in the low-operant level groups. Rice (1966) was cautious in drawing conclusions from the data. He suggested that the failure to demonstrate a clear contingency effect in the GSR-EMG groups may have been due to the low overall rate of non-EMG related electrodermal responses when compared to the rate of all electrodermal responses.

On the other hand, it is not clear that Rice (1966) used an optimal procedure to produce dissociation of electrodermal activity and forearm EMG. Subjects were unaware of the nature of the responding that was required. No shaping procedure was employed in an attempt to augment the occurrence of electrodermal responses in the absence of EMG change. Finally, the feedback provided to the subjects concerning their responding was quite limited. Experimental subjects only received a success signal upon production of the criterion response. The extent to which they attempted to learn is uncertain.

Finally, there are a number of studies which bear upon the nature of electrodermal concomitant relations in various indirect fashions. Gavalas (1968) conducted a study in which subjects were reinforced, by means of a light flash and the comment "that's good", only for electrodermal responses that were elicited by deep

respirations. Non-specific electrodermal responses, those not following a criterion deep inspiration within a certain time window, were not reinforced. Subjects were not told that the experiment involved a learning task; rather they were told that it was a study of the day to day variation in a number of physiological variables. Subjects were given a total of four and one-half sessions of contingent reinforcement which were preceded by one session of baseline measurement and followed by three sessions of extinction. Control subjects were matched to experimental subjects on the basis of operant level and received yoked, non-contingent presentations of the reinforcer.

Gavalas (1968) reported that the frequency of deep inspirations increased throughout training and continued to increase throughout extinction in the experimental subjects but not the controls. The rate of respiration-elicited electrodermal responses, however, did not show the same pattern. These responses occurred at about the same absolute rate throughout training and extinction. It is not clear from the Gavalas data whether or not control and experimental subjects differed on this measure.

Gavalas (1968) argued that the electrodermal responses became dissociated over the course of training, since the proportion of deep inspirations which elicited electrodermal responses declined from about 80% at the start of training to about 30% at the end.

These data do suggest that the electrodermal response to deep inspirations may habituate in this experimental context. Consequently, Gavalas (1968) suggested that deep breaths are not likely to serve as the basis for operantly conditioned increases in electrodermal activity

since this respiratory maneouver does not appear sufficient to sustain responding. However, Gavalas felt that her data did not provide convincing evidence of learning because the reinforced response (respiration elicited GSRs) did not increase in frequency. Her findings do not rule out the possibility that subjects who do learn to control electrodermal activity might employ respiratory change as part of the performance mechanisms involved.

Edelman (1970) reinforced subjects for increasing the magnitude of the electrodermal response to the presentation of electric shock. Reinforcement consisted of a light flash and monetary reward. Respiration amplitude and rate and forearm EMG were recorded from all subjects. Edelman included a control group which received reinforcement for criterion electrodermal responses only if no discernible change occurred in the respiration and EMG records. Edelman reports that only the group reinforced for electrodermal responses irrespective of skeletal activity showed evidence of learning. These subjects also tended to evidence increased respiratory amplitude and decreased respiratory rate during reinforcement periods.

While these data are suggestive of a respiratory involvement in the performance of learned electrodermal change, the results must be interpreted with caution. The procedure of eliciting responses with electric shock and then reinforcing larger than average responses is not a usual training procedure. Edelman (1970) reports that the best conditioning was observed in groups receiving relatively intense shock. Poorer conditioning was observed in subjects who only received threshold

level shocks. The extent to which these results can be generalized to more usual learning procedures is by no means clear.

Summary

In summary, the available literature concerning the performance mechanisms involved in learned electrodermal control is not definitive. Early studies employing cryptic conditioning procedures are suggestive of response specificity. These studies, however, often measured only one or two potential concomitants and usually provided incomplete or unspecified analyses of the concomitant data. Furthermore, whether the results were due to learning is unclear.

More recent studies utilizing instructed operant control or continuous feedback provide more consistent evidence for the presence of concomitant activities. However, these experiments do not provide clear information with respect to the role of these activities in the production of learned electrodermal change.

The one dissociative study that attempted to separate electrodermal responding from forearm muscle activity produced equivocal results (Rice, 1966). The procedures employed in this and other intervention studies may not have been optimal for the production of highly specific autonomic changes, however. Relatively brief training durations (maximum of 5 days, usually 1-3) were employed, and often very limited information about electrodermal performance was made available to subjects through feedback. Such studies certainly do not close the door on the possibility of producing learned autonomic specificity with more powerful methods.

The Organization of the Cardiovascular System

The cardiovascular system includes the heart and all of the blood vessels in the body. While a variety of psychophysiological measures can be taken from the cardiovascular system, I shall be concerned primarily with heart rate, the simplest to record and most commonly used psychophysiological measure.

The overall function of the cardiovascular system is to maintain the flow of blood to body tissues. This supplies oxygen and other nutrients to the tissues and removes waste products. Cardiac output and blood pressure are the primary determinants of blood flow. Cardiac output is a product of the stroke volume and heart rate. Variations in heart rate play a major role in adjusting cardiac output to meet the actual and anticipated metabolic demands of the organism (Obrist, 1981; Schever & Tipton, 1977).

The heart receives a dual innervation from the sympathetic and parasympathetic branches of the autonomic nervous system. The sympathetic input is adrenergic in the post-ganglionic fibres but cholinergic pre-ganglionically. Increases in sympathetic tone increase both heart rate and contractile force. These increments may occur as a consequence of neurogenic control or as a consequence of the secretion of epinephrine by the adrenal medulla.

The parasympathetic input originates in the vagus (10th cranial nerve) and is cholinergic in both the pre- and post-ganglionic fibres. Parasympathetic effects are antagonistic to sympathetic effects. Increases in vagal tone decrease both contractile force and heart rate.

However the interaction between sympathetic and parasympathetic influences is not always a simple one (see Levy 1971, 1977).

Control of cardiac function also occurs at the level of the heart itself, where various intrinsic mechanisms alter the properties of the heart muscle so as to maintain adequate stroke volume (see Berne and Levy, 1977). In addition, baroreceptors and chemoreceptors respond to changes in blood pressure and blood gas tensions, respectively, to participate in cardiovascular regulation (Berne & Levy, 1977). Adrenal catecholamines can alter cardiac output through direct action on the myocardium or indirectly through dilation and constriction of the peripheral vasculature.

Finally, the activity of the heart is co-ordinated with the ongoing behaviour of the organism. Obrist and his co-workers (Obrist, 1976, 1981; Obrist, Galosy, Howard, Lawler, & Gaebelin, 1975; Obrist, Gaebelin, Shanks, Langer & Botticelli, 1976; Obrist, Webb, Sutterer, & Howard, 1970) have studied the relationship between heart rate and ongoing somatic activity in a variety of situations. They reported that in a diversity of experimental contexts, including various classical conditioning paradigms, reaction time tasks, and shock avoidance procedures, heart rate and somatomotor activity remained very closely linked. Only under conditions of considerable stress (Obrist, 1976, 1981) was heart rate found to vary independently of current somatic activity. The close linkage of changes in heart rate to somatomotor activation has been reported by many other investigators over a wide range of species and experimental conditions (Black, 1959; Clifton, 1974; Elliott, 1974; Roberts & Young, 1971; Freyschuss, 1970).

Obrist (1981) has summarized evidence indicating that cardiosomatic relationships which are evident under nonstressful conditions are mediated through parasympathetic control. In fact, Obrist suggests that whenever parasympathetic control of heart rate is dominant, a close covariation between heart rate and somatomotor activity will eventuate. On the other hand, when sympathetic influences of beta-adrenergic origin are potentiated by stress, the cardiac-somatic relationship changes to one of relative independence (Obrist, Howard, Smithson, Martin, & Manning, 1974). These sympathetic effects appear to be predominantly of neural origin, although evidence for an adrenal contribution under some conditions exists (Obrist, 1981; Steptoe, 1982).

Brener and his associates (Brener, 1974; Brener, Phillips, & Connally, 1977) have also noted a close relationship between heart rate and somatomotor activity. Brener et al. (1977) measured oxygen consumption as an index of the total motor outflow of the organism, and found a very close relationship between heart rate and oxygen consumption in rats trained to avoid shock by increasing or decreasing heart rate. Changes in heart rate appear to be the major mechanism by which cardiac output is altered to meet the metabolic demands of muscular activity. However, Grignola, Light and Obrist (1981) showed that cardiac output could be made to exceed the metabolic (O_2) requirements of muscular activity of dogs exposed to strong electric shocks during tread mill exercise. This effect was shown to be of beta-adrenergic origin.

In summary, there is a considerable body of evidence suggesting that a strong relationship exists between heart rate and ongoing somatic

activity. However, the relationship does not always eventuate, especially if sympathetic influences are brought into play. Finally, the preceding studies have, for the most part, examined heart-rate changes either in non-human species or utilizing a paradigm where overt heart-rate control was not the behavioral goal of the subject. It is possible that a more flexible relationship might exist in circumstances where human subjects are overtly attempting to manipulate heart rate through biofeedback or operant conditioning.

The Concomitants of Learned Heart-Rate Control

There has been considerably more research on the concomitants of learned heart rate control than on the concomitants of learned electrodermal control. Heart-rate studies can be classified into four groups based upon the approach employed to understand the relationships between the target heart-rate changes and the concomitant activity. The heart-rate training procedures discussed here were presented to the subjects as learning tasks.

The first group of procedures includes studies that have basically employed a correlational approach. These studies trained subjects to control heart rate, and examined what other alterations occurred in concurrently measured activities such as respiration or motor activity. The majority of studies fall into this category. A large number of studies have reported respiratory changes that accompanied learned changes in heart rate (Shearn, 1962; Brener & Hotherhsall, 1966, 1967; Brener, Kleinman, & Goesling, 1969; Levenson, 1976, 1979; Lacroix & Roberts, 1978; McCanne & Iennarella, 1980; Levenson & Ditto, 1981). Similarly, various somatomotor changes have

been associated with learned heart-rate changes in numerous studies (Obrist et al., 1970, 1975; Brener, 1974; Lacroix & Roberts, 1978; Levenson, 1979; Hatch & Gatchel, 1979; Levenson & Ditto, 1981).

A second class of studies includes those that have attempted to control one or more concomitant responses by restricting subjects to a constant level of that particular activity. This includes such procedures as pacing the subject's respiration or having the subject produce a constant level of motor activity and then attempting to train changes in heart rate. For example, a widely-cited study by Obrist et al. (1975) imposed various levels of somatomotor and respiratory constraint on subjects by means of verbal instructions and respiration pacing techniques. Obrist et al. found that the magnitude of heart-rate changes evidenced by subjects varied inversely with the degree of constraint imposed. Magnusson (1976) reported similar findings when comparing learned heart-rate increases with and without the addition of somatomotor responding.

A different method of controlling somatomotor activity was used by Clemens & Shattock (1979), who trained subjects to produce bidirectional changes in heart rate while simultaneously performing a static hand grip either 0%, 30% or 50% of maximal force. They report that subjects were able to achieve bidirectional changes in heart rate while maintaining the constant motor output required by the hand grip task.

Goldstein, Ross, and Brady (1977) trained subjects to decrease heart rate while performing a constant exercise of walking on a treadmill at a rate of 2.5 mph on a 6% grade. They found that subjects

provided with feedback were able to lower their heart rate when compared with subjects who received instructions to lower heart rate but no feedback.

Perski and Engel (1980) performed a similar experiment to Goldstein et al. (1977). Perski and Engel (1980) found that subjects were able to decrease their heart rate, relative to controls, during exercise on a bicycle ergometer, when provided with heart-rate feedback.

While these three studies demonstrate that subjects can learn to alter rate when also performing a constant motor task, they do not rule out the possibility that other aspects of motor behavior have changed. It is conceivable that subjects are able to lower heart rate while exercising at a constant level by eliminating motor activities that are unnecessary to the production of the exercise task. That is, the subjects may simply be more efficient at the required exercise, and thus reduce total motor outflow and therefore metabolic demand and heart rate. Subjects may also be altering some aspect of their respiratory behavior as well. None of these studies recorded respiration or any reliable measure of total somatic activity such as oxygen consumption.

Vandercar, Feldstein, and Solomon (1977) studied heart-rate learning when respiratory changes were controlled. Vandercar et al. (1977) first reinforced subjects for bidirectional heart-rate changes when respiration was unconstrained. Then subjects were forced to breath at a constant rate by means of a respirator and were again reinforced for heart-rate changes. They reported that the magnitude of heart-rate control was attenuated when respiration frequency was controlled and

that what heart-rate changes were seen were associated with manipulations of respiratory amplitude or volume. Vandercar et al. (1977) interpreted their results as evidence for a functional coupling between heart-rate change and respiratory activity. No special procedures were employed in an attempt to shape the desired pattern of responding. Subjects were simply reinforced for heart-rate changes that met criterion while respiration frequency was controlled.

A third type of study involves manipulating the concomitant activity in order to assess the changes then produced in the heart rate measure. For example, Engel and Chism (1967) examined the effects of 20% increases and decreases in breathing rate on changes in heart rate. They reported that average heart rate was not altered by such respiratory change, but that increases in respiration rate tended to decrease the variance of heart rate and decreases in respiration rate tended to increase the variance in heart rate. However, Stern and Anschel (1968) reported that larger alterations in respiration rate and amplitude did produce significant changes in heart rate. Similarly, Holmes, Solomon, and Buchsbaum (1979) reported that subjects instructed to "...breath rather rapidly and fairly deeply" produced heart-rate increases comparable to subjects given feedback for producing heart-rate increases. They also report that instructions to "...breath rather slowly and fairly shallowly" did not succeed in producing signficant decreases in heart rate.

These findings indicate that at least some alterations of respiratory behavior alone are sufficient to produce significant increases in heart rate.

Lynch, Schuri and D'Anna (1976) and Clemens and Shattock (1979) both demonstrated that static increases in muscle tension reliably elicited increases in heart rate. The exercise physiology literature (e.g. Schever & Tipton, 1977) has provided ample evidence that heart rate will vary directly with increasing levels of motor output.

The final type of study involves the attempt to actually train subjects to dissociate heart-rate change from one or more particular concomitant responses, by providing information to the subject about both activities. One of the earliest studies of this type was that of Schwartz (1972). Schwartz attempted to dissociate heart rate from another cardiovascular response, systolic blood pressure, rather than a response of the striate or respiratory musculature. Schwartz referred to his procedure as "pattern feedback". Four groups of subjects were trained to produce one of the following response patterns: (1) increase heart rate and systolic pressure; (2) decrease both heart rate and systolic pressure (Schwartz referred to these two groups as "integration" conditions); (3) increase heart rate and decrease systolic pressure, and (4) decrease heart rate and increase systolic pressure (the latter two were referred to as "differentiation" conditions). Feedback was provided to the subject each time both responses changed in the desired direction. No information was provided when either or both responses failed to change in the prescribed direction.

Schwartz (1972) reported that subjects could alter heart rate and systolic blood pressure in opposite directions, although the magnitude of the changes was smaller than those seen in the integration conditions. Schwartz also examined temporal correlations between these

two responses. This procedure was extended, with similar findings, to diastolic pressure and heart rate by Shapiro, Schwartz and Tursky (1972). While those data do not directly bear upon the relationship between heart rate and other non-cardiovascular behaviours, Schwartz (1974, 1977) has since argued that such a paradigm can be extended to examining relationships between various responses that may be functionally related.

Levenson (1976) provided subjects with discrete feedback for both respiration rate and heart rate. Subjects were trained to produce bidirectional changes in heart rate while they were instructed to maintain a constant respiration rate. Levenson found that significant changes in respiration-rate paralleled the heart-rate changes his subjects produced. He also reported that significant increases in respiratory volume accompanied heart-rate increases.

These data are supportive of the position that the respiratory changes seen by Levenson (1976) contributed to the production of the target heart-rate changes. However, the data must be interpreted with caution. Levenson points out that he found no evidence that learning contributed to the heart-rate changes evidenced by his subjects. Subjects provided with feedback for heart rate performed no better than subjects simply instructed to alter their heart rates. It is possible that had subjects developed their heart-rate control from the feedback information that was provided, a dissociation between heart rate and respiration might have been produced. Subjects only received a single session of training.

Newlin and Levenson (1978) attempted to train subjects to dissociate respiration from heart-rate changes using a form of the pattern feedback first employed by Schwartz (1972). Subjects were presented with a success signal (a numerical display and a tone) whenever the desired pattern of responding had been accomplished. For example, if a subject's task was to increase heart rate while decreasing respiration rate, the feedback stimulus was presented only if both response requirements (increased heart rate and decreased respiration rate) were met at the same time. Six groups of subjects were trained to produce the following patterns of heart rate and respiration-rate responding: (1) increase heart rate and respiration rate; (2) increase heart rate and hold respiration rate constant; (3) increase heart rate and decrease respiration rate; (4) decrease heart rate and respiration rate; (5) decrease heart rate and hold respiration rate constant; and (6) decrease heart rate and increase respiration rate. Subjects received a total of 11 trials, each trial being 80 heart beats in duration.

Newlin and Levenson (1978) reported that only the two groups that were required to hold respiration rate constant while either increasing or decreasing heart rate showed evidence of learning. Significant heart-rate changes in the appropriate directions were observed in both groups. Respiration rate changed in the same direction as heart rate, but the respiration changes did not reach significance. It should be noted that groups expressly reinforced for changing both responses in the same direction were not successful. Newlin and Levenson (1978) also reported that changes in heart rate when

respiration rate was held constant were accompanied by either changes in respiratory amplitude or somatomotor activity.

The data of Newlin and Levenson (1978) are supportive of the position that respiratory changes are instrumental to the production of heart-rate changes. They do not rule out the possibility, however, that extended training, or feedback procedures that provide more, or at least different, information might be more successful. It is also possible that failure of dissociation may have derived in part from task difficulty rather than from a functional coupling between respiratory activity and heart-rate change. Several aspects of the Newlin and Levenson data suggest this alternative. First, it is surprising that subjects were unable to succeed when required to alter both responses in the same direction. Second, subjects were not informed about the nature of the target responses, nor were they informed that feedback depended upon two responses. They were simply told that "...their thoughts, feelings, and internal state could activate the feedback display" (Newlin & Levenson, p. 279). These instructional conditions, and the short training period provided, may have made any dual response task too difficult to master even in the absence of a functional relationship between the two responses involved.

Chapter Summary

The evidence reviewed in the preceding section suggests a strong relationship between respiratory-somatic activities and heart-rate change. These relationships have persisted despite the use of training procedures intended to dissociate the responses, although it is possible that more powerful methods might succeed where others have failed.

On the other hand, the situation with regard to learned electrodermal control appears different. The presence of concomitant activities has been demonstrated, particularly respiratory changes but also somatomotor responding. This evidence comes primarily from studies employing instructed operant or biofeedback procedures, or intervention methods. However, two features of this evidence should be emphasized. First, there is reason to question whether the relation of these activities to changes in electrodermal responding is one of functional coupling. For example, Gavalas (1968) reported respiratory and electrodermal responses became uncoupled over trials, and Lacroix and Roberts found that concomitant behaviours were not augmented by feedback training as were sudomotor changes. Second, the evidence with regard to the role of concomitant activities in learned electrodermal control is not altogether adequate. The available evidence is less extensive than in the case of heart rate, the measurement and analysis of concomitant activities has been less thorough, and the application of dissociative procedures has been infrequent.

CHAPTER 3: AN EXAMINATION OF THE CORRELATES OF LEARNED ELECTRODERMAL AND HEART-RATE CONTROL

The previous chapter reviewed evidence which suggests that somatomotor and respiratory concomitants are observed when heart rate is the target response, and that these activities occur at least in part because of coupling between them and the cardiovascular system. Efforts to eliminate somatomotor concomitants by verbal instruction or dissociative conditioning have met with little success. There is also evidence that concomitant activities accompany learned sudomotor control. However, the source of these concomitants is less clear. There are psychophysiological data which suggest the possibility of functional coupling with both respiratory (Wang, 1964) and somatomotor (Edelberg, 1972) activity, but the available evidence from feedback studies questions whether concomitants arise from this source. Instead these concomitants may occur because of the instructions given (see Brener, 1974) to the subject, or because of chance contiguous occurrences of feedback and that activity.

The initial experiment of this thesis further examined the concomitants that accompany the learned control of electrodermal activity. One purpose was to examine within-subject correlations between changes in skin conductance and concomitant activities that might be functionally coupled with and contribute to performance of this response. While the presence of within-subject correlations between concomitant activities and target responding does not rule out all

explanations other than functional coupling, the absence of such correlations would certainly suggest a lack of coupling.

A second purpose was to compare the concomitants associated with learned sudomotor control with the concomitants of heart-rate control. For this purpose two groups of subjects were employed, one given feedback for changes in skin conductance and the other for changes in heart rate. Apart from the target response, all other aspects of the training procedures were the same for each group. Consequently differences in the concomitants observed over the course of training could not be attributed to instructional effects or other procedural details common to the two groups, but necessarily implied differences in relationship of the concomitants to the visceral targets. Concomitants that differentiated between the target conditions were expected to show differential within-subject relationships to skin conductance and heart rate as well. Thus comparison of response patterns between the target groups was expected to assist identification of concomitants that might be functionally coupled with skin conductance (Fetz, 1974).

While increases in electrodermal responding are readily trained, decreases appear to be more difficult to produce (Lacroix & Roberts, 1978). Subjects were trained bidirectionally but the concomitants were analysed separately for the two types of trials.

Method

Subjects

Twenty male students ranging in age from 16 to 26 years served as subjects. None had previously participated in any feedback training experiment. Subjects were screened by means of a standardized interview

to eliminate any volunteer with a history of cardiovascular or major respiratory disorder. They received $2.00 per hour for participating as well as a performance incentive of up to $1.00 per session.

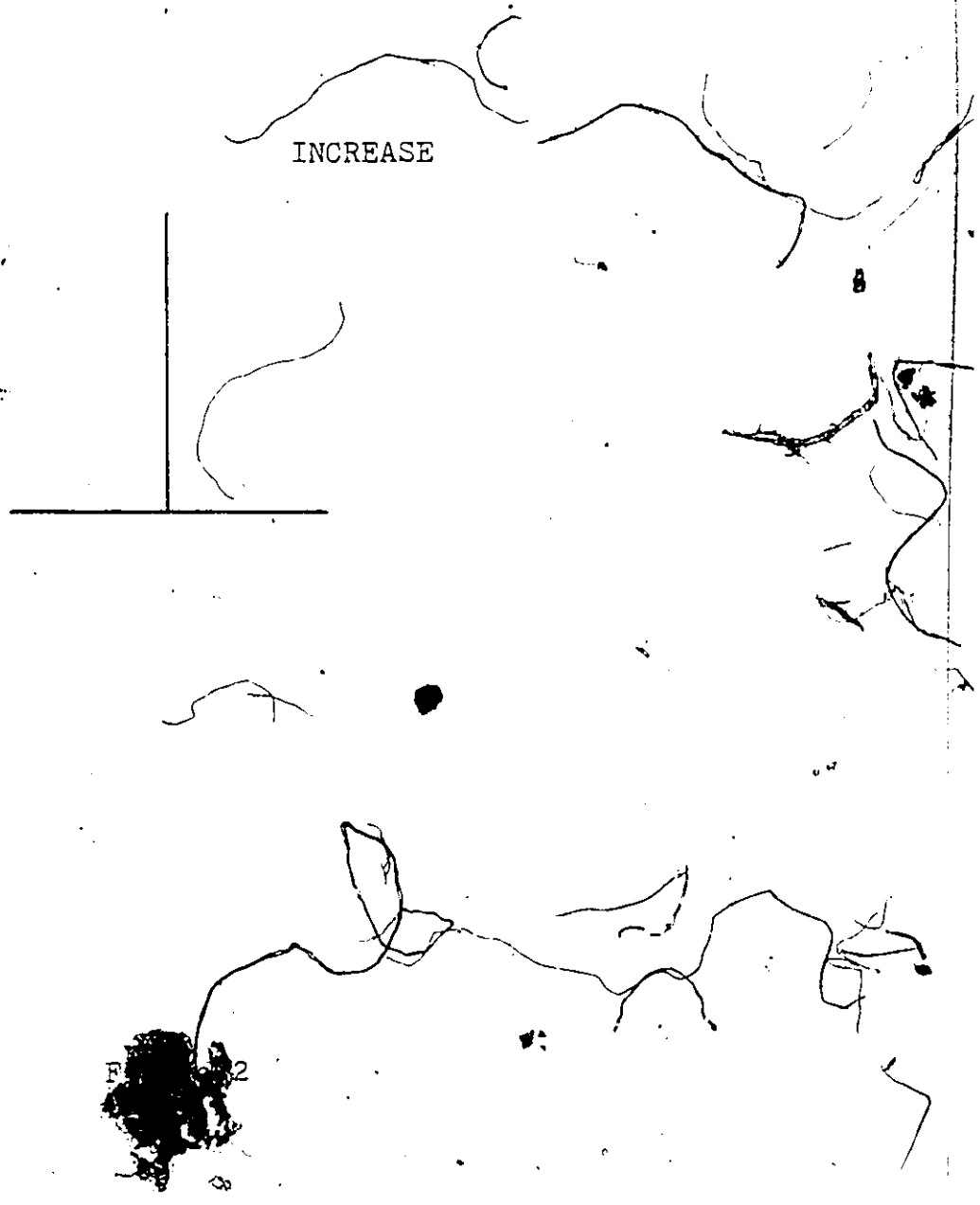
Apparatus

The subjects were tested in an electrically shielded, acoustically dampened room. A padded armchair was placed in the centre of a 2m by 3m carpeted enclosure formed by curtains suspended from the ceiling. The subject sat facing a Sony videomonitor (Model 110 - screen size 18 cm x 23 cm) situated 1.2 m away at eye level.

The feedback display (shown in Figure 2) consisted of a fixed horizontal line of 8 cm in length presented slightly below the center of the screen, and a vertical line of variable length which originated from the midpoint of the horizontal line. Increases in the target from the pretrial baseline resulted in increases in the length of the vertical line upwards towards the top of the screen. Decreases from baseline resulted in the vertical line increasing in length downwards from the horizontal line. The length of the vertical line was proportional to the magnitude of the target change. The word "INCREASE" or "DECREASE" was also presented in the upper right hand corner of the screen to indicate to the subject the desired direction of change on a particular trial.

The feedback display, trial sequencing and timing, and all other aspects of the experimental procedure were controlled on-line by a PDP-8/L computer. Five channels of electrophysiological data were sampled at a fixed rate through the analog to digital converter on the PDP-8/L.

Figure 2. A schematic representation of the feedback display used in Experiment 1. The horizontal line represents the subject's starting point at trial onset. Changes in the length and direction of the vertical line correspond to changes in the visceral target.


INCREASE
8

These data were also monitored throughout the session with a Beckman Type R polygraph operating at a chart speed of 1 mm/sec.

The feedback display was generated by a Computec 118 display interface and a Textronix 4501 scan converter.

Electrophysiological Recordings

Skin conductance was recorded from the hypothenar eminence of each hand through Beckman Ag/AgCl surface electrodes 15 mm in diameter. Electrode sites were cleaned with alcohol prior to the application of the electrodes. The reference sites, placed on the ventral surface of each wrist, were abraded lightly with sandpaper and rubbed with Beckman Electrolytic paste to reduce epidermal resistance. Active and reference electrodes were filled with a paste containing .1M NaCl mixed with Parke Davis Unibase in a ratio of 2.5:1 by volume. Contact with the skin was through an opening 10 mm in diameter. Skin conductance was measured as the current generated by a 500 mv DC source applied between the reference and active sites through a series resistance of 2K-ohms. Recordings were taken through a Beckman AC/DC coupler (9806A) set in the DC mode. A calibrated zero-suppression circuit was used to suppress and retain the tonic level.

The electrocardiogram was recorded with Beckamn Ag/AgCl electrodes placed over the sternum and the lower left rib cage. Electrode sites were cleaned with alcohol and rubbed with Beckman paste. The electrode medium was also Beckman Electrolytic paste. A beat-by-beat measure of heart rate was obtained by a Beckman 9857B cardiotachometer. The analog output of this device was (1v/30 upmv) amplified and fed to the PDP-8/L. The raw electrocardiogram was also

recorded through a Beckman AC/DC coupler set to an RC constant of .03 seconds.

Respiration was recorded by means of a mercury filled strain gauge (Parks Electronics Laboratory) encircling the subject's upper torso. A Beckman mercury gauge coupler (9875B) measured expansion of the gauge with each respiratory cycle.

Forearm electromyographic activity (EMG) was recorded through Beckman Ag/AgCl electrodes placed over the ventral surface of the forearm as described by Lippold (1967). Electrode sites were chosen to be sensitive to movements of the fingers (such movements are generated by the forearm musculature). These sites were cleaned with alcohol, abraded slightly and then rubbed with Beckman paste. The electrodes were also filled with Beckman paste. The signal from these electrodes was fed through a Beckman AC/DC coupler (9806A) set to an RC constant of 0.03 secs with an amplifier gain of 40 mv/cm. Preamplifier output was amplified (X 50) and rectified and integrated by a Beckman 9873B integrator coupler (2 mv/cm; IC = 1; TMW = 3.0).

Gross body movement was recorded by means of an inflated cushion concealed in the seat of the subject's chair. The air valve of the cushion was connected to a Beckman 9853A pressure coupler. The cushion was inflated to 25 mm Hg and the coupler calibrated to 1 mm Hg/mv. Preamplifier output was amplified (X 5) and rectified for integration by a Beckman 9873B integrator coupler (50 mv/cm; IC = 1; TMW = 3.0).

Palmar skin temperature was measured through two Yellow Springs thermistors (model YS1429) placed immediately adjacent to the active

skin conductance electrodes. The thermistor signal was recorded through a Beckman thermistor coupler (9858).

Beckman Ag/AgCl mini-electrodes were attached to the subject's upper left and upper right forehead. Both sites were cleaned with alcohol and coated with Unibase. No signals were recorded from these electrodes during the experimental session.

The following data were recorded on the polygraph during each experimental session: bilateral skin conductance; heart rate; the electrocardiogram; respiration; gross body movement; and forearm electromyographic activity and skin temperature from the target limb. The target limb was selected on the first day and was the side which provided the better skin conductance signal on that day. The target limb then remained constant throughout all five days of training. Measurements of skin conductance, heart rate, respiration, and skin temperature were subject to post amplification (X 5) before being transmitted to the analog to digital converter of the PDP-8/L computer. Integrator resets for electromyographic activity and gross body movement were counted via digital input buffers on the PDP-8/L.

Procedure

Subjects were assigned to target condition (skin conductance or heart rate) randomly. One group received feedback contingent upon changes in heart rate (HR target group), the other received feedback for changes in palmar skin conductance (SC target group). Subjects in both groups were treated identically except for the response upon which the feedback was contingent. The experimenter who instrumented with the

subject was blind with respect to which of the two groups the subject had been assigned.

Upon arrival in the laboratory on the first day of training all subjects were administered a brief medical interview (see Appendix A). The recording electrodes were then applied and the subject was seated in the experimental room.

Tape-recorded instructions (for complete text see Appendix B) informed subjects that they were to learn to control a physiological response that was not usually thought of as being controlled voluntarily. The nature of the feedback display was then explained. The subject was also told that he would be asked to control the response without feedback on some trials (referred to herein as "transfer" trials). The subject was instructed to "use any method you wish to control the response but do not get out of the chair or touch the electrodes". Finally, he was told that he would receive bonus money to a maximum of one dollar for successful performance.

Each experimental session consisted of 32 trials lasting 30 sec each. Twenty of these trials were "training trials" during which both visual analog feedback and an instruction word (INCREASE or DECREASE) were presented. Training trials were administered in a random sequence of ten INCREASEs and ten DECREASEs. Preceding and following this block of 20 training trials was a block of four "transfer" trials (2 INCREASE and 2 DECREASE) on which the instruction to increase or decrease was presented but no feedback was available. Also included in each transfer block were two "blank" trials (extended inter-trial intervals) during which neither an instruction word nor feedback was presented to the

subject. The interval between trials was variable and averaged one minute. Each trial was preceded by a 30 sec pretrial period during which neither feedback nor instruction words were presented. All physiological data were monitored and recorded throughout the pretrial and trial periods.

Subjects received five such sessions usually once daily for five consecutive days. No subject received more than one session per day and all subjects completed the five sessions within seven days. Subjects were reminded not to discuss details of the study with others in case they should be recruited as participants at a later date.

Data Reduction

All polygraph recordings were examined on a trial by trial basis to eliminate trials with significant recording artifact. Two subjects, one in each target group, were excluded from further analysis because of excessive artifact in the recordings. A third subject, from the HR target group, was dropped from analysis due to a computer failure when transferring his data to magnetic storage. This left nine subjects in the SC target group and eight subjects in the HR target group. For these subjects fewer than 5% of the trials were excluded due to artifact or equipment malfunction.

Bilateral conductance was sampled every 250 msec as was palmar skin temperature from the target limb. These measurements were made throughout the 30 sec trial period and for a 30 sec pretrial period immediately preceding each trial. These data were used to compute

5-second averages for both measures throughout the pretrial and trial periods. "Change scores" depicting performance on each trial were computed by subtracting the pretrial mean from the trial mean.

The analog output of the cardiotachometer was sampled every 125 msec to obtain heart rate scores. Five-second averages and change scores were computed as above.

EMG and gross body movement were integrated and the number of integrator resets per 125 msec period were counted via the digital input buffer of the PDP-8L. Five-second averages and change scores were computed on the basis of these reset counts.

Respiratory movements were recorded by means of the mercury strain gauge fastened about the subjects' chest. The output of the guage was sampled every 125 msec allowing for a reconstruction of the waveform of respiratory cycles. Mean amplitude and frequency were calculated for both the pretrial and trial period. In addition a measure of respiratory "volume" was calculated by integrating the entire respiratory signal with respect to the pretrial mean (see Appendix C for a description of the computer algorithm employed to do this). Change scores for frequency were calculated by subtracting mean during the pretrial period from the mean during the trial. Amplitude and volume could not be calibrated across subjects, or even in the same subject across days. Change scores for these measures were expressed as a proportion of the trial mean to the pretrial mean rather than as an arithmetic difference.

Statistical Analysis

A 2x2x5 analysis of variance was performed separately for each response measure. Target (HR or SC), trial type (Increase or Decrease), and days of training were variates. Blank trials were not included in this analysis.

Within-subject Pearson Product-Moment correlations were computed between changes in target responding and each concomitant measure across feedback trials in Group SC and Group HR. These correlations were computed on each of the five days of training separately for increase and decrease feedback trials. The distribution of correlations for each measure was compared against the symmetrical distribution about zero that would be expected if no true relationship existed between the concomitant activity and target responding.

It was often convenient in the following sections to describe the effect of feedback training on a particular response by referring to the difference in performance observed between increase and decrease trials. Comparisons of this type will be described as "bidirectional" in this thesis.

Results

The results will be presented in two sections. First, the effects of feedback training on each of the response measures (targets and concomitants) will be described. Second, the relationships evidenced between target responding and the concomitant measures will be examined by means of correlational analysis.

With the exception of the first transfer block given prior to the first feedback session, responding did not differ between feedback and transfer trials. In other words, transfer was complete. Therefore, the following analyses are presented for training trials only because of the larger data base offered by these trials. Table 1 summarizes the results of analysis of variance applied to each response.

Effects of Training on Target and Concomitant Responding

Heart Rate and Skin Conductance. Figure 3 depicts changes in both heart rate (upper panel) and skin conductance (lower panel) for both target groups across the five days of training. Both groups showed significant control of both autonomic targets as evidenced by significant main effects due to trial type for heart rate $F(1,15) = 67.58$, $p < .001$, and skin conductance, $F(1,15) = 47.42$, $p < .001$ (see Table 1). The two groups did not differ in heart-rate performance. However, the SC target group produced significantly larger changes in conductance than did the HR target group, $F(1,16) = 6.24$, $p < .05$. Figure 3 suggests that this difference was observed only on increase trials. However, the group by trial type interaction failed to reach significance.

While a large degree of control was evident on the first day of training, changes occurred across days. A trial type by days interaction for the heart-rate measure indicated that responding on increase and decrease trials diverged across days, $F(4,60) = 10.50$, $p < .001$. By day five there was some evidence of successful decrease control of heart rate in the HR target group. Decrease heart-rate performance on the final day of training was significantly lower than

Table 1 Summary of F-statistics from Experiment 1

Effect	Measure						
	SC	HR	EMG	MVT	RA	RV	RF
Groups ($F_{1,16}$)	6.24*	.08	.24	.06	1.34	3.85	5.09*
Trial Type ($F_{1,15}$)	47.42°	67.58°	19.12°	13.34°	30.08°	39.27°	2.75
Days ($F_{4,60}$)	2.44	1.31	3.67**	3.10*	.27	1.71	.45
Group x Trial Type ($F_{1,15}$)	2.13	.52	.60	.03	4.24	5.78*	.14
Group x Days ($F_{4,60}$)	13.08**	.16	.35	.51	1.11	2.29	.33
Trial Type x Days ($F_{4,60}$)	3.81**	10.50°	4.88*	2.47	.80	3.26*	.11
Group x Trial x Days ($F_{4,60}$)	1.14	1.11	.36	.85	.51	.89	.12

* $p < .05$
** $p < .01$
° $p < .001$

Table 1: Summary of F statistics from Analyses of Variance. A 2 x 2 x 5 anova (group x trial type x days) with repeated measures on the last two factors was performed for each measure.

blank trial performance, but only in Group HR, $t(15) = 3.65$, $p < .01$. The heart-rate decrements evidenced by these subjects were also significantly lower than the decrements shown by subjects in Group SC, $t(15) = 2.57$, $p < .05$.

Analysis of skin-conductance performance revealed a significant group by days interaction, $F(4,60) = 13.08$, $p < .001$, and trial type by days interaction, $F(4,60) = 3.81$, $p < .05$. Examination of Figure 3 suggests that these interactions are not simply interpreted. Decrease trial and blank trial performance at no time differed from one another on the conductance measure. No clear trend is obvious across days.

Forearm EMG and Gross Body Movement. Figure 4 shows the changes in forearm EMG (upper panel) and gross body movement (lower panel), across the five days of training. EMG and movement showed significant bidirectional differences in both target groups as evidenced by significant main effects attributable to trial type [EMG: $F(1,15) = 19.12$, $p < .001$; MVT: $F(1,15) = 13.34$, $p < .001$]. There was no difference between groups for either variable. However, both variables did show an effect of days [EMG: $F(4,60) = 3.67$, $p < .01$; MVT: $F(4,60) = 3.10$, $p < .05$]. Figure 4 indicates that this was attributable to larger changes on increase trials as a function of continued training in both target groups.

Respiration. Figure 5 shows the changes in the three respiratory measures across days for both target groups. Respiration amplitude, $F(1,15) = 30.08$, $p < .01$, and respiratory volume, $F(1,15) = 39.27$, $p < .01$, differed between increase and decrease trials. Inspection of Figure 5 suggests that changes in these two respiratory

Figure 3 Mean changes from pretrial to trial performance in heart rate (upper panel) and skin conductance (lower panel) on increase training, decrease training and blank trials for group SC and HR. Blank trial performance did not differ between the two target groups and thus was averaged to simplify the figure.

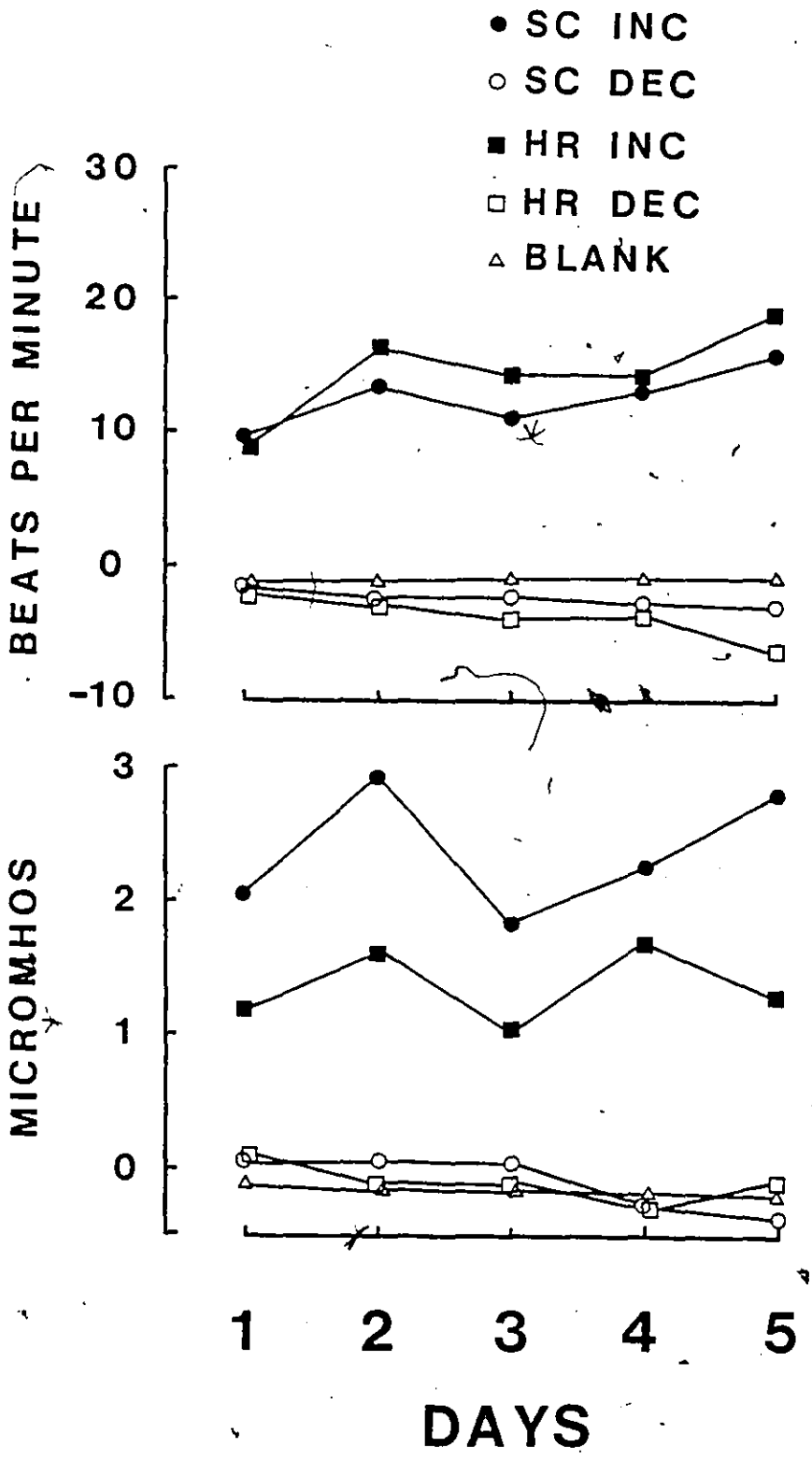

SC INC
SC DEC
HR INC
HR DEC
BLANK
BEATS PER MINUTE
30
20
10
0
-10
MICROMHOS
3
2
1
0
1
2
3
4
5
DAYS

Figure 3

Figure 4 Mean changes from pretrial to trial performance in forearm EMG (upper panel) and gross body movement (lower panel) on increase and decrease training trials and blank trials for groups SC and HR. Units are arbitrary.

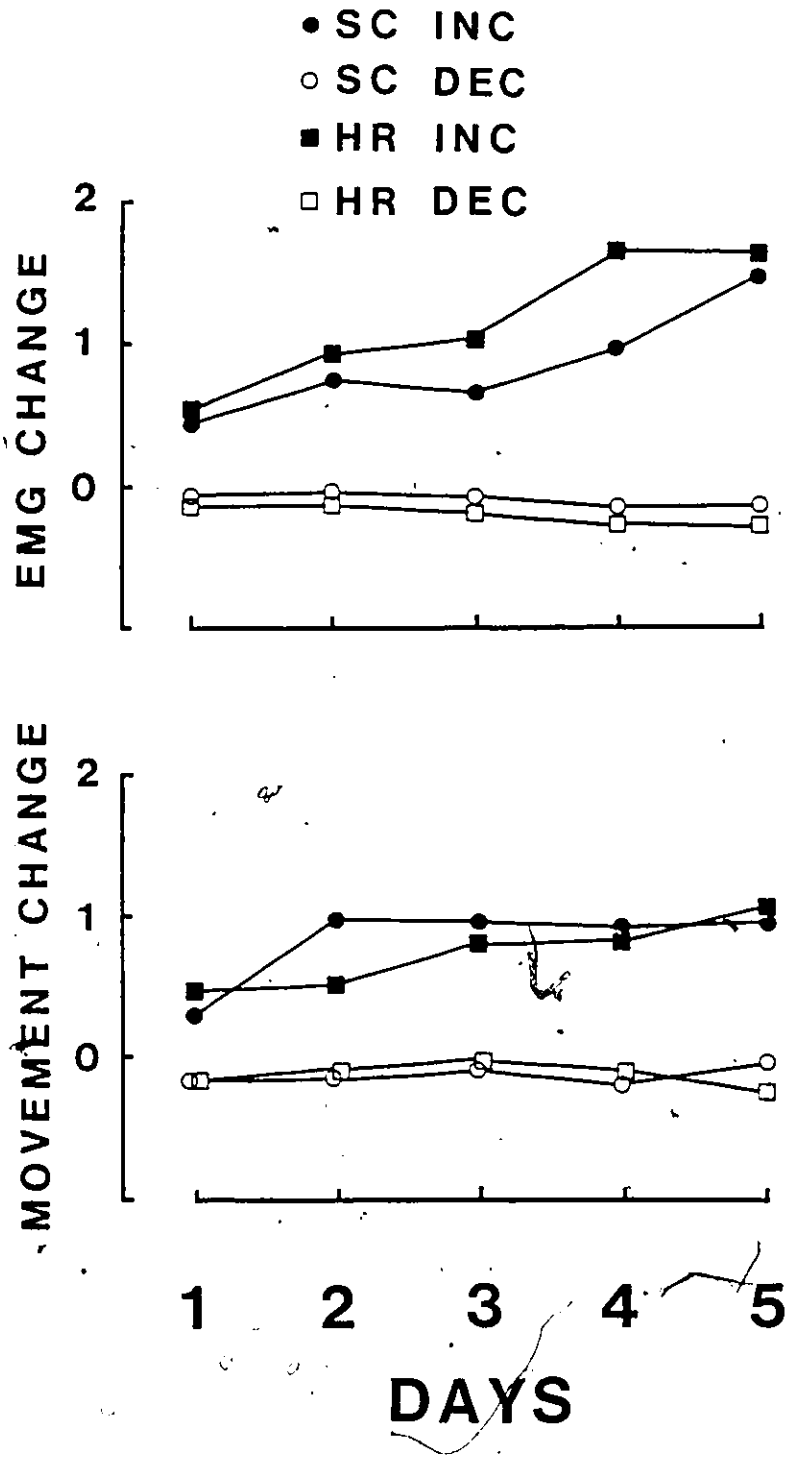

SC INC
SC DEC
HR INC
HR DEC
EMG CHANGE
2
1
0
MOVEMENT CHANGE
2
1
0
1
2
3
4
5
DAYS

Figure 4

measures were more pronounced in the SC group. Although neither variable showed a significant main effect attributable to target condition (HR or SC), a group by trial type interaction was observed for respiratory volume, $F(1,15) = 5.78$, $p < .05$. Figure 5 suggests that this effect was due to larger increases in volume on increase trials for the SC target group, primarily on the last three days of training.

Respiratory frequency did not evidence a main effect of trial type, suggesting there was no difference in this measure between trial types in either target group (HR or SC). There was, however, a significant main effect of groups, $F(1,16) = 5.09$, $p < .05$. Figure 5 suggests that this effect may have been due to somewhat larger increases in respiration frequency on increase trials in Group SC than in the HR condition.

Temperature. There were no consistent changes in palmar skin temperature, associated with any trial type in either group.

In summary, both groups exhibited sizeable and significant bidirectional control of the target responses, although only the HR target group showed evidence of successful decrease performance. Significantly larger changes in skin conductance were obtained under conditions of skin conductance training than under conditions of heart-rate training. On the other hand, both target groups evidenced sizeable changes in forearm EMG, body movement, respiration amplitude, and respiration volume, particularly on increase trials. The only difference in concomitant activities between the target groups was that the SC target group showed somewhat greater manipulation of respiration, notably during the last three days of training, although the exact

Figure 5 Mean changes from pretrial to trial in respiratory amplitude (upper panel), volume (middle panel), and frequency (lower panel) on increase and decrease training trials and blank trials for groups SC and HR. Units are arbitrary.

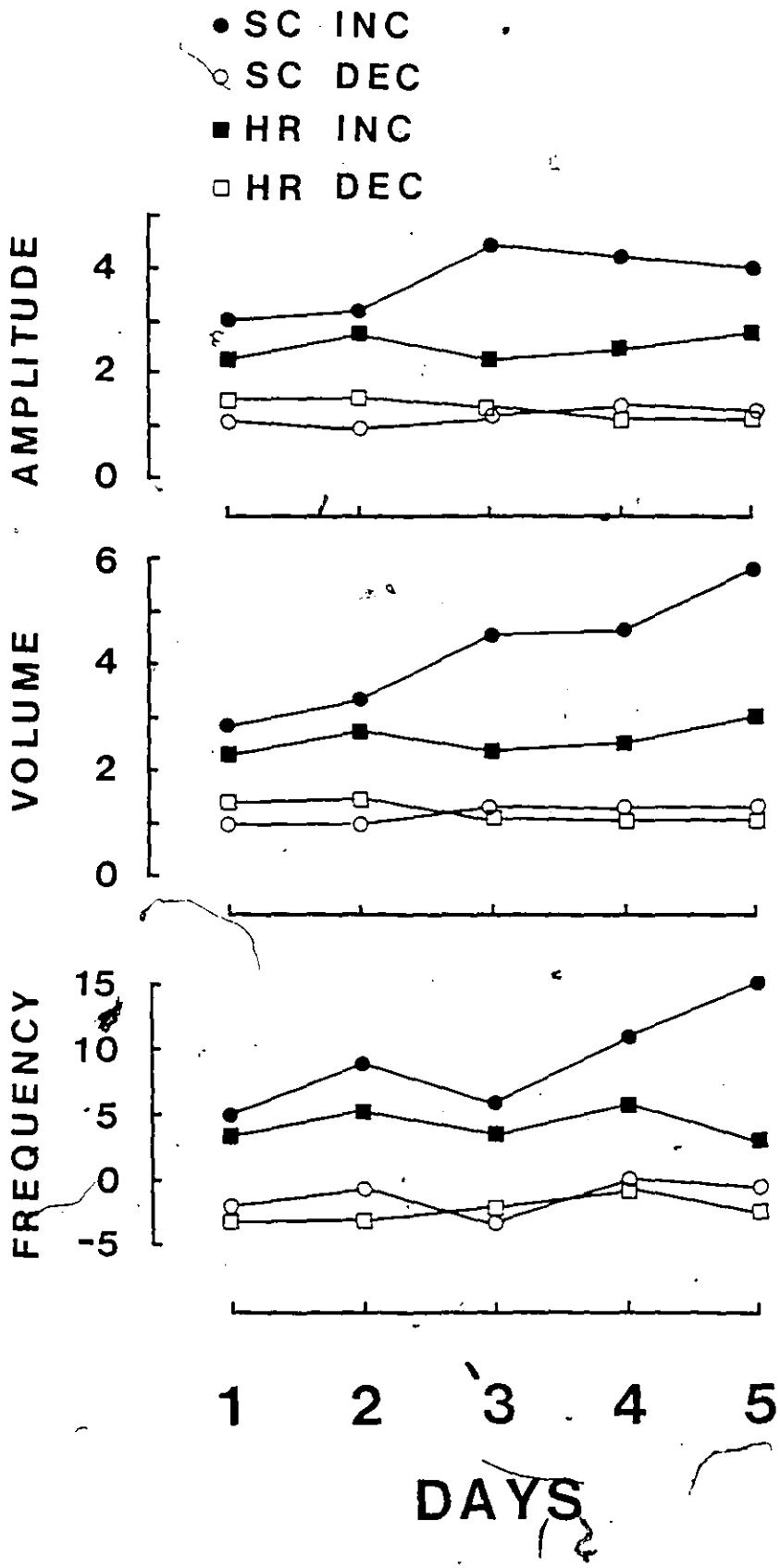

SC INC
SC DEC
HR INC
HR DEC
AMPLITUDE
4
2
0
VOLUME
6
4
2
0
FREQUENCY
15
10
5
0
-5
1
2
3
4
5
DAYS

Figure 5

nature of these respiratory changes is not clear. Augmentation of respiratory changes by conductance feedback is suggestive of functional coupling between these responses.

Within-Subject Correlational Analyses

Within-subject correlations were computed between the target response and each remaining concomitant activity for Groups HR and SC. These correlations were computed separately for increase and decrease trials on each day of training for individual subjects. Frequency distributions of these correlations were then compiled for each target group. These distributions were tested using a sign test to determine if significantly more than half of correlations fell on either side of the zero point. This allowed an assessment of whether or not, as a group, these correlations deviated from a random sampling of zero correlations. When the distribution is statistically asymmetrical then it is clear that significant correlation exists. However, the possibility exists that when the distribution is not asymmetric individual subjects might still have evidenced significant correlations between the autonomic target and a given concomitant.

The distributions for the HR target group are presented in Figure 6. The correlations for increase trials between heart rate and the remaining concomitants are presented on the left side of the figure; the comparable correlations for decrease trials are on the right-hand side. On increase trials heart-rate changes were positively correlated with skin conductance, forearm EMG, body movement, respiratory amplitude, and respiratory volume (maximum $p < .05$). On decrease trials heart rate showed a strong tendency to be positively correlated with

Figure 6 Frequency distributions of within subject Pearson product movement correlations between heart rate and all other concomitant measures for the HR target group. Correlations from increase trials are shown on the left; correlations from decrease trials are shown on the right. Probabilities values represent the likelihood of each distribution having been sampled from a population of coefficients symmetrical about zero.

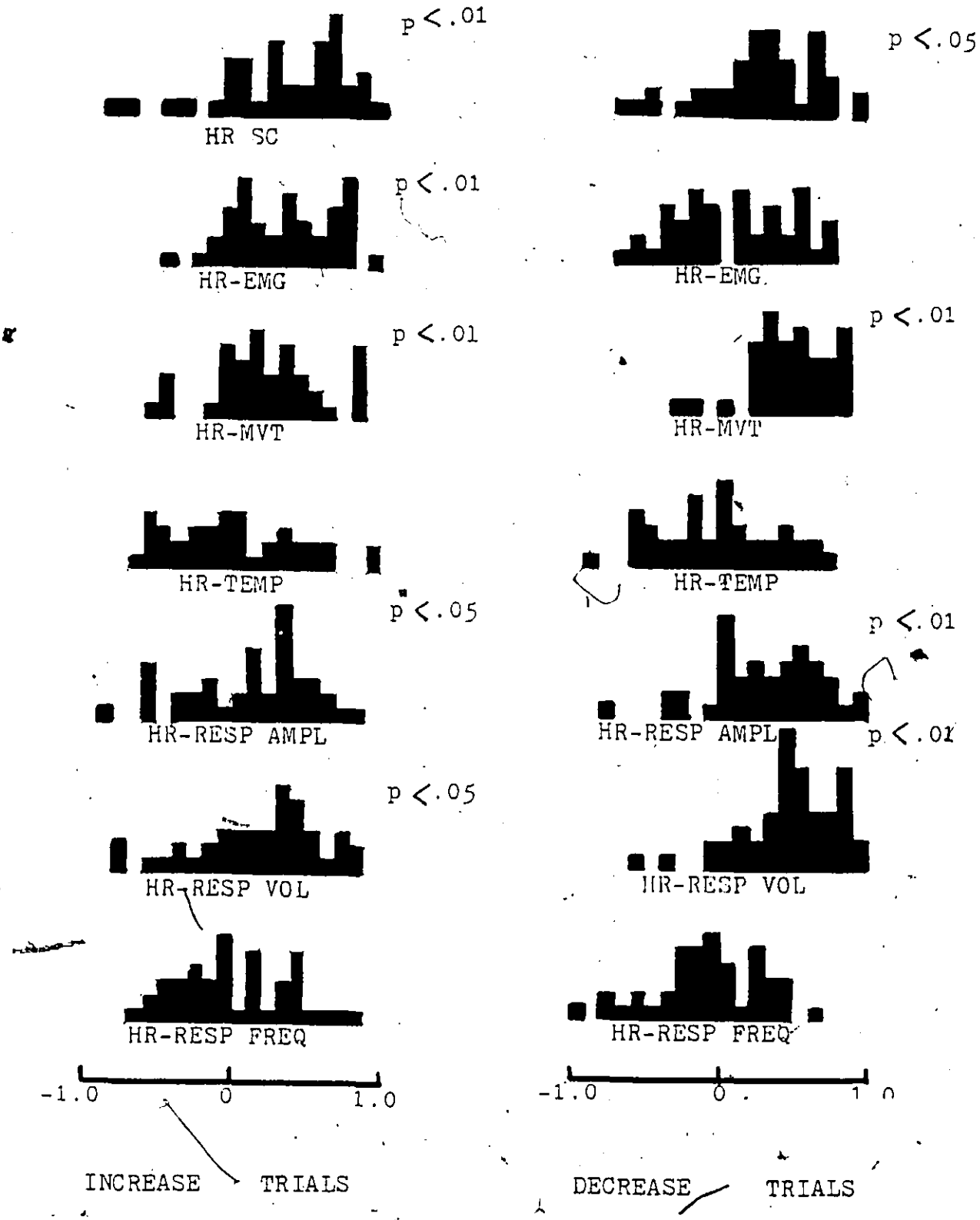

p < .01
HR SC
p < .05
p < .01
HR-EMG
HR-EMG
p < .01
HR-MVT
p < .01
HR-MVT
HR-TEMP
HR-TEMP
p < .05
HR-RESP AMPL
p < .01
HR-RESP AMPL
p < .01
p < .05
HR-RESP VOL
HR-RESP VOL
HR-RESP FREQ
HR-RESP FREQ
-1.0
0
1.0
-1.0
0
1.0
INCREASE TRIALS
DECREASE TRIALS
HR TARGET GROUP

Figure 6

gross movement and respiratory amplitude and volume (maximum $p < .01$). Heart rate also showed a positive correlation with skin conductance on decrease trials ($p < .05$).

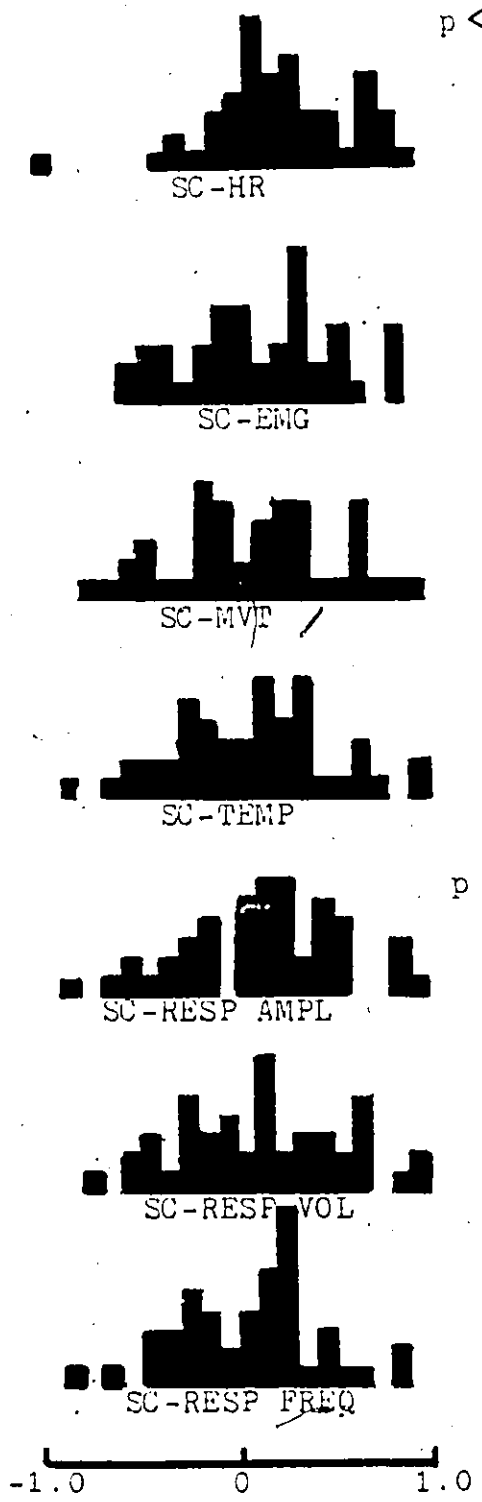
Figure 7 presents the correlation distributions for the skin conductance target group, on increase trials. Decrease trials are not included since no learned conductance changes occurred on those trials. For the SC target group, heart rate and conductance were again correlated ($p < .01$). Skin conductance increases were also significantly correlated with respiratory amplitude ($p < .01$). No other significant correlations were seen.

In summary, the distribution of within-subject correlations shows that, while the two autonomic measures showed consistently positive correlations with each other, heart-rate increases were consistently correlated with increases in somatomotor and respiratory activity in Group HR, whereas conductance increases were correlated only with respiratory amplitude in the SC target group.

Discussion

The results obtained in this experiment for learned heart-rate control are consistent with previous research. Heart-rate increases were found only in the context of somatomotor and respiratory changes. Furthermore, the correlational data suggest a functional coupling between the heart-rate changes and the concomitant activities. Within individual subjects, those trials upon which largest somatomotor changes occurred also tended to be those trials upon which the largest changes in heart rate occurred. Parallel, though not as pronounced, results were also observed with respiratory activity. Within-subject

Figure 7 Frequency distributions of within subject Pearson product movement correlations between skin conductance and all other concomitants on increase trials for the SC target group. P values represent the likelihood that each distribution represents a sample drawn from a population of coefficients symmetrical about zero.



INCREASE TRIALS

SC TARGET GROUP

Figure 7

correlational analyses also suggested that these concomitants contributed to the heart-rate changes observed on decrease trials in Group HR.

In the case of skin-conductance control, the pattern of contributing concomitants appeared to be different. Significantly larger increases in skin conductance were produced on increase trials by subjects given feedback for skin conductance than by subjects given feedback for heart rate. This facilitation of conductance control by conductance feedback was associated with larger changes in respiratory volume in the conductance group, although this effect was only evident, on the final three days of training whereas the superiority of conductance control appears to have been present at the outset. At the within-subject level, those trials on which the larger conductance increases occurred appeared to be those trials on which large changes in respiratory amplitude occurred. These data suggest a possible coupling between respiratory activity and conductance responding. However, there are inconsistencies in the data. The within-subject correlations were evidenced with respiratory amplitude while the group differences were seen in respiratory volume and frequency. This may indicate that the respiratory alterations used by subjects did not map easily on to one of these respiratory dimensions. The second experiment of the thesis, described in the next chapter, directly examined the nature of the relationship between conductance and respiratory activity by attempting to actively dissociate the two responses.

A question raised by the findings of Experiment 1 asks why concomitant changes in gross body movement and forearm EMG were observed

in the skin-conductance condition, if they were not functionally coupled to the target response. One answer proposes that these concomitants are determined by the way subjects approach tasks of the current type rather than by functional coupling. It is plausible to suggest that a variety of activities is initiated by the subject at the beginning of training in an attempt to control responding (see Roberts & Marlin, 1979). If the subject is successful in achieving the desired result he may continue to emit all of these activities without engaging in any attempt to reject those responses which are not contributing to target change. Such an outcome might be expected in situations like the current study, in which a subject is biased (through the use of explicit increase-decrease instructions, the lack of a specific label to identify the target, and so forth) towards the production of a variety of behaviors, some of which are effective and some of which are not. Under such conditions subjects may fail to identify the irrelevant components of their performance unless an explicit requirement is imposed to produce changes specific to the electrodermal system. The present data offer no evidence that specificity of electrodermal control is likely to develop over five days of training in the absence of such a requirement.

The second interpretation proposes that concomitant changes in somatomotor behavior contributed to sudomotor activation in the present study. However, changes in any one of a subset of such behaviorss may have been sufficient for sudomotor control, although no particular concomitant was necessary as long as one of the subset was present. Under these circumstances response strategies could have been highly variable, even within subjects, as was true in the present work.

Application of dissociative training procedures to selected somatomotor activities will be required to more adequately address this and related alternatives.

CHAPTER 4: A DISSOCIATION OF RESPIRATORY AND ELECTRODERMAL CHANGES

To briefly recapitulate, the previous experiment examined concomitants of learned sudomotor and cardiac control and began to look at the relationships between those concomitants and the autonomic target. Two groups of subjects were trained to produce bidirectional autonomic changes in either skin conductance or heart rate. At the end of five days of training both groups showed large and significant bidirectional differences in skin conductance, heart rate, EMG activity, gross body movement, and respiratory activity. The SC-target group evidenced larger conductance changes on increase trials than did the HR-target group. Heart-rate changes on increase trials did not differ between the two groups. Within-subject correlational analyses found that the concomitant activities evidenced by the SC-target group were not consistently related to target change for the group as a whole, with the exception of respiratory activity. This is in contrast to the HR-target group where both the somatomotor variables and respiration were clearly associated with target autonomic change within subjects.

These data suggest that respiratory activity may be functionally related to the conductance changes evidenced in the SC-target group. However, the picture is not totally clear. The data supporting a functional relationship are:

1) Accompanying the significant group difference in conductance was a significant group difference in respiration frequency and a significant group by trials interaction for respiratory volume;

2) The SC-target group evidenced a distribution of within-subject correlations between skin conductance and respiratory amplitude that was significantly biased towards positive relationships. No other concomitant evidenced such a relation with conductance.

This relationship, however, is somewhat clouded by the observation that the group differences that occurred were for respiratory volume and frequency while the within-subject relations were evidenced between conductance and respiratory amplitude. However, this may reflect the fact that the subject's respiratory manipulation does not map simply onto a single one of these respiratory dimensions.

These data suggest that, of the concomitant activities measured in the previous experiment, respiration is the most likely to be functionally tied to the production of electrodermal changes. The most direct means of assessing the role of respiratory change is to examine the ability of subjects to dissociate learned conductance increases from changes in respiration.

The logic of the dissociation experiment was described in the first chapter of the thesis. Subjects are trained to increase skin conductance while, at the same time, altering their respiratory pattern (integration trials) or holding their respiratory pattern constant (dissociation trials). If the subjects are able to produce comparable changes on both types of trials, then it is clear that respiratory changes are not necessary for the production of increases in skin conductance. However, if subjects are unable to produce increases in conductance on dissociation trials that are comparable to increases seen on integration trials, then it can be concluded that the respiratory

changes are contributing to the production of the conductance increases. The more discrepant the conductance performance on the two types of trials, the stronger is the functional relationship between the two responses (Fetz, 1974).

As discussed in the first chapter, it is important to control for task difficulty. It is possible that subjects may perform poorly in the dissociation condition, not because of a functional coupling between the two responses, but because it may be more difficult to alter any two responses in opposite directions than in the same direction. If this is the reason for poor performance on dissociation trials, then the identity of the concomitant activity should be irrelevant. To evaluate this possibility, the experiment reported in this chapter employed two groups of subjects. The first group (SC-RESP) was given training to dissociate skin-conductance increases from changes in respiration. The second group was trained to dissociate gross body movement from conductance increases (SC-MVT). Based upon the data from the first experiment it seemed that the latter dissociation should be possible for at least some subjects, since no correlations were noted between movement and conductance for the group as a whole in that study. If subjects succeed at this dissociation but fail at the respiration-conductance dissociation, then it must be something specific to the respiratory concomitant rather than the difficulty of a dissociative task per se that accounts for the poor performance on dissociation trials.

It was noted earlier in Chapter 2 that previous attempts at dissociation training have not been particularly successful. Schwartz

(1972) was able to dissociate two responses within the cardiovascular system, heart rate and systolic blood pressure. Levenson (1976) and Newlin and Levenson (1978) were unable to dissociate heart-rate changes from respiration-rate changes. Rice (1966) failed to provide convincing evidence of learned skin-conductance responses in the absence of EMG changes. These failures may have been due to functional coupling between the responses involved, or due to limitations of the procedures employed. A number of steps were taken in this study to attempt to develop a more powerful dissociative training procedure than had been employed in the past.

(1) During integration-dissociation training subjects were provided with continuous, analog feedback for both the target conductance response and the concomitant activity. Unlike the pattern feedback employed by Schwartz (1972) and Newlin and Levenson (1978), this feedback provides information about both responses separately and continuously even if the subject is not currently succeeding at either one or both of the concurrent task requirements.

(2) Subjects were given feedback, not just for changes in respiration rate (Newlin & Levenson, 1978), but for changes in any aspect of their respiratory behavior from the pretrial baseline as measured by the respiration transducer. This was accomplished by utilizing the subject's pretrial respiratory behavior to construct a respiratory template for the pretrial period. Subjects were then given feedback for any deviation in their current respiration pattern from the pretrial template.

(3) A total of 15 one-hour sessions was provided for subjects to acquire the dissociation task. It was important to be reasonably sure that a failure to dissociate a concomitant from target responding was not due to insufficient training.

(4) The dissociation and integration procedures of this experiment required that the subject be able to (a) increase skin conductance, (b) increase the concomitant activity, and (c) hold the concomitant activity constant. Subjects were given three days of feedback training to perform each of these component tasks separately before beginning 15 sessions of integration-dissociation training.

(5) Finally, aspects of the integration-dissociation task were introduced gradually over the three pretraining days. On day 1, subjects received feedback for changes in skin conductance and respiratory activity. However, feedback was given for only one of these responses on each feedback trial (i.e., skin conductance alone or respiration alone). On day 2, the second feedback display was activated on feedback trials, but subjects were instructed to manipulate only one of the responses on this day. The response to be manipulated (target or concomitant) varied across trials. On day 3, trial sequences were made more irregular than on days 1 and 2, and the requirement to perform in the absence of feedback (transfer) was introduced. On day 4, integration-dissociation training was begun.

In addition to introducing the component tasks gradually, the pretraining phase was designed to assess whether subjects could perform the components separately prior to integration-dissociation training.

Method

Subjects

Ten male students aged 21 to 38 years (mean = 25 years) served as subjects. None had participated in any feedback training experiment and all were in good health with no history of cardiovascular or respiratory disorder. They received $5.00 per session as well as a performance incentive of up to a maximum of $2.00 per session. Five subjects received feedback training for dissociation of skin conductance and respiration (Group SC-RESP) and five for dissociation of skin conductance and movement (Group SC-MVT).

Apparatus

The subjects were tested in the same experimental room as described in Experiment 1 with the following modifications. The Sony videomonitor described earlier was replaced with a Toshiba C990C color monitor (screen size approximately 38 cm x 45 cm). The feedback displays were generated by an Apple II computer in high resolution graphics mode. The experiment was controlled on-line by a PDP-11/03 computer. Parameters for the display were calculated by the PDP-11 and transmitted to the Apple II via an RS-232 serial interface.

Electrophysiological data were recorded on a Beckman type R polygraph and sampled at 125 msec intervals by the computer. Physiological recordings were identical to those described in the first experiment with the following exceptions. First, skin temperature was not recorded in this experiment. Second, the R-wave of the electrocardiogram activated a Schmidt trigger on the clock of the PDP-11 which allowed for direct measurement of the cardiac interbeat interval

(IBI) to the nearest millisecond. Third, EMG and gross body movement signals were not recorded digitally as before. Instead these signals were sampled every 125 msecs via the analog to digital converter of the PDP-11.

Feedback Display

The feedback display, shown in Figure 8, provided information for two responses in a manner similar to the single display of Experiment 1. The display on the left side of the screen in Figure 8 provided information on changes in skin conductance whereas the display on the right provided information on changes in the concomitant response (either respiration or movement). In each case the horizontal line represented the level of responding prior to trial onset. For the display on the left, increases in skin conductance from the pretrial baseline were displayed as increases in the length of the vertical line upwards from the horizontal line. An increase in conductance followed by a decrease would result in the line increasing in length upwards and then decreasing in length. However, decreases in skin conductance below the pretrial baseline were not displayed (i.e., the vertical line never projected below the horizontal line).

The display on the right-hand side of Figure 8 provided information about the concomitant responses in a similar fashion. In Group SC-RESP any deviation from the baseline pattern of breathing resulted in an upward excursion of the vertical line. The exact procedure for calculating respiratory feedback is described in Appendix D. In Group SC-MVT increases in the level of movement from the pretrial

Figure 8 A schematic representation of the feedback display used in Experiment 2. The display on the left corresponds to skin conductance, the display on the right corresponds to the concomitant response, either respiration or movement. In each case, any increase in the response (for respiration any alteration in the pattern of breathing) resulted in an upward increase in the length of the vertical line. The magnitude of increase in length was proportional to the magnitude of change in the response.

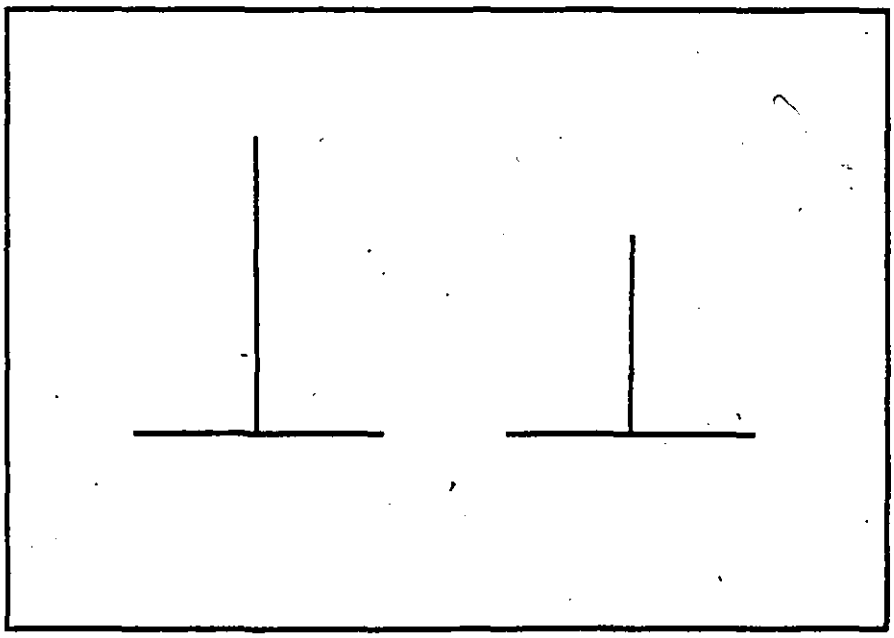


Figure 8

baseline increased the length of the line. Decreases in movement from the pretrial baseline (a rare event in any case) were not displayed.

The color of the feedback displays indicated to the subject the nature of the change requested in a particular response (skin conductance and/or the concomitant, depending upon how the displays were illuminated). If a display were presented in green, the subject was to increase the vertical line towards the top of the screen as much as possible (i.e., change the response as much as possible). If a display appeared in orange, the subject was to keep the vertical line as close to the horizontal as possible (i.e., hold the response constant). When a display was presented in white, the subject was not to manipulate that response in any way, either by changing it or by actively trying to hold it constant.

On transfer trials, rectangles of color were presented in the same physical locations on the screen where feedback had previously appeared, but no information about responding was given. The color of the rectangle designated the same instructions as the color of the display on feedback trials.

Procedure

Subjects were assigned to the two groups randomly, until each group was filled. Group SC-RESP received feedback for both skin conductance and respiratory activity. Group SC-MVT received feedback for skin conductance and gross body movement. Subjects were informed of the responses that were trained. No information was provided as to how subjects might manipulate or control either response. Instead, subjects

were instructed to use the feedback display to provide such information.

Upon arrival in the laboratory on the first day, subjects were administered the standard medical interview described in Experiment 1. They were then given a typed set of instructions to read which explained the nature of their task, the procedures that would be followed, and described the feedback display (see Appendix E for the complete text of these instructions).

The recording electrodes were then applied and the subject was seated in the experimental room. After the experimenter verified that all the recordings were of good technical quality, pre-recorded instructions were given which described the procedure for that day. On the first day of training simulated feedback displays were shown to the subject as part of the instructions (see Appendix F for the complete text of these instructions).

Pretraining Phase. Days 1 to 3 constituted the pretraining phase of the experiment.

On day 1 of this phase subjects received a total of 15 feedback trials. All trials were 60 seconds in duration and were separated by a variable length inter-trial interval that averaged 70 seconds in duration. On five of these trials the subject was to increase skin conductance. The conductance display was presented in green, indicating that the subject should alter the response as much as possible. The horizontal line for the concomitant was presented in the appropriate location on the screen, but it was presented in white indicating that the subject should not try to manipulate the concomitant in any fashion.

Furthermore, the vertical line for the concomitant was not activated and thus the subject received no information concerning the concomitant on those trials when he was to alter conductance. The subject was informed that the concomitant display would be inactive. These trials were presented consecutively for a total of five trials of this type.

Subjects also received a second block of five trials during which the concomitant display was presented in green, instructing him to alter the concomitant (either movement or respiration) as much as possible. On these trials the vertical line of the concomitant display was now activated. However, only the horizontal referent was presented for the conductance display, and it was shown in white, as was done previously for the concomitant.

Finally, the subject received a block of 5 trials during which the concomitant display was presented in orange, instructing him to hold the concomitant constant. The vertical line of the concomitant display was active, but once again only the horizontal line of the conductance display was presented, and it was in white.

The actual order of these three blocks of trials was varied randomly from subject to subject. The blocks were separated by blank trials during which data were collected but no display was presented. The first and last trials of the session were also blank trials. The purpose of blank trials was to measure response activity in the absence of a performance requirement.

On the second day of pre-training the same procedure was employed except that now the vertical line of the second display was active. This display was still presented in white indicating that the

subject should not attempt to control it in any fashion, but the vertical line now varied with changes in responding (skin conductance or the concomitant).

On the third and final day of pretraining two changes were introduced to the procedure. First, the trials were no longer presented in blocks but were ordered randomly. Each subject received 4 "increase SC" trials, 4 "increase the concomitant" trials, and 4 "hold the concomitant constant" trials, with the order of these trials arranged randomly. In addition, subjects were asked, for the first time, to perform in the absence of feedback (transfer). One transfer trial of each type was given at the beginning and end of the session. As before, blank trials were inserted before and after the series of feedback trials. This session concluded the pretraining phase of the experiment.

Training Phase. The next 15 days (sessions 4-18) constituted the training phase. Subjects received six trials during which they were to increase both skin conductance and the concomitant activity (integration trials) and six trials during which they were to increase skin conductance but hold the concomitant response constant (dissociation trials). Subjects received continuous analog feedback for both skin conductance and the concomitant response. Trials were 60 seconds in duration with an inter-trial interval that varied between 50 and 90 seconds with a mean of 70 seconds. Trials were arranged in an irregular sequence such that three trials of the same type did not occur consecutively.

In addition, subjects received a block of 4 transfer trials (2 integration, 2 dissociation) at the beginning and end of each session. On these trials no feedback display was presented; instead, patches of color were displayed in the same physical locations as the displays given previously. Transfer trials were ordered randomly arranged within the block, although the same sequence was used at the end of a session as was employed at the start of that session. Sequences varied randomly from session to session. A single blank trial preceded and followed each transfer block.

Following the 10th and 15th day of integration-dissociation training (sessions 13 and 18 of the experiment, respectively), a questionnaire was administered to inquire as to the subject's reportable knowledge of his performance. The questionnaire asked the subject to describe how he altered the target response and to rate the difficulty of the integration and dissociation trials on a ten point scale (1 = very easy; 10 = impossible). The same questionnaire was repeated on both days. A complete text of the questionnaire may be found in Appendix G. Throughout training subjects were observed via closed circuit TV and the experimenter recorded any noticeable behaviors emitted.

Results

Statistical Analysis

All statistical comparisons were made at the individual subject level. Comparisons were made by means of individual t-tests. In spite of the large number of such tests, no correction could be applied to the

α level since the interdependence of the various dependent measures is unknown. To avoid breaking up the text, the actual t-values are presented in Appendix H. Results will be referred to as significant in the text when $\alpha < .05$.

All subjects succeeded in producing the required performance during the pretraining phase of training. That is, all subjects were able to produce significant increases in skin conductance, to alter the concomitant activity (either respiration or movement), and to hold the concomitant constant, when performing these tasks individually. In addition, all subjects performed well on transfer trials. That is, they were able to maintain their performance in the absence of feedback on the final day of pretraining. Therefore, the pretraining performance will not be presented for each subject.

I shall begin by giving an overview of the performance of Group SC-RESP. Individual subjects in that group will then be discussed. Following this, the same organization will be repeated for Group SC-MVT. The results section concludes with a brief summary of performance in both groups.

Group SC-RESP: Overview

Figure 9 summarizes the skin conductance and respiratory performance of Group SC-RESP on integration, dissociation, and blank trials. The left-hand panels show the conductance changes individually for all five subjects. Inspection of these panels shows that Subjects MR01, MR02, MR03, and MR05 were able, by the end of training (sessions 13-18), to produce large-magnitude changes in skin conductance on dissociation trials. These changes approximated those seen in the same

Figure 9 Mean changes from pretrial to trial performance in skin conductance (left hand panels) and respiratory volume (right hand panels) on integration and dissociation training trials and on blank trials, for sessions 4 to 18. On sessions 1 to 3 performance on skin conductance increase trials is shown, each pair of panels presents a single subject's performance. All subjects in group SC-MUT are shown.

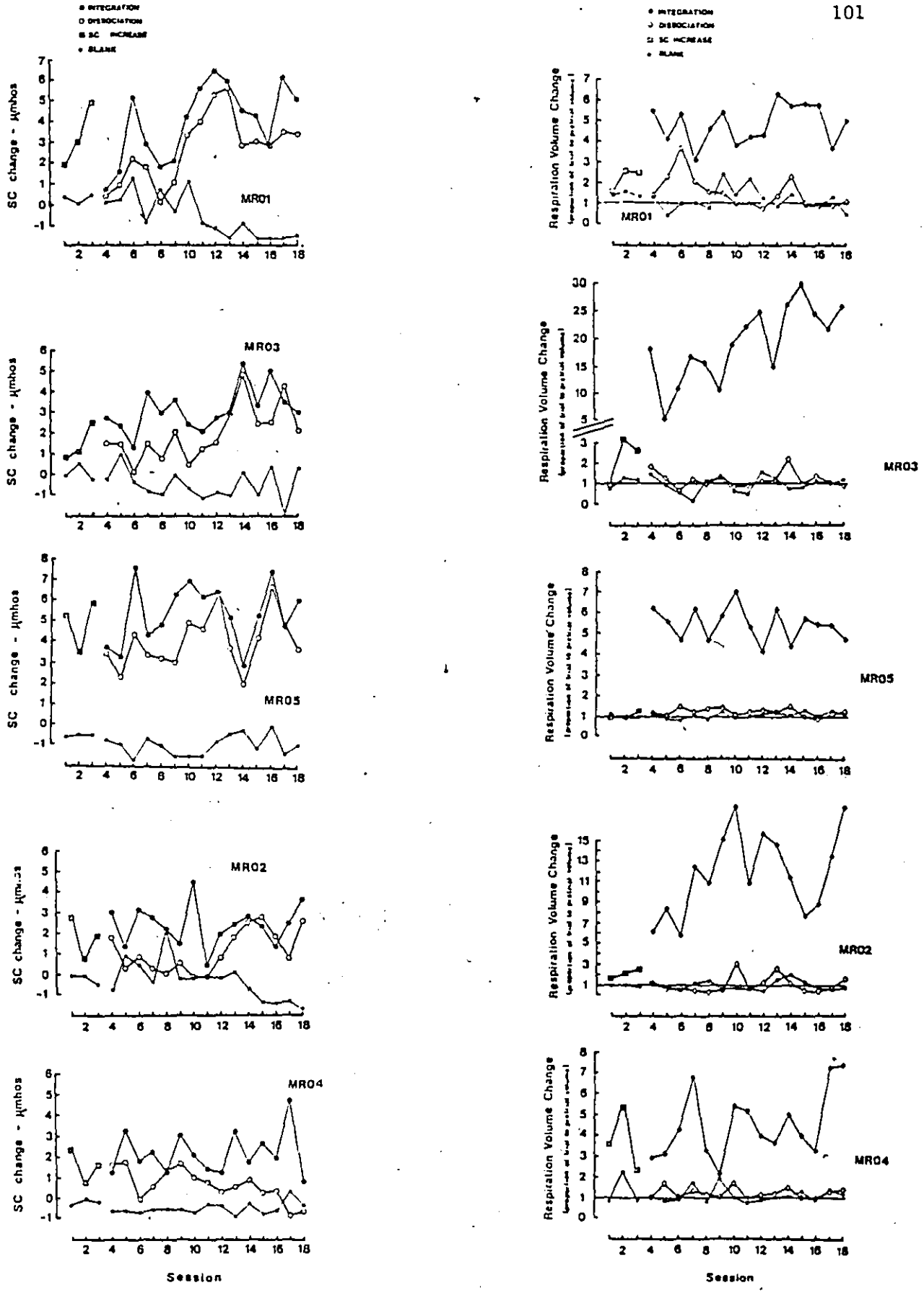

INTEGRATION
DISSOCIATION
SC INCREASE
BLANK
SC change - μmhos
Respiration Volume Change
MR01
MR03
MR05
MR02
MR04
Session

Figure 9

subjects on integration trials where sudomotor performance was also robust (typically in excess of two μmhos). However, the remaining subject in this group, MR04, was an exception to this pattern. Although MR04 produced sizeable increases in skin conductance on integration trials, dissociation performance deteriorated over sessions so that skin-conductance changes on this type of trial were not significantly different from blank trial performance at the end of integration-dissociation training.

The right-hand panels of Figure 9 show changes in respiratory activity for these same subjects. For convenience respiratory performance is depicted by volume changes since this variable was sensitive to changes in the remaining two respiratory measures (amplitude and cycle duration). Inspection of these data shows that all subjects produced substantial increases in respiratory volume on integration trials. In addition, respiratory volume was held constant at the pretrial level on dissociation trials, and did not differ from that seen on blank trials, for all subjects. Thus it appears that the large-magnitude changes in skin conductance that were produced by four of the five subjects on dissociation trials occurred in the absence of measurable respiratory change. Analyses of respiratory amplitude and cycle duration to be presented below confirmed this result.

These findings indicate that changes in respiratory behavior are not required for the production of learned increases in skin conductance. However, control of responding was not entirely specific to skin conductance on dissociation trials. All subjects in Group SC-RESP gave evidence of manipulations of the phalangeal and palmar

surfaces during dissociation that may have contributed to conductance changes on this trial type. In four cases this evidence was contained both in measurements of forearm EMG and in the verbal report, whereas in the last instance it was confined to the latter measure only. There was also a general correspondence between EMG and conductance changes over the course of dissociation training, although it will be seen that this correspondence was not perfect.

The data given in Figure 9 for integration and dissociation performance were taken from feedback trials. Analysis of transfer trials showed that there was a tendency for dissociation performance to deteriorate in the absence of feedback, although, as will be noted below, this varied considerably between subjects.

Group SC-RESP: Individual Subjects.

Subject MR01: The data of Subject MR01 will be reviewed in detail. The data for the remaining subjects will be discussed only to the extent that their data deviates from the results seen with MR01.

For convenience, MR01's skin conductance and respiratory volume changes are reproduced on a larger scale in Figure 10. Significant and sizeable increases in skin conductance were evidenced during the pretraining phase and on both integration and dissociation trials, especially during the latter half of training. Changes in skin conductance were significantly larger on both integration and dissociation trials than on blank trials. Overall, the magnitude of conductance change in integration trials was significantly larger than on dissociation trials and this difference remained significant when tested for the last five days of training only. On the other hand,

Figure 10 Conductance (left hand panel) and respiratory volume (right hand panel) change scores for subject MR01. These panels are reproduced from Figure 9.

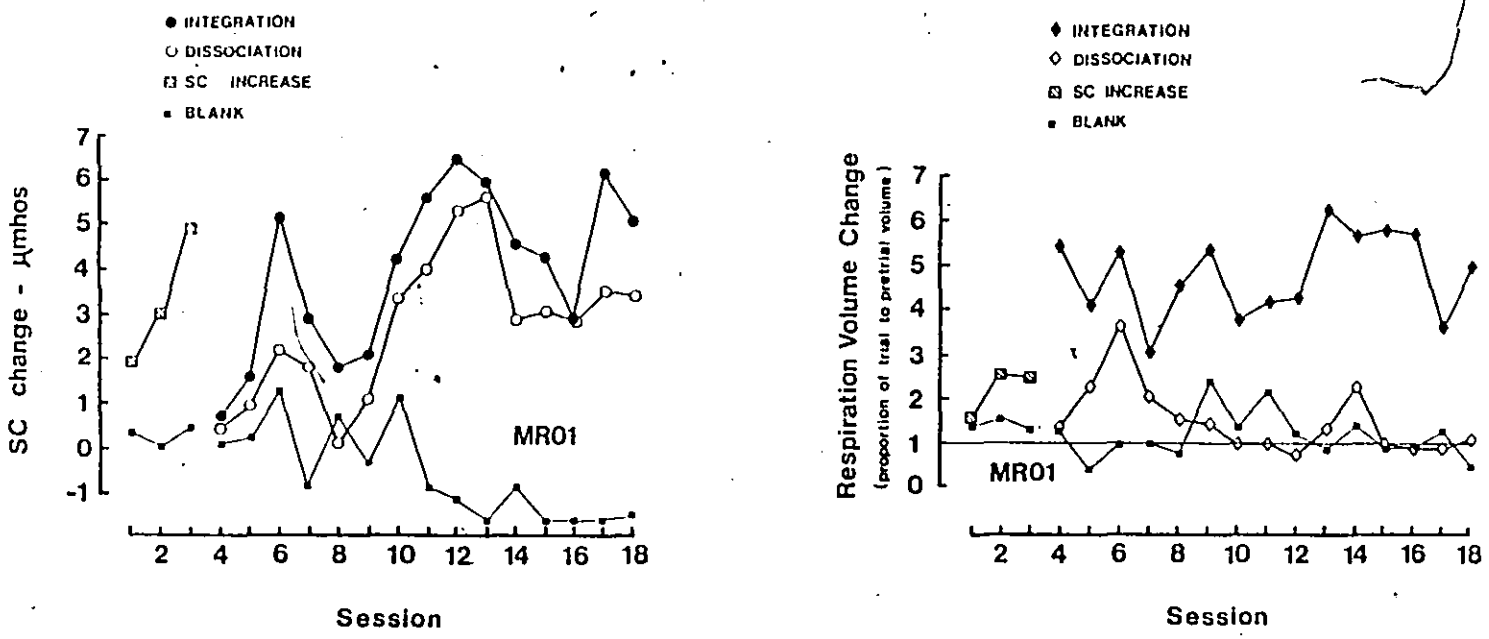

INTEGRATION
DISSOCIATION
SC INCREASE
BLANK
SC change - μmhos
MR01
Session
INTEGRATION
DISSOCIATION
SC INCREASE
BLANK
Respiration Volume Change
(proportion of trial to pretrial volume)
MR01
Session

Figure 10

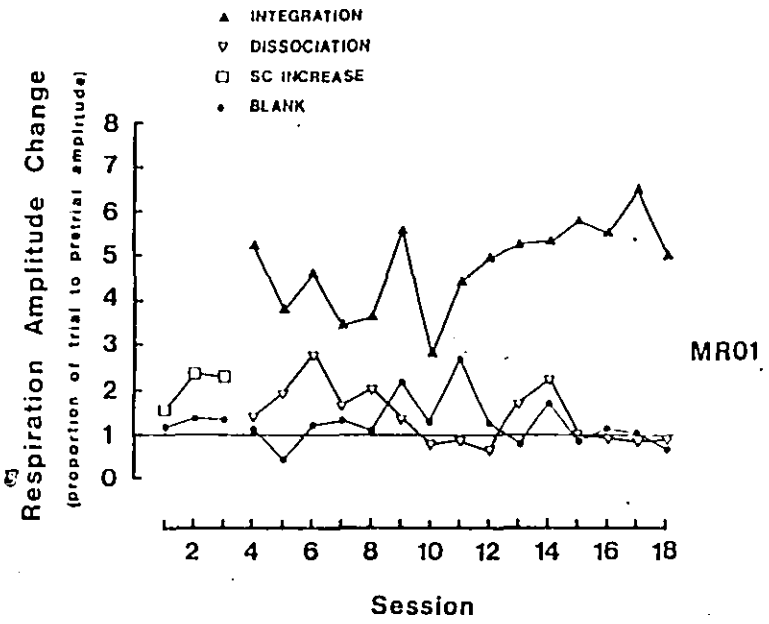
respiratory volume increased three- to five-fold on integration trials while remaining unchanged on dissociation trials during the latter half of training. The only exception was day 14 where a slight increase in volume was seen on dissociation trials. Overall, integration and dissociation trials were significantly different with respect to respiratory volume. Dissociation trials did not differ significantly from blank trials.

Figure 11 shows the respiratory amplitude and cycle duration data for MR01. The amplitude data paralleled the volume data. Dissociation and integration trials differed significantly, while dissociation trials did not differ from blank trials, especially during the latter stages of training. On the other hand, respiration cycle duration changes for this subject exhibited considerable variability but were not consistently associated with any particular trial type. Overall, integration trials did not differ significantly from dissociation trials, and neither of these trial types differed from blank trials.

In summary, MR01 demonstrated significant and large magnitude changes in respiratory volume and amplitude throughout training on integration trials. While some changes in these measures were seen on dissociation trials in the early sessions, there were no changes in these measures in the latter stages of training. Cycle duration did not change consistently on any of the trial types.

Figure 12 shows the changes in forearm EMG, gross body movement, and cardiac IBI throughout training. The left hand panel shows the EMG changes. Non-zero changes in this response occurred on approximately 7

Figure 11 Respiratory amplitude (left hand panel) and cycle duration (right hand panel) change scores for subject MR01. Only data from training trials are shown.


INTEGRATION
DISSOCIATION
SC INCREASE
BLANK
Respiration Amplitude Change
(proportion of trial to pretrial amplitude)
MR01
Session

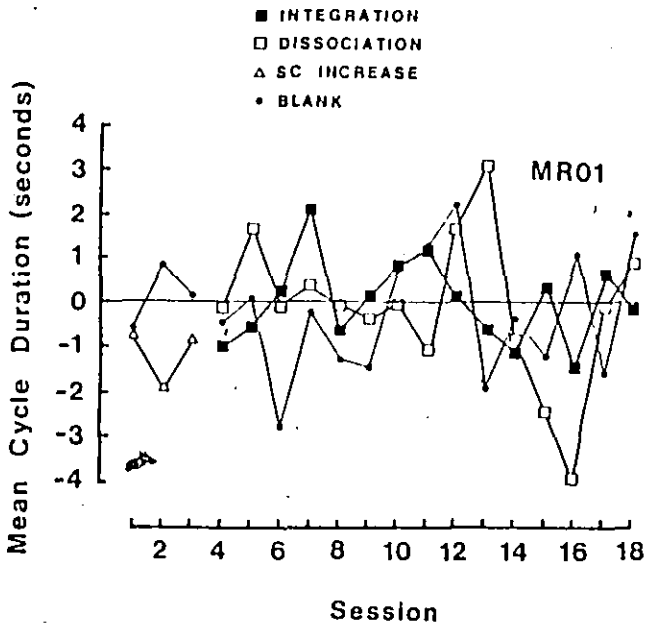

INTEGRATION
DISSOCIATION
SC INCREASE
BLANK
Mean Cycle Duration (seconds)
MR01
Session

Figure 11

out of 15 training sessions. A comparison of the EMG data with the conductance changes shown in Figure 10 suggests that while both responses increased in the last half of training, changes in skin conductance developed during sessions 10 and 11 whereas measurable EMG changes did not begin to occur until approximately sessions 12-14. Statistically, forearm EMG responses were not different on integration and dissociation trials. Across all 15 training sessions EMG changes were significantly larger on dissociation trials than on blank trials, however.

Changes in gross body movement on integration, dissociation and blank trials are shown in the middle panel of Figure 12. A slight, but consistent increase in movement was recorded on integration trials that was significant when compared to blank trials. An examination of the polygraph records suggested that somatomotor change could not be separated from changes in the movement transducer produced by the large magnitude respiratory changes on integration trials. No change in movement was seen on dissociation trials, and these trials did not differ from blank trials.

The right-hand panel of Figure 12 depicts the changes in cardiac IBI. The abscissa is reversed so that shortened IBIs (representing an increase in heart rate) are plotted upwards. The average IBI shortened significantly by about 200 msecs during integration trials. Except for very early in training, no change in mean IBI was evidenced on dissociation trials. These trials did not differ significantly from blank trials overall.

Figure 12 Forearm EMG (left panel), gross movement (middle panel) and 1B1 (right panel) change scores for subject MR01, on dissociation training, integration training and blank trials. Units for EMG and movement are arbitrary.

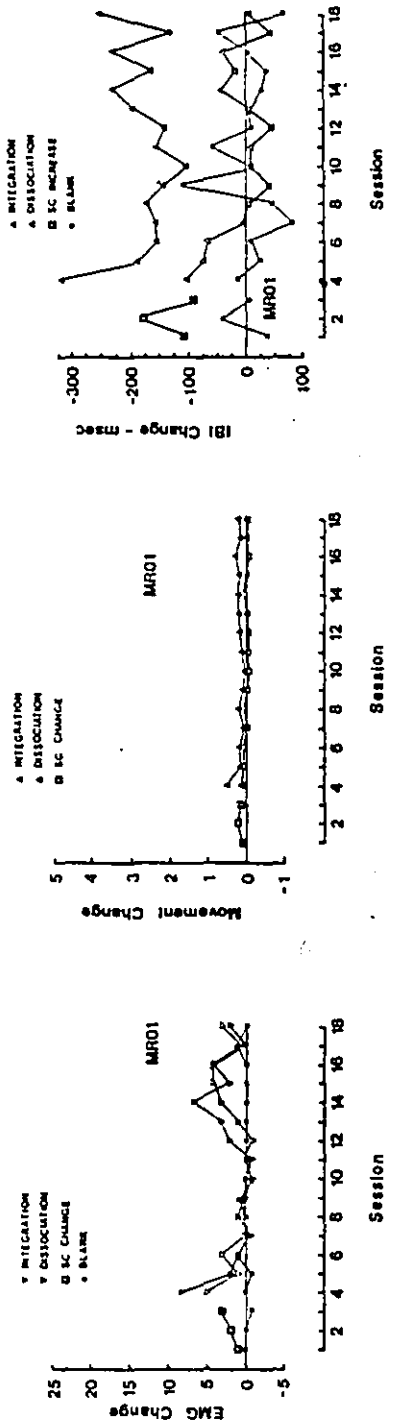

INTEGRATION
DISSOCIATION
SC INCREASE
BLANK
MR01
IBI Change - msec
-300
-200
-100
0
100
Session
2
4
6
8
10
12
14
16
18
INTEGRATION
DISSOCIATION
SC CHANGE
MR01
Movement Change
5
4
3
2
1
0
-1
Session
INTEGRATION
DISSOCIATION
SC CHANGE
BLANK
MR01
EMG Change
25
20
15
10
5
0
-5
Session

Figure 12

All of the previous data were from trials on which the subject was receiving feedback for both skin conductance and respiration. At the start and end of each session the subject was also required to perform both the integration and dissociation tasks without feedback present (transfer). For this subject there were no significant differences on any of the dependent measures between feedback and transfer trials for the integration task. On dissociation trials, however, respiratory control was not as precise in the absence of feedback as when feedback was available. Respiratory volume, amplitude, and cycle duration all showed significant differences between feedback and transfer trials. No other dependent measure showed a significant difference between feedback and transfer on dissociation trials.

It is always possible that averaging across trials, even for a single subject in a single session, might obscure or "average out" changes in respiratory or other measures that might have occurred. It is also possible that the particular respiratory measures (i.e., volume, amplitude, cycle duration) might have failed to capture subtle alterations in the signal that could have occurred. To assess this possibility, Figure 13 shows actual polygraph recordings taken from individual trials for Subject MR01 during the latter stages of training (session 15). A blank trial, during which the subject received no feedback display and made no attempt to control responding, is shown in the left-hand panel. The left-most vertical line on each recording indicates the start of the 60 second trial period. The right-most vertical line indicates the trial termination. The number at the right hand edge of each record is the change score (pretrial to trial change)

Figure 13 Duplicates of polygraph records of individual trials taken from the terminal performance of subject MR01. Recordings shown in each panel, from top to bottom, are skin conductance (SC), forearm EMG (EMG), gross body movement (MUT), cardiotachograph representation of heart rate (HR) and respiration (RESP). The left most panel shows a blank trial, the middle panel an integration trial, and the right most panel a dissociation trial. The vertical line on each record shows trial onset.

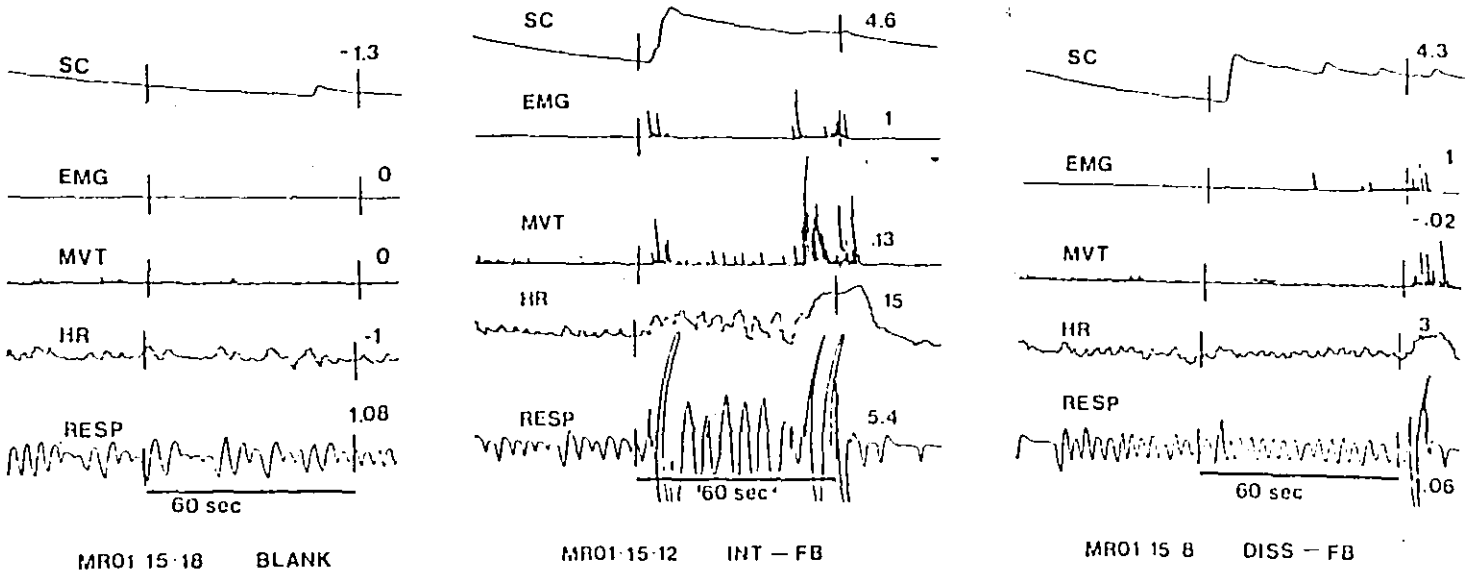

SC
-1.3
EMG
0
MVT
0
HR
-1
RESP
1.08
60 sec
MR01 15-18 BLANK
SC
4.6
EMG
1
MVT
.13
HR
15
RESP
5.4
60 sec
MR01-15-12 INT — FB
SC
4.3
EMG
1
-.02
MVT
HR
3
RESP
.06
60 sec
MR01 15 8 DISS — FB

Figure 13

for that measure. This panel illustrates respiratory, heart rate, and somatomotor variability in the resting state, and the corresponding tonic decrease in skin conductance that occurs under this condition.

The middle panel of Figure 13, on the other hand, shows an integration trial. In this instance large changes are seen in skin conductance, heart rate, respiration, and movement shortly after trial onset. Some bursts of forearm EMG are also seen at the start and end of the trial. It is worthwhile to note the close association between the bursts of movement and the respiration recording. Notice also how the heart-rate changes mirror the movement and respiratory changes.

Finally, a dissociation trial from the same session is depicted in the right-most panel of Figure 13. Large changes in skin conductance are seen shortly after trial onset, but no other dependent measure is substantially changed. However, some EMG activity is manifested during dissociation, particularly during the latter half of the trial.

The trials of Figure 13 are representative of the degree of control that this subject (and other subjects as well) was able to exert over his responding during the latter stages of training.

When asked via the post-experiment questionnaire to describe what he did to alter skin conductance, this subject described the following strategy.

> "between trials I keep my hands clasped together on my lap and try to breathe as slowly and shallowly as possible. Upon trial onset, I spread my hands apart and slowly moved them."

This subject indicated that he employed the same strategy on <u>both</u> integration and dissociation trials. He indicated that he tried such

strategies as body movement, frightening thoughts, muscle tension and foot and tongue movements, but that these were unsuccessful. In terms of difficulty he indicated dissociation trials somewhat more difficult (a rating of 4 on a 10 point scale, 1 = very easy, 10 = impossible) than integration trials (rating of 2).

Subject MR02: Figure 14 shows the change scores for skin conductance and respiratory volume on feedback and blank trials for Subject MR02 (repeated from Figure 9 earlier). Inspection of the left-hand panel shows that this subject produced conductance changes of 1-4 μmhos on integration trials throughout training. Consistent increases of a similar magnitude were not evidenced on dissociation trials until session 12 or 13. Overall, integration changes were significantly larger than dissociation changes. However, performance converged at the end of training where the two curves overlapped. Conductance performance on dissociation trials differed significantly from performance on blank trials overall but did not differ from performance on integration trials when tested for the last 5 sessions of training.

Respiratory volume changes for MR02 are shown in the right-hand panel of Figure 14. Very large (5 to 15 fold) increases in respiratory volume were produced on integration trials. These differed significantly from those produced on dissociation trials. Respiratory volume remained unchanged from the pretrial baseline on dissociation trials, with the exception of days 10 and 13. Overall dissociation trials did not differ significantly from blank trials.

Changes in respiratory amplitude for Subject MR02 mirrored those seen in respiratory volume and will not be presented. Respiratory cycle

Figure 14 Conductance (left) and respiratory volume (right) change scores for subject MRO2. These panels are reproduced from Figure 9.

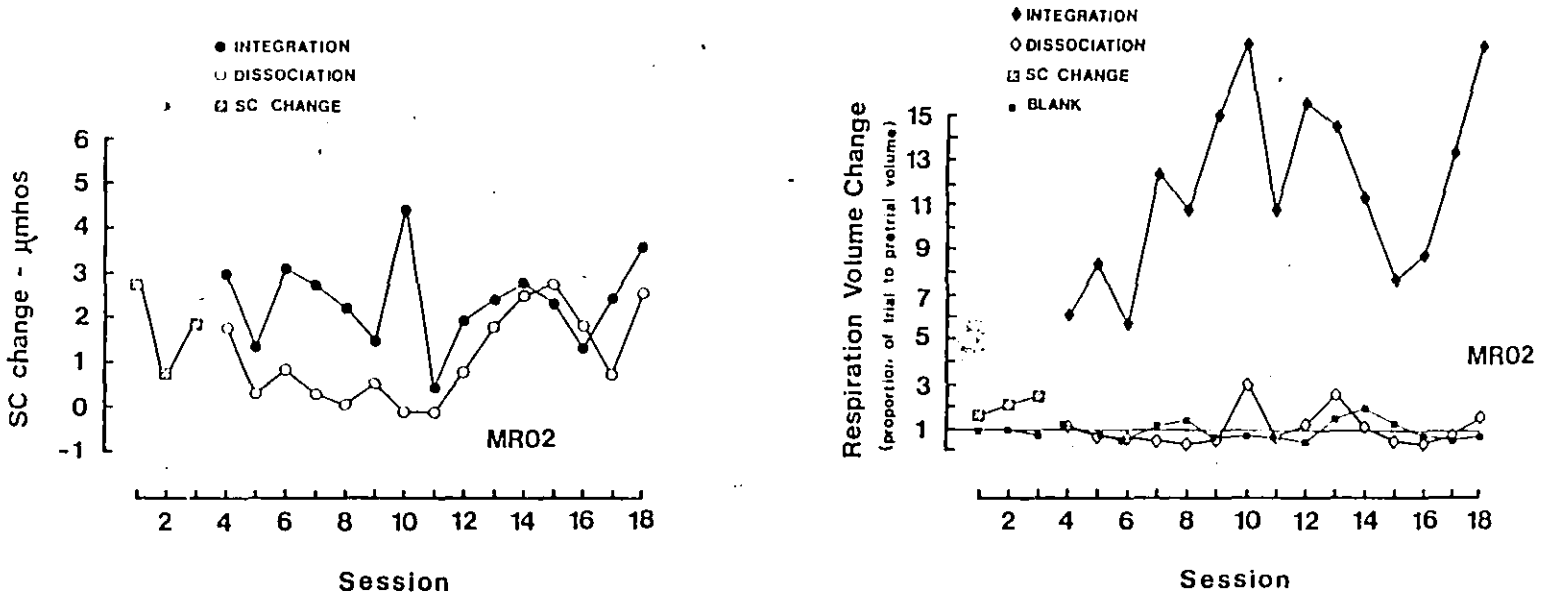

INTEGRATION
DISSOCIATION
SC CHANGE
SC change - μmhos
6
5
4
3
2
1
0
-1
MR02
2
4
6
8
10
12
14
16
18
Session
INTEGRATION
DISSOCIATION
SC CHANGE
BLANK
Respiration Volume Change
(proportion of trial to pretrial volume)
15
13
11
9
7
5
3
1
MR02
2
4
6
8
10
12
14
16
18
Session

Figure 14

duration tended to lengthen on integration trials. Duration on these trials differed significantly from that seen on dissociation trials. Mean cycle duration showed a certain amount of variability on the latter trial type but did not consistently change in any direction, and did not differ from those changes seen on blank trials.

In summary, MR02's respiratory performance was similar to that of MR01. Large magnitude changes were seen in volume and amplitude on integration trials, and, with the exception of sessions 10 and 13 no changes, were seen in these measures on dissociation trials.

Figure 15 shows the changes that occurred in forearm EMG as a function of trial type. On integration trials increases were evidenced early in training (sessions 4-7), but then were not seen again with the exception of session 17. A different pattern was evident on dissociation trials. Initially in training there were some small EMG changes that did not persist, but beginning with sessions 12 and 13 EMG increases reappeared and were sizeable. A comparison with Figure 14 shows that this trend coincides with the production of consistent increases in conductance on dissociation trials. Statistically, dissociation trials differed from blank trials over the 15 days of training.

As was true earlier of Subject MR01, Subject MR02 produced consistent, small magnitude increases in gross body movement on integration trials. No consistent change in movement was evident on dissociation trials, however, which did not differ from blank trials. Increases in movement and EMG were accompanied by shortened IBIs, as was

Figure 15 Forearm EMG change scores for subject MRO2 on integration and dissociation trials, blank trials and SC increase trials (days 1-3 only). Units are arbitrary.

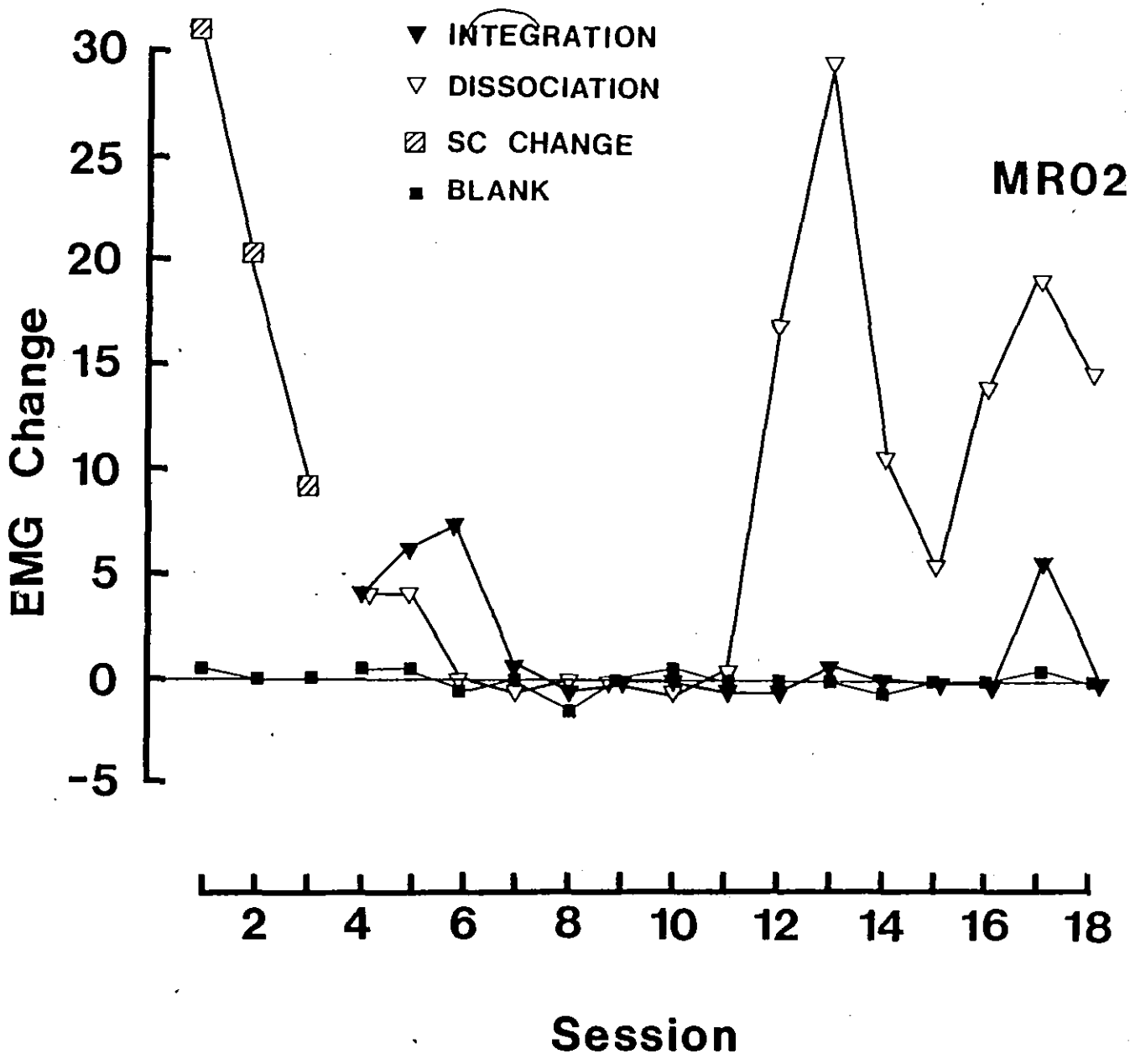

INTEGRATION
DISSOCIATION
SC CHANGE
BLANK
MR02
EMG Change
30
25
20
15
10
5
0
-5
2
4
6
8
10
12
14
16
18
Session

Figure 15

true earlier of Subject MR01. Because of the similarity of the subjects, these data are not presented for MR02.

On integration trials performed in the absence of feedback (transfer), Subject MR02 produced slightly but significantly smaller conductance changes than when feedback was present. The magnitude of respiratory amplitude and volume changes was also significantly smaller when feedback was not available. On dissociation trials the only significant difference between feedback and transfer was that respiratory cycle duration was significantly longer in the absence of feedback.

This subject reported that he "tried to get that rush of exhilaration that I get when skydiving..." and that he "...tried to maintain (an) overall excited state" when trying to increase skin conductance on both integration and dissociation trials. He also rated dissociation trials as somewhat more difficult (rating of 3) than integration trials (rating of 1).

Subject MR03: The skin conductance and respiratory volume changes produced by Subject MR03 on feedback and blank trials are reproduced in Figure 16. Inspection of the left-hand panel shows that this subject produced conductance changes ranging from 2 to 5 micromhos on integration trials. On dissociation trials early in training the magnitude of conductance change was somewhat smaller (0-2 μmhos), but during the latter sessions the conductance changes produced on dissociation trials was very similar to that produced on integration trials. These trial types did not differ significantly from one another when compared over the last five sessions, although a significant

Figure 16 Conductance (left) and respiratory volume (right) change scores for subject MR03. These panels are reproduced from Figure 9.

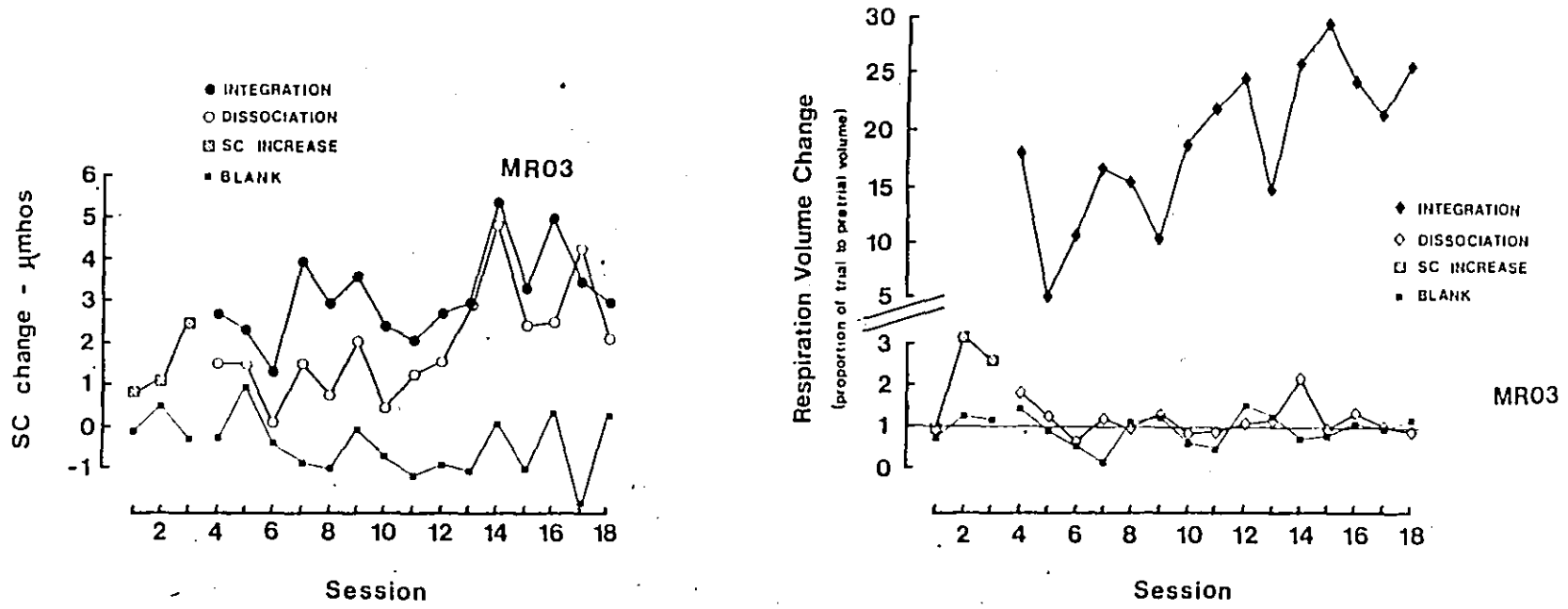

INTEGRATION
DISSOCIATION
SC INCREASE
BLANK
MR03
SC change - μmhos
Session
Respiration Volume Change
(proportion of trial to pretrial volume)
INTEGRATION
DISSOCIATION
SC INCREASE
BLANK
MR03
Session

Figure 16

difference was found when the trial types were compared overall. The conductance changes produced on integration and dissociation trials were significantly greater than those seen on blank trials.

The right-hand panel of Figure 16 shows that very large increases in respiratory volume were produced by MR03 on integration trials throughout training. On dissociation trials no change in respiratory volume was seen, with the exception of session 14. Respiratory volume on dissociation trials was not significantly different from that on blank trials.

As was true of the previous subjects in Group SC-RESP, the changes in respiratory amplitude produced by MR03 mirrored those in the volume measure. Also, cycle duration tended to lengthen somewhat on integration trials, while showing no change on dissociation trials where it did not differ significantly from changes on blank trials. This pattern was similar to that produced by Subject MR02.

The concomitant changes evidenced by Subject MR03 resembled those shown by Subject MR01. On integration trials, small increases in body movement were consistently seen and were accompanied by a shortening of the cardiac IBI. However, unlike Subject MR01, no increases in forearm EMG were present on integration trials. On dissociation trials, no changes were evidenced in forearm EMG, movement, or IBI, and none of these measures differed significantly from the changes found on blank trials.

Transfer and feedback performance did not differ significantly on any of the dependent measures on dissociation trials for Subject MR03. In the case of integration performance, conductance changes were

slightly, but significantly, larger in the absence of feedback than in its presence. Also, the respiratory cycle was slightly longer, on the average, during transfer.

This subject reported that he usually only needed to alter his respiration on integration trials in order to produce conductance increases. However, if conductance did not "...increase all by its self (sic)..." on integration trials, he then utilized the strategy employed on dissociation trials. On dissociation trials this subject described rubbing his palms on his thighs and "touch(ing) (the) thumb on each hand to (the) tips of fingers." He also reported that he tried to increase conductance by "...thinking of frightening situations" but that "...this did not work." He also reported that clenching his fists was unsuccessful. Finally, this subject reported that integration trials were slightly more difficult (a rating of 3) than dissociation trials (a rating of 2).

Subject MR04: The changes in skin conductance and respiratory volume exhibited by this subject are illustrated in Figure 17. As can be seen in the left-hand panel, this subject was able to produce increases in skin conductance that averaged between 1-3 μmhos on integration trials. These changes were significantly greater than those produced on dissociation trials over 15 sessions of training. Although the conductance increases produced on dissociation trials appeared to be consistently larger than those evidenced on blank trials at the outset of training, dissociation performance deteriorated over sessions so that by the end of training these trial types did not differ significantly

Figure 17 Conductance (left) and respiratory volume change scores (right) for subject MRO4. This figure is reproduced from Figure 9.

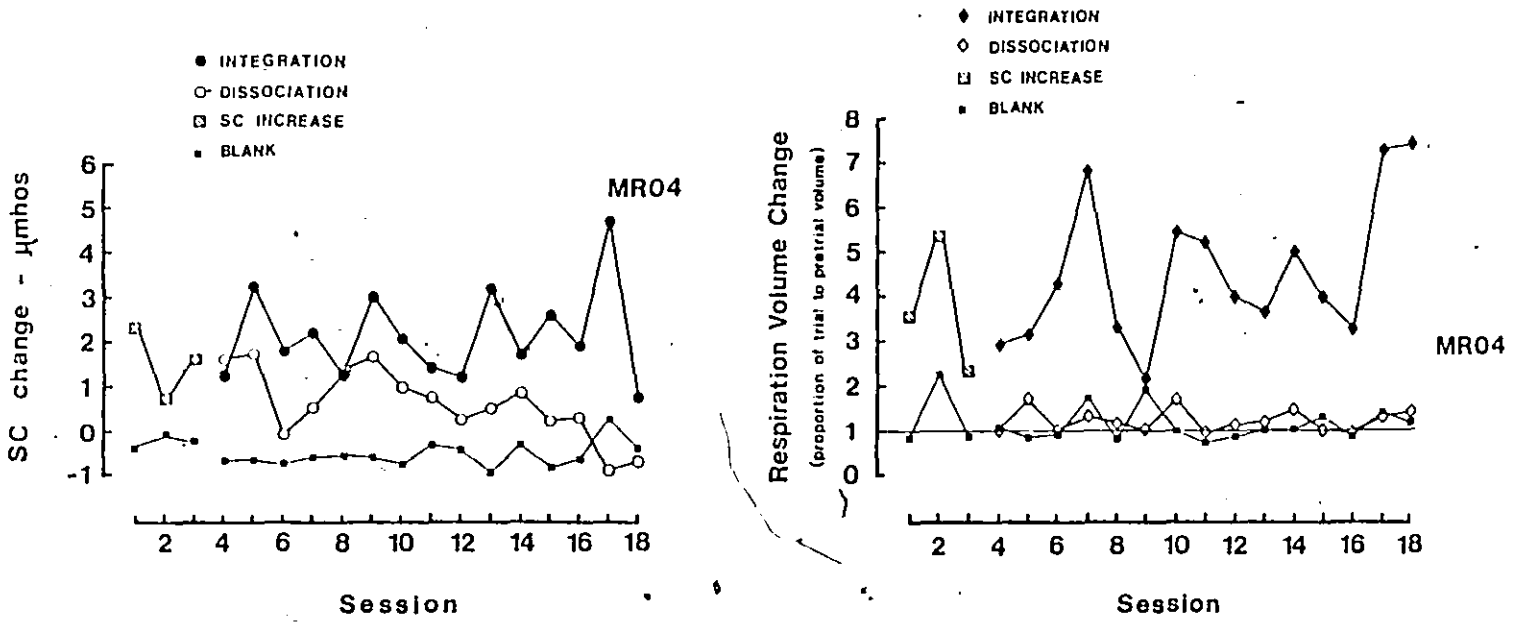

INTEGRATION
DISSOCIATION
SC INCREASE
BLANK
MR04
SC change - μmhos
Session
Respiration Volume Change
(proportion of trial to pretrial volume)
MR04
Session

Figure 17

from one another. MR04 was the one respiration subject who was unable to perform the dissociation task.

The right-hand panel of Figure 17 depicts the changes in respiratory volume on feedback and blank trials over the course of training for this subject. On integration trials increases in volume that were 2 to 5 times the pretrial levels were produced throughout training. On dissociation trials the respiratory volume was maintained at pretrial levels, as evidenced by change scores that hovered about 1 and did not differ significantly from the changes seen on blank trials.

The changes produced in respiratory amplitude closely paralleled those shown for respiratory volume and are therefore not presented. The changes evidenced in respiration cycle duration, on the other hand, are shown in Figure 18. On both integration and dissociation trials, duration was significantly shorter than on blank trials.

On integration trials Subject MR04 evidenced consistent increases in body movement, accompanied by shortened cardiac IBIs. Increased forearm EMG was also observed. On dissociation trials, EMG increases were produced early in training, but then diminished to zero or near zero, during the second half of training. It will be noted that this pattern paralleled the conductance performance of this subject on dissociation trials.

The magnitude of conductance changes did not differ between feedback and transfer on integration trials. There was a tendency for respiratory amplitude and volume to diminish, and for respiratory cycle to lengthen, on integration transfer trials, but these effects did not reach significance. On the dissociation task the magnitude of

Figure 18 Respiratory cycle duration change scores, in seconds, for subject MRO4.

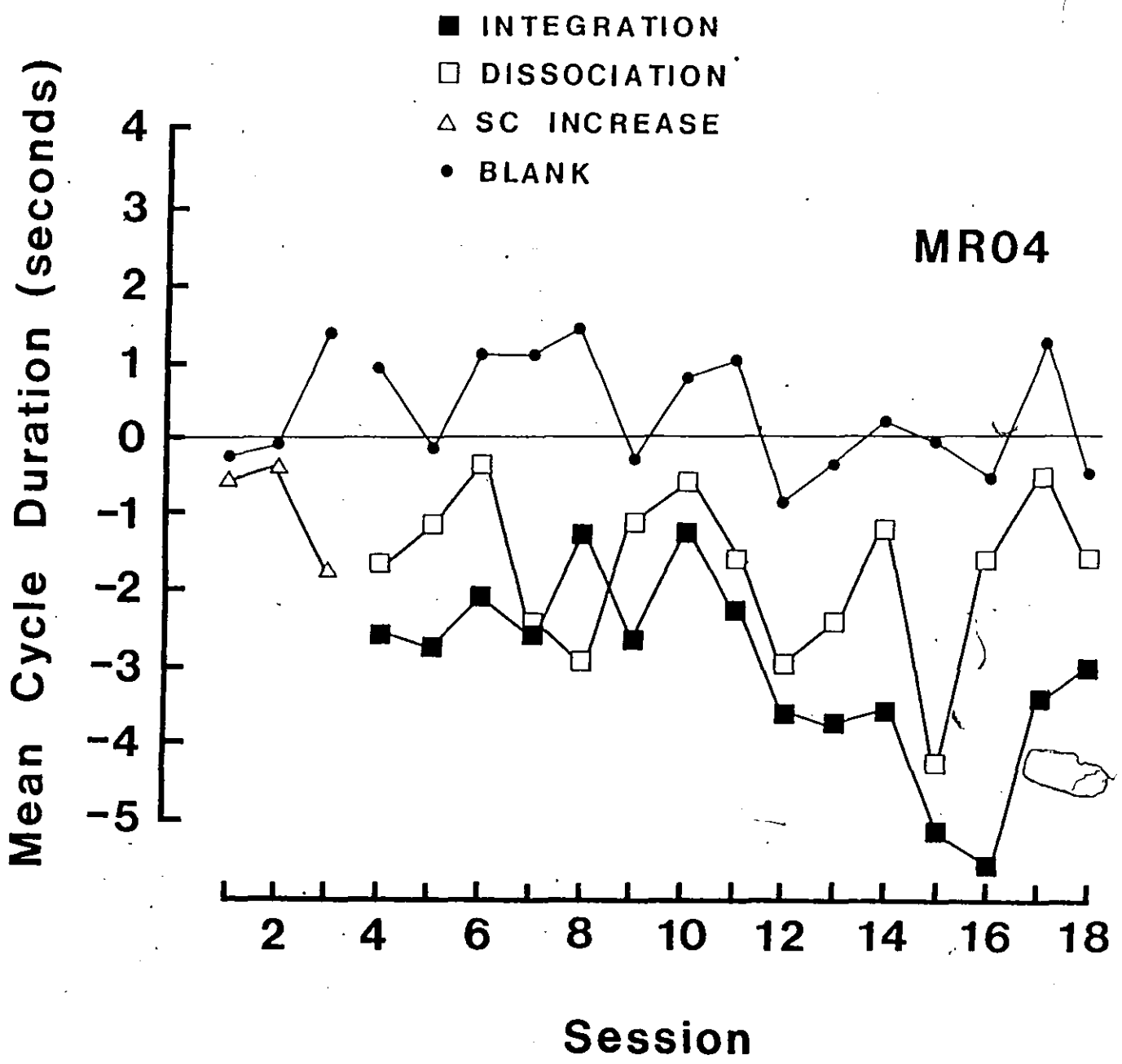

INTEGRATION
DISSOCIATION
SC INCREASE
BLANK
MR04
Mean Cycle Duration (seconds)
4
3
2
1
0
-1
-2
-3
-4
-5
2
4
6
8
10
12
14
16
18
Session

Figure 18

conductance changes was significantly reduced in the absence of feedback. The respiratory cycle also was significantly longer on transfer trials than on feedback trials in the dissociation task.

The verbal report of Subject MR04 stated that respiratory manoeuvers alone were successful at producing large conductance changes on integration trials. On dissociation trials MR04 reported that he "...tried rubbing my hands, or tapping my feet or some such limited movement that seemed to alter GSR, but made the respiration task more difficult". He also reported that dissociation trials were much more difficult (a rating of 8) than integration trials (a rating of 3).

Subject MR05: The conductance and respiratory volume changes produced by Subject MR05 on feedback and blank trials are shown in Figure 19. The left-hand panel of this figure shows that large (4-6 μmho) increases in skin conductance occurred on integration trials throughout training. Dissociation performance was highly similar to integration performance during the last third of training. The changes on both integration and dissociation trials were significantly larger than those seen on blank trials for this subject. Inspection of the volume data in the right-hand panel of Figure 19 shows that MR05 complied with the respiratory requirements of this procedure, as did other subjects in Group SC-RESP. When volume changes on dissociation trials were compared to blank trials for the last 5 sessions of training, no statistical difference was seen.

As was also true of the previous subjects, respiratory amplitude changes paralleled the change in volume. Respiratory cycle duration, while exhibiting a certain amount of variability, did not change

Figure 19 Conductance (left) and respiratory volume changes (right) for subject MRQ5. These panels are reproduced from Figure 9.

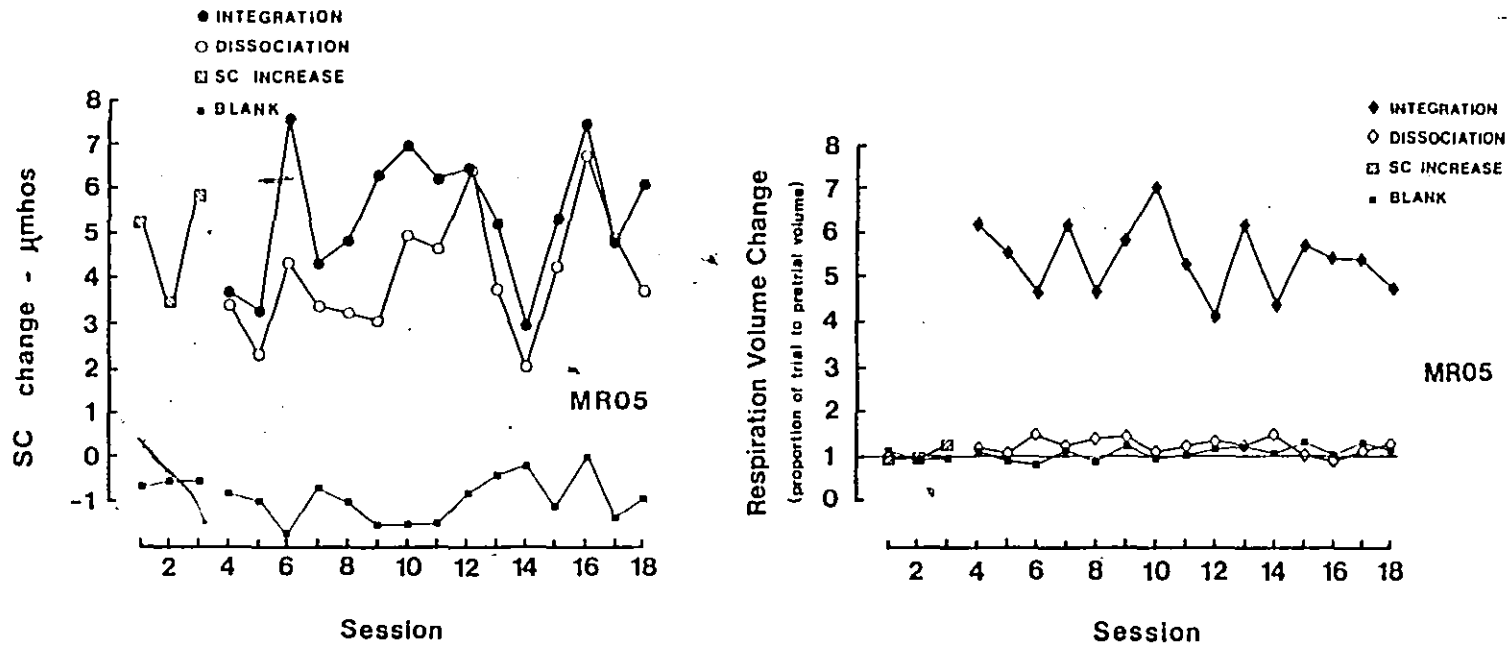

INTEGRATION
DISSOCIATION
SC INCREASE
BLANK
SC change - μmhos
MR05
Session
Respiration Volume Change
(proportion of trial to pretrial volume)
MR05
Session

Figure 19

consistently on either integration or dissociation trials. Neither trial type differed significantly from blank trials on this measure.

Forearm EMG and body movement both showed consistent increases on integration trials. Cardiac IBI was shortened by 130 to 210 msecs on these trials as well. On dissociation trials similar increases in forearm EMG were evidenced, along with consistent but smaller magnitude increases in overall movement. Cardiac IBI shortened by an average of 50 to 60 msecs on dissociation trials.

There were no significant differences on any of the dependent measures, on either integration trials or dissociation trials, between feedback and transfer.

This subject reported wiggling his fingers or hands on both integration and dissociation trials. He also reported that, on integration trials, when "inhaling a breath, skin conductance display increases regardless of hand movement". MR05 reported that dissociation trials were more difficult (rating of 5) than integration trials (rating of 2).

Group SC-MVT: Overview

The following data give an overview of performance in the group that was trained with gross body movement rather than respiration as the concomitant response. Figure 20 shows the conductance and movement changes for the five subjects trained in Group SC-MVT. Inspection of the conductance data in the left-hand panels shows that all subjects produced large increases in skin conductance on integration trials (typically in excess of 3 μmhos). In addition, 4 of the 5 subjects

Figure 20 Mean changes in skin conductance (left panels) and gross movement (right panels) for the subjects in group SC-MVT. SC increase trials are shown on sessions 1-3. Integration and dissociation training trials are shown on sessions 4-18. Blank trials performance on all sessions is also shown. Units for movement are arbitrary.

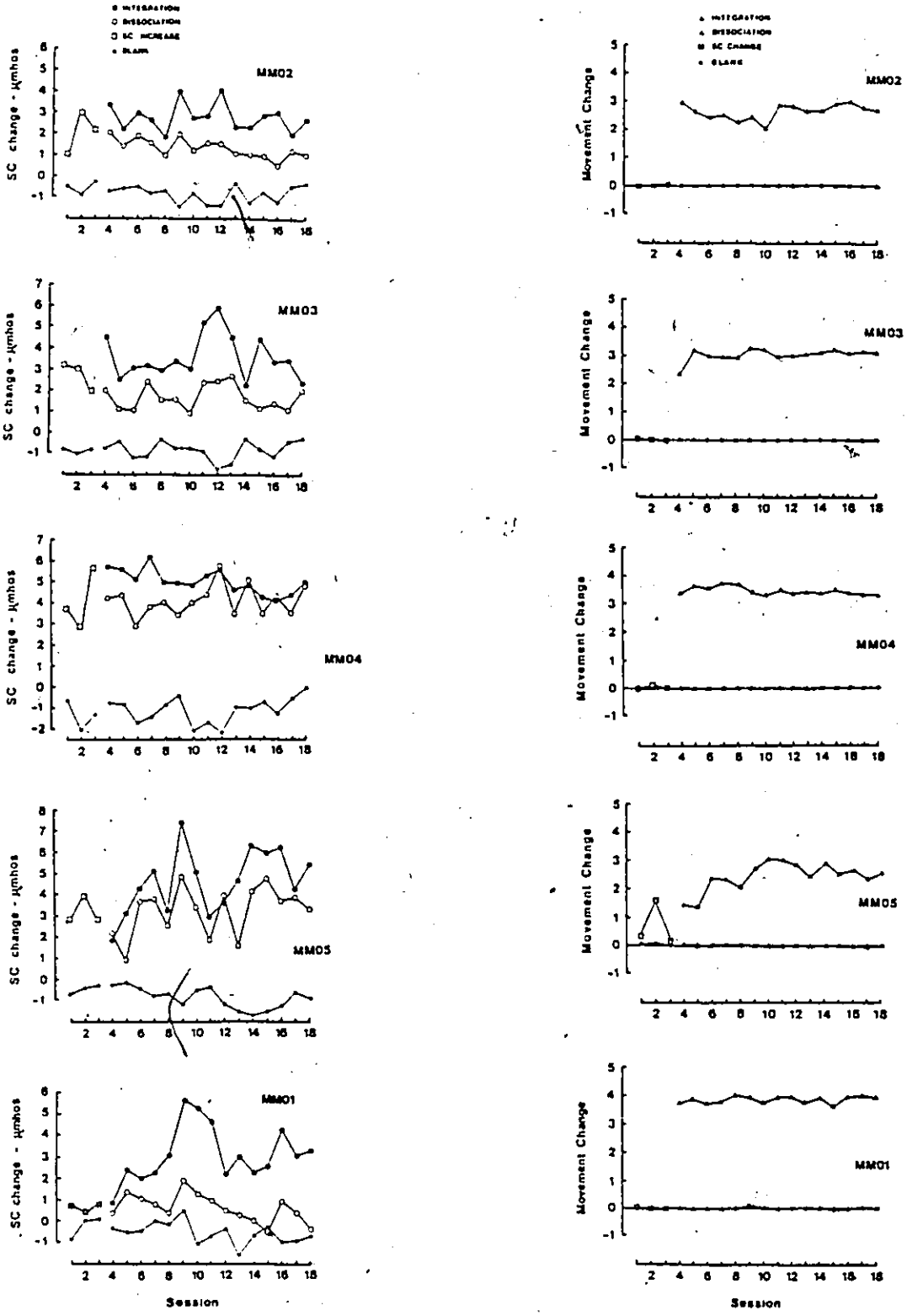

INTEGRATION
DISSOCIATION
SC INCREASE
BLANK
MM02
MM03
MM04
MM05
MM01
SC change - μmhos
Movement Change
Session

Figure 20

produced substantial increases in skin conductance on dissociation trials as well, although in only one instance (MM04) did the magnitude of these changes match that attained on integration trials. The remaining subject in this group (MM01) produced only small and rather inconsistent increases in skin conductance during dissociation. Performance on dissociation trials for this subject deteriorated over sessions, and was not significantly different from that observed during blank trials at the end of training.

Inspection of the movement data presented in the right-hand panel of Figure 20 shows that all subjects appeared to comply successfully with the movement requirements of the integration-dissociation task. In every case large increases in movement were seen on integration trials. For 4 out of 5 subjects changes in movement on dissociation trials did not differ significantly from zero or from changes that were obtained on blank trials by the end of training. This result shows that increases in gross body movement were not required for the conductance changes that were observed during dissociation in subjects trained in group SC-MVT.

Performance during dissociation trials was not specific to skin conductance, however. Each of the four subjects that succeeded at increasing skin conductance on dissociation trials also evidenced changes in forearm EMG, respiratory activity, and cardiac interbeat interval during these trials. It will be seen that the magnitude of these concomitant activities varied considerably from subject to subject.

The aforementioned findings were based upon performance in the presence of feedback. Performance during transfer, on the other hand, was more complex. Three of the five subjects showed larger skin conductance changes in the integration condition during transfer than they did when feedback was present. None showed this effect on dissociation trials, but one did show smaller skin conductance changes in the absence of feedback during attempted dissociation. One subject failed to completely inhibit movement on dissociation trials in the absence of feedback. Further information regarding individual performance is given below.

Group SC-MVT: Individual subjects

Subject MM01: The skin conductance and movement changes exhibited by this subject are reproduced on a larger scale in Figure 21. During the pretraining phase this subject produced increases in conductance of only 0.5 to 1 μmho. On subsequent integration trials the magnitude of conductance increased to between 3 and 5 μmhos. The increases seen in conductance on dissociation trials, on the other hand, were not consistent. When statistically analysed over all 15 days of training, the magnitude of conductance change on dissociation trials was significantly larger than on blank trials. However, examination of the data suggest some initial success and then a trend of diminishing control. Dissociation and blank trial performance did not differ significantly across the last five sessions of training.

The changes in body movement for this subject are depicted in the right-hand panel of Figure 21. The subject clearly succeeded at the movement components of the task on both integration and dissociation

Figure 21 Conductance (left) and movement (right) change scores for subject MM01 (reproduced from Figure 20).

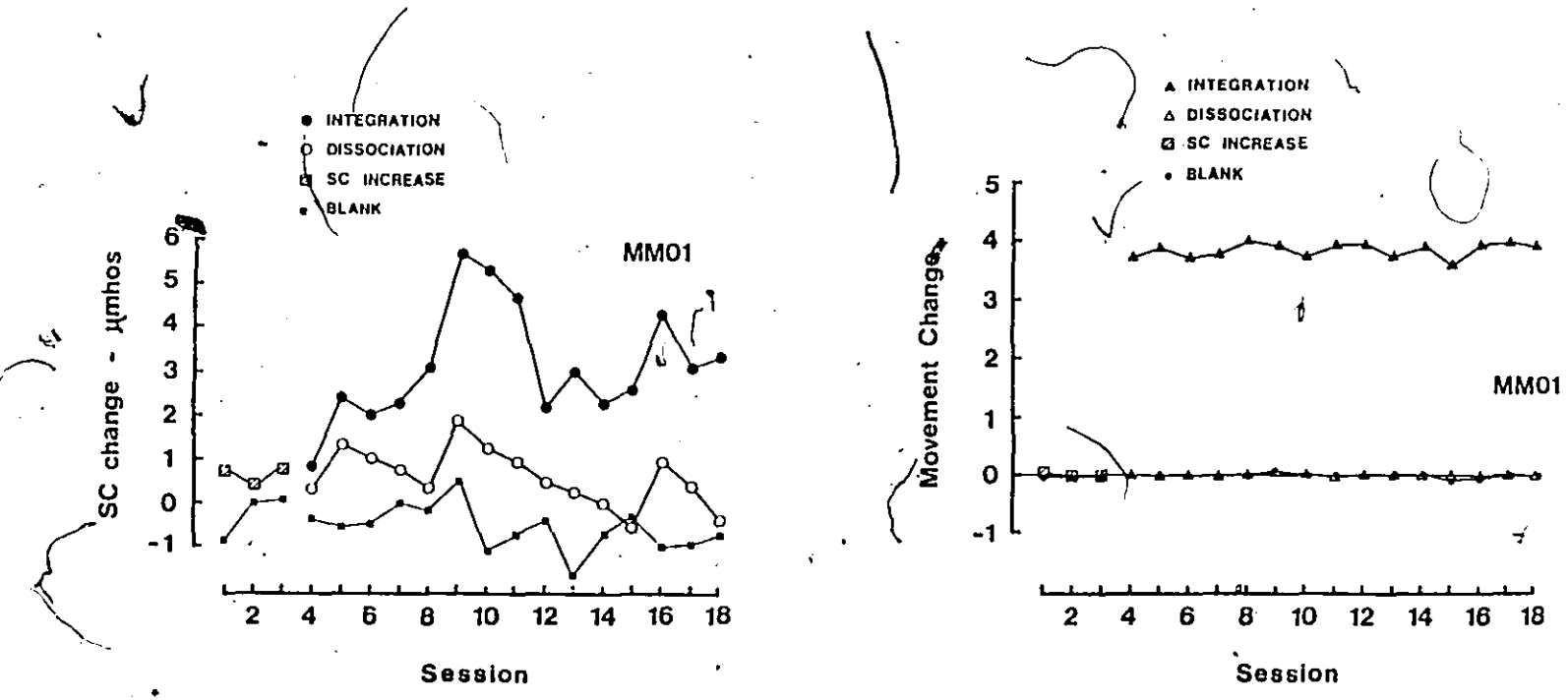

INTEGRATION
DISSOCIATION
SC INCREASE
BLANK
MM01
SC change - μmhos
Session
INTEGRATION
DISSOCIATION
SC INCREASE
BLANK
MM01
Movement Change
Session

Figure 21

trials. Statistically, movement on dissociation trials did not differ from blank trials, while movement changes on integration trials were significantly larger than on dissociation trials.

On integration trials this subject showed moderate, but consistent increases in forearm EMG throughout training. In addition, the cardiac interbeat-interval shortened by an average of 200 msecs. On dissociation trials, changes in forearm EMG, cardiac IBI and respiratory cycle duration did not differ from blank trials.

It was not possible to accurately analyze respiratory changes on integration trials for this subject because the vigor of his movement resulted in a complete obscuring of the respiratory component of the strain gauge signal. However, respiratory volume and amplitude both showed a tendency to decrease on dissociation trials, although this only reached statistical significance, compared to blank trials, for respiratory volume.

On integration trials this subject produced significantly larger conductance increases during transfer than during feedback. On dissociation trials the reverse was true. Movement change scores did not differ between transfer and feedback on either integration or dissociation trials.

This subject reported that to increase his skin conductance he tried to "...imagine scenes of myself moving-running, riding a bicycle, etc." but indicated that this did not work on dissociation trials. He also said that he always held his hands with the palms facing each other. When asked, in the post-experimental questionnaire, to write a set of instructions for another subject to employ on dissociation trials

he replied "I couldn't". When interviewed following the completion of the questionnaire this subject reported that strategies such as manipulation of respiration or isometric muscle tension did work on dissociation trials but were "uninteresting". He indicated that he attempted to produce "direct - nonartifactual control" of skin conductance on dissociation trials. This subject indicated that dissociation trials were very difficult (a difficulty rating of 8) relative to integration trials (rating of between 2 and 3).

Subject MM02: The conductance and gross movement changes shown by this subject on feedback and blank trials are shown in Figure 22. This subject produced increases in skin conductance that ranged between 2 and 3 μmhos on integration trials and between 1 and 2 μmhos on dissociation trials. Increases in skin conductance were significantly greater on integration trials than on dissociation trials and on dissociation trials than on blank trials. This subject successfully increased movement on integration trials, but did not completely inhibit movement on dissociation trials. Very small increases were seen on some dissociation trials. Because of a complete lack of movement on blank trials, dissociation trials did differ significantly from blank trials, even during the final five sessions of training where the changes that were seen were less than 1% of the magnitude seen on integration trials.

This subject also exhibited a moderate level of forearm EMG activity on integration trials. Cardiac IBI was shortened by three to four hundred milliseconds on integration trials as well. The respiratory data on integration trials contained some movement artifact,

Figure 22 Conductance (left) and movement (right) change scores for subject MM02 (reproduced from Figure 20).

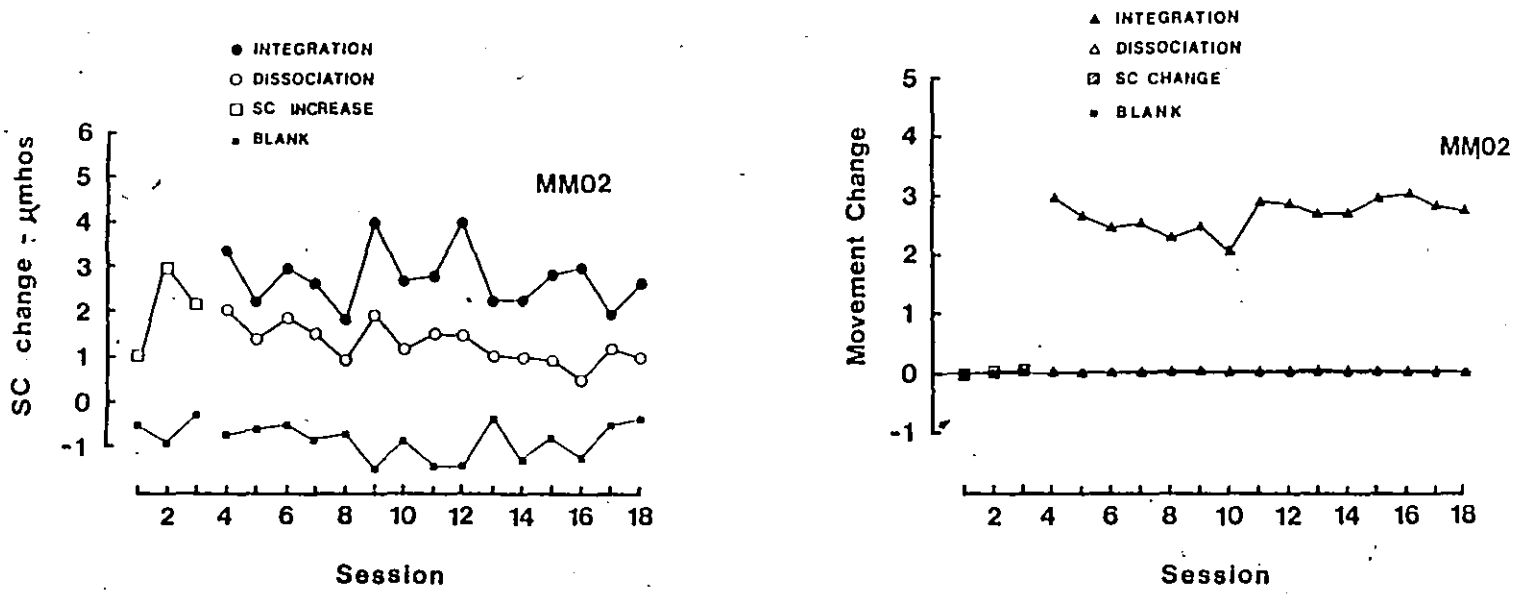

INTEGRATION
DISSOCIATION
SC INCREASE
BLANK
MM02
SC change - µmhos
Session
INTEGRATION
DISSOCIATION
SC CHANGE
BLANK
MM02
Movement Change
Session

Figure 22

but not so much as MM01, and seemed to indicate a marked shortening of the respiratory cycle duration, and a moderate increase in respiratory volume. On dissociation trials this subject evidenced an apparently larger increase in forearm EMG than on integration trials. A moderate shortening of the IBI (about 50-100 msecs) and a slight shortening of the mean respiratory cycle duration were also observed during dissociation, and both were statistically significant when compared to blank trials.

In the integration condition, this subject showed significantly larger increases in skin conductance on transfer trials than on feedback trials. The magnitude of movement change did not differ between the two trial types. On dissociation trials, conductance increases were again larger in the absence of feedback than when feedback was present, but here slight increases in movement were evidenced on transfer trials that were not seen during feedback trials.

This subject reported that on integration trials movement alone was generally employed to alter both movement and skin conductance. However, on the few occasions that this did not work, he reported that he employed the strategies used on dissociation trials. These he described as: (1) pressing his hands together; (2) squeezing fingers; (3) lower hands relative to heart; (4) pinch skin of hands; and (5) pinch nerve bundles in neck (sic). He also reported that it was necessary to rotate strategies on dissociation trials in order to maintain their effectiveness in increasing skin conductance. Dissociation trials were reported to be much more difficult (difficulty rating of 7) than integration trials (rating of 2).

Subject MM03: Figure 23 shows the changes seen in skin conductance and gross movement on feedback and blank trials for this subject. Conductance increases of 2 to 4 μmhos were evidenced on integration trials, which were significantly larger than the increases seen on dissociation trials. The increases on dissociation trials averaged 1 to 2 μmhos and were significantly larger than those seen on blank trials.

This subject showed consistent, large magnitude increases in gross body movement on integration trials. On dissociation trials, very small increases in movement occurred early in training (sessions 4, 5, and 6), and similar increases reappeared on sessions 12, 14, and 18. Those changes were less than one percent of the magnitude of the changes produced on integration trials and cannot be seen in Figure 23. On the remainder of the sessions no changes in movement were evidenced. Overall, movement increases were slightly but significantly larger on dissociation trials than on blank trials over all 15 training sessions, but not when only the last 5 sessions of training were considered.

On integration trials, this subject evidenced consistent increases in forearm EMG, and a shortening of the cardiac IBI of about 125 msecs. The respiration data were obscured by the large magnitude movements produced on integration trials. On dissociation trials this subject produced consistent increases in forearm EMG that were present throughout training and were significantly larger than those seen on blank trials. The cardiac IBI for this subject also shortened consistently by an average of about 25 msecs. Again, this was significantly different from the changes seen on blank trials. The

Figure 23 Conductance (left) and movement (right) change scores for subject MM03 (reproduced from Figure 20).

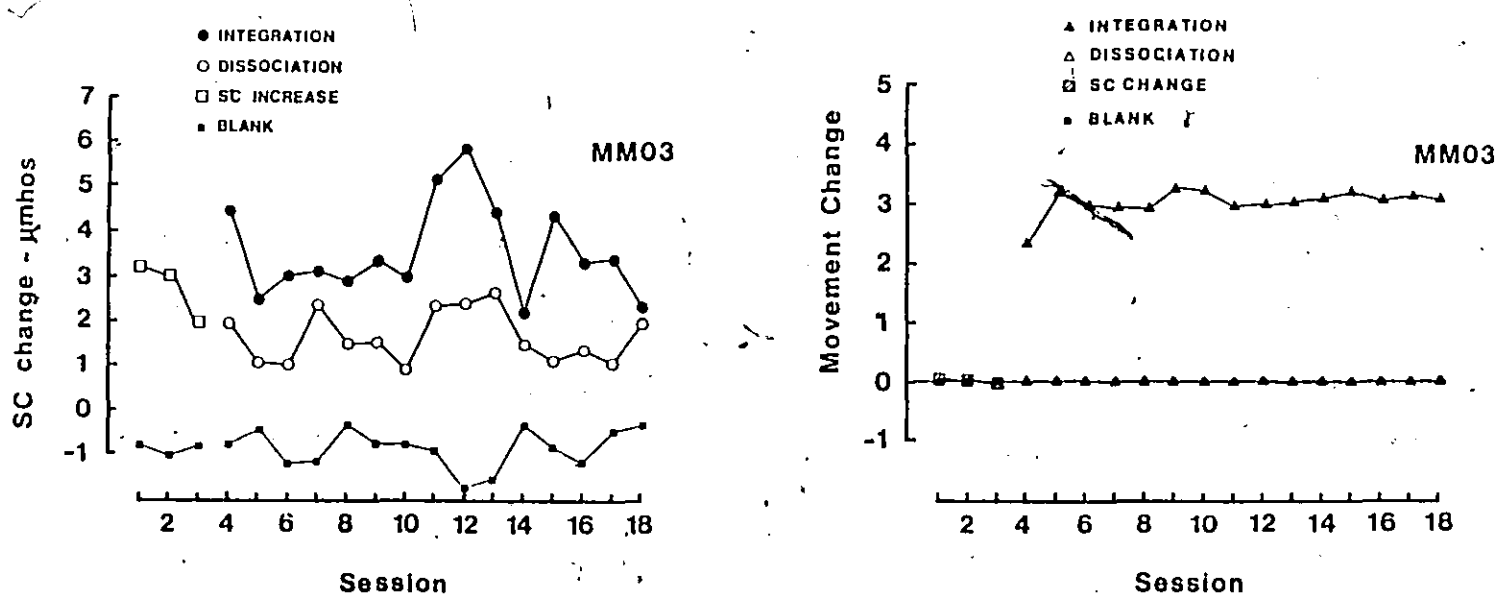

INTEGRATION
DISSOCIATION
SC INCREASE
BLANK
MM03
SC change - µmhos
Session
INTEGRATION
DISSOCIATION
SC CHANGE
BLANK
MM03
Movement Change
Session

Figure 23

respiratory data showed a slight decrease in amplitude and volume and a shortening of the mean cycle duration on dissociation trials, all of which reached statistical significance.

Skin conductance changes in the integration condition were significantly larger on transfer trials than in the presence of feedback. No other differences were noted between feedback and transfer trials.

When asked to describe what he did to increase skin conductance on trials when he also held movement constant, this subject reported the following:

> "-create friction with the fingers in each hand"
> "-create friction by evenly rubbing the palms of my hands against my legs"
> "-try to emotionally or mental (sic) excite myself about some topic"

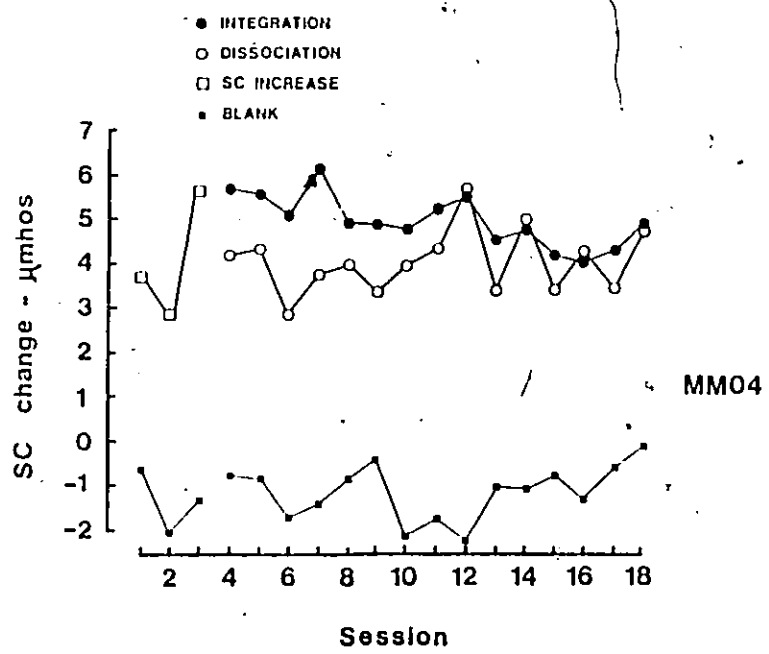
When describing how he went about finding out how to respond correctly he reported:

> "-Generally trial and error (i.e., finding out what things did and did not work)."

He described dissociation trials as somewhat more difficult (rating of 4) than integration trials (rating of 2).

Subject MM04: The changes in skin conductance and gross movement produced by this subject are shown in Figure 24. Conductance increases of 4 to 6 μmhos were consistently produced on integration trials. When analysed over all 15 days of training, these changes were significantly greater than those produced on dissociation trials. However, Figure 24 shows a clear convergence of the two trial types, such that by the last third of training (sessions 14-18) the two

Figure 24 Conductance (left) and movement (right) change scores for subject MM04 (reproduced from Figure 20).


INTEGRATION
DISSOCIATION
SC INCREASE
BLANK
SC change - μmhos
7
6
5
4
3
2
1
0
-1
-2
2
4
6
8
10
12
14
16
18
Session
MM04

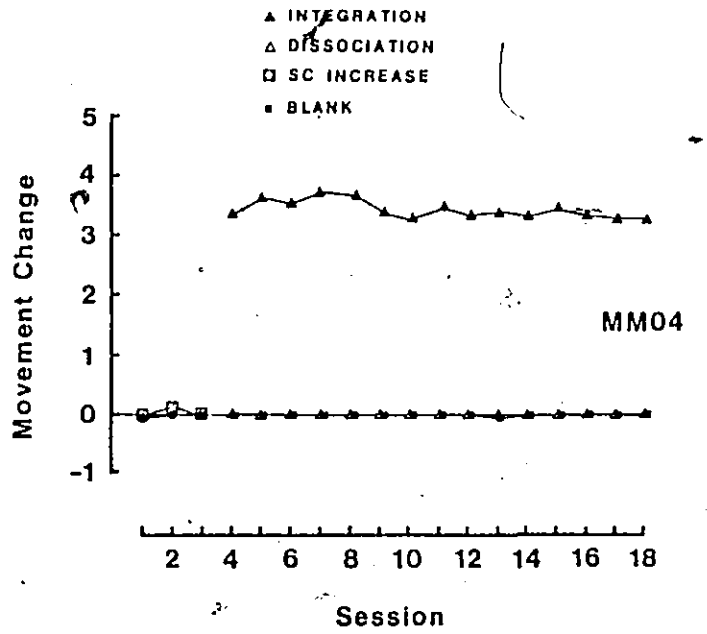

INTEGRATION
DISSOCIATION
SC INCREASE
BLANK
Movement Change
5
4
3
2
1
0
-1
2
4
6
8
10
12
14
16
18
Session
MM04

Figure 24

performances did not differ significantly from one another. The increases produced on dissociation trials ranged from 3 to 6 μmhos. These were significantly greater than the changes seen on blank trials.

This subject successfully produced large magnitude increases in gross body movement throughout training on integration trials, and successfully inhibited all changes in movement on dissociation trials. The change in movement on dissociation trials was essentially zero throughout training, and did not differ significantly from the changes seen on blank trials.

On integration trials, this subject evidenced moderate increases in forearm EMG, increases in respiratory volume and amplitude, and a noticeable shortening of the mean duration of the respiratory cycle. The cardiac IBI also shortened by about 200 msecs, on the average.

On dissociation trials this subject showed moderate increases in forearm EMG that differed significantly from the changes seen on blank trials. In addition, there tended to be a slight but consistent increase in respiratory volume and amplitude, both of which differed significantly from the trend of diminished respiratory activity generally evidenced on blank trials. Mean cycle duration for respiration was unchanged. There also tended to be a small (25-40 msec) shortening of the IBI, which again was significantly different from that observed on blank trials.

The only difference between feedback performance and transfer for this subject was that increases in movement on integration trials were significantly larger in the absence of feedback.

This subject described his strategies for altering conductance on dissociation trials as:

"(1) rub fingers and thumb together;
(2) Partially clenched fist;
(3) Sometimes sang";

On integration trials he reported also performing the same responses and moving as much as possible. He gave dissociation trials a difficulty rating of 3 and integration trials a rating of 2.

Subject MM05: Figure 25 depicts the changes in skin conductance and movement on feedback and blank trials throughout training for Subject MM05. Increases in skin conductance on the order of 3 to 7 μmhos were produced on integration trials. These were significantly larger than the 2 to 5 μmho increases in conductance evidenced on dissociation trials. The increases produced on dissociation trials were, however, significantly greater than those seen on blank trials.

This subject had no difficulty producing large magnitude increases in movement on integration trials. On dissociation trials the subject was able to completely eliminate changes in movement during the last ten days of training. Overall, the movement changes on dissociation trials did not differ from those produced on blank trials.

On integration trials, this subject showed increased forearm EMG, increased respiratory amplitude and volume, a shortened mean respiratory cycle duration, and a shortened IBI. On dissociation trials this subject evi[illegible] increased respiratory amplitude, volume and cycle duration. The [illegible] IBI shortened by about 90 msecs. These effects were significant when compared to blank trials. Increases in forearm EMG were evidenced early in training, but these tended to drop out later

Figure 25 Conductance (left) and movement (right) change scores for subject MM05 (reproduced from Figure 20).

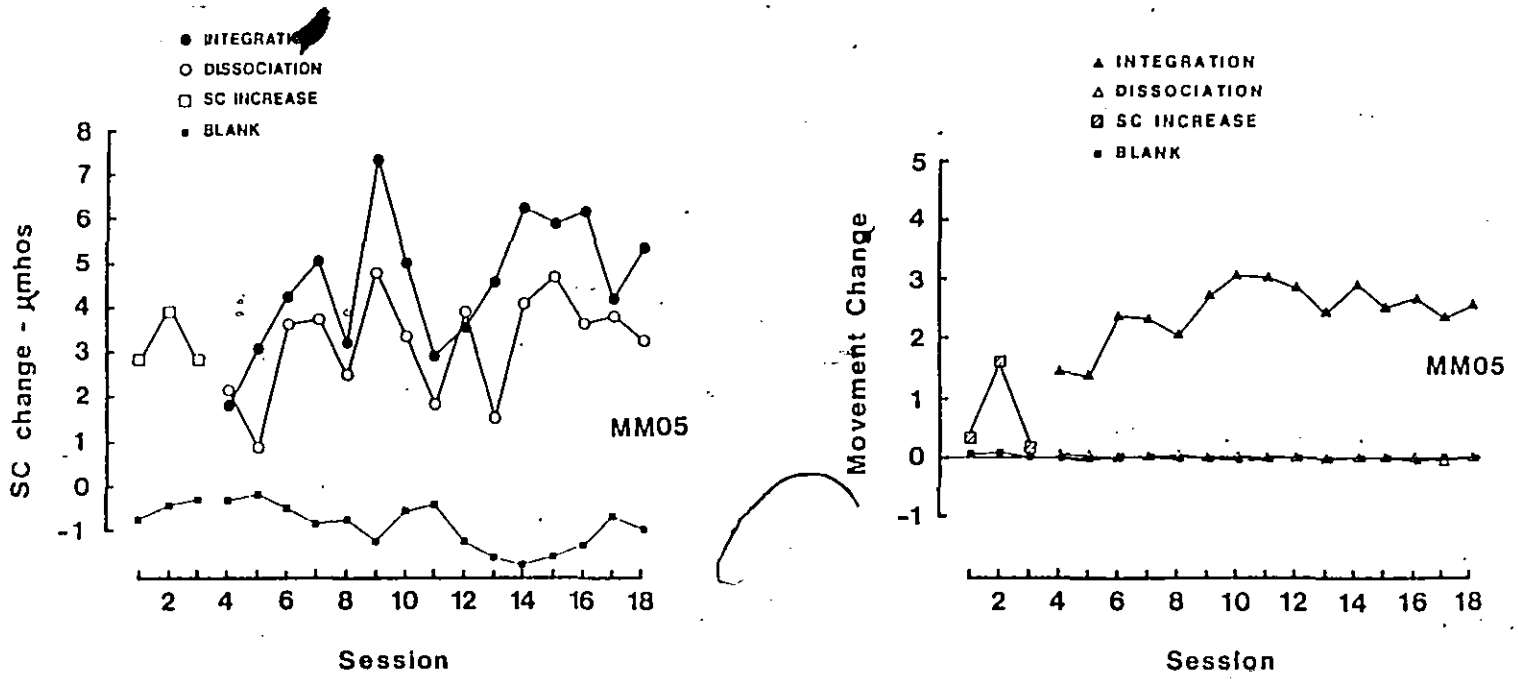

● INTEGRATION
○ DISSOCIATION
□ SC INCREASE
▪ BLANK
SC change - μmhos
8
7
6
5
4
3
2
1
0
-1
MM05
2 4 6 8 10 12 14 16 18
Session
▲ INTEGRATION
△ DISSOCIATION
▨ SC INCREASE
▪ BLANK
Movement Change
5
4
3
2
1
0
-1
MM05
2 4 6 8 10 12 14 16 18
Session

Figure 25

in training, such that only 3 of the last 7 sessions evidenced any increase in EMG, while all 8 of the initial sessions showed EMG increases.

There were no significant differences between feedback and transfer trials on any of the dependent measures for this subject.

This subject described his performance on dissociation trials as taking "deep prolonged breaths" and simultaneously clenching and unclenching his fist. On integration trials he reported the same fist clenching strategy accompanied by rapid shallow breathing. Both integration and dissociation trials received a difficulty rating of 2.

Summary of Results (Group SC-RESP and Group SC-MVT)

The main findings of this experiment may be summarized briefly as follows. Four out of five subjects in Group SC-RESP were able to produce large magnitude changes in skin conductance on dissociation trials without any measureable change in respiration. These changes approached the magnitude of changes evidenced on integration trials where substantial changes in respiration were concomitantly produced. In the SC-MVT group, skin-conductance changes were evidenced on dissociation trials in the absence of changes in gross body movement, but in 4 of 5 subjects these conductance responses remained about half the magnitude (or less) of those produced on integration trials where alterations in movement were required. Other measureable concomitants, particularly forearm EMG, accompanied many but not all of the conductance increases evidenced on dissociation trials. Such concomitants were also observed in the majority of subjects in Group SC-RESP on dissociation trials.

Discussion

The performance of subjects in Group SC-RESP of this experiment demonstrates that respiratory manipulations of sufficient magnitude to measureably alter the chest circumference are not necessary in order to produce large magnitude increases in electrodermal responding in a feedback training situation. Subjects can be trained with appropriate procedures to produce and sustain large magnitude increases in conductance while simultaneously holding a constant pattern of respiratory activity.

A second finding, demonstrated in this case by subjects in Group SC-MVT, was that significant increases in skin conductance can also be produced in the absence of measurable changes in gross body movement. However, the magnitude of the conductance increases produced by SC-MVT subjects on dissociation trials was not as large as that seen on integration trials in this group.

It will be recalled that Group SC-MVT was included in this experiment to assess whether possible differences between integration and dissociation performance in Group SC-RESP might be due to differential task difficulty rather than to the possible necessity of respiratory manipulation for functionally-coupled electrodermal changes. Since within-subject correlations between movement and conductance change did not materialize at the group level in Experiment 1, it was felt that any difference between integration and dissociation performance in Group SC-MVT would be due to task difficulty. As it turned out, this control was unnecessary since 3 of 5 subjects in Group

SC-RESP appeared to perform equally well on integration and dissociation trials by the end of training.

However, it remains to be explained why 4 out of 5 subjects in Group SC-MVT showed a clear superiority of integration over dissociation performance when movement changes did not show consistent relationships to conductance changes in Experiment 1. One interpretation proposes functional coupling of conductance changes and changes in gross body movement, the findings of Experiment 1 notwithstanding. The dissociative procedure may simply be better at detecting functional relationships than simple correlational analyses. Alternatively, it may be that the instructions provided to Group SC-MVT resulted in subjects not attempting, on dissociation trials, certain localized manipulations of the digital and palmar surfaces that did not actually activate the movement transducer, but that seemed to constitute "movement". Certainly subjects in Group SC-RESP reported such activities, which tended to be reflected in their EMG scores but not in the movement measure. In other words, the movement instructions given to subjects in Group SC-MVT on dissociation trials unnecessarily eliminated certain effective responses (manipulation of the volar surfaces) from their response repertoires. This study appears to have provided a significant amount of circumstantial evidence that such manipulations are functionally coupled to conductance changes.

Finally, certain aspects of these data suggest that the nature of concomitant-conductance relationships is not simple. For example, several subjects in both groups mentioned that respiratory maneouvers alone were often sufficient for performance. For example, MR04 asserted

this to be true for integration, whereas MM05 reported a differential respiration strategy on integration and dissociation trials (deep prolonged breaths versus rapid shallow breathing) that may well have determined his success at this task since EMG changes dropped out toward the end of dissociation training. However, MR01 superimposed an apparently massive respiratory manipulation upon a volar manipulative strategy that was reported to be successful on both trial types, but there was no measurable effect of respiration on skin conductance. Inspection of Figure 10 suggests that the problem was not a ceiling effect in the conductance response since respiratory differences were apparent before success at integration/dissociation was achieved. These findings suggest substantial individual differences in the relationship of concomitant changes to electrodermal changes between subjects. The additional report of several subjects (for example, MM02) that it was necessary to vary response strategy over time suggests as well habituation, or within-subject changes in response organization (functional coupling) over time. The mechanisms of these phenomena are not well understood, but they may affect the course of learning during biofeedback training for changes in the electrodermal system.

CHAPTER FIVE: GENERAL DISCUSSION

In the introduction to this thesis it was noted that it is possible to divide the factors that determine whether or not learned control of an autonomic response will be associated with concomitant behavior into two general classes. First, concomitants may occur during training because the neural organization of the nervous system is such that performance of the concomitant contributes to changes in the autonomic response. The response may be necessary for occurrence of the autonomic target, or it may contribute to performance of the target through functional relations of a less determinant type.

The second class of factors has to do, not simply with functional relations, but with how learning occurs during biofeedback tasks. A particular concomitant may occur, not because it is necessary for autonomic change, but because it is sufficient for such change and is preferred over alternative means for producing the response owing to the nature of learning itself. Or, the concomitant may not contribute to performance at all, but might be present as a consequence of how subjects go about attempting to solve biofeedback problems.

I conclude the thesis with a brief discussion of the bearing of current findings on our understanding of the role of functional coupling and learning in the generation of response patterns during biofeedback.

Functional Coupling and Learned Electrodermal Control

Early investigators were concerned that respiratory manoeuvers were necessary for the production of learned autonomic changes. Katkin and Murray (1968) argued that the influence of such mediators had not

been ruled out in research conducted with human subjects. Although some disagreed (e.g., Crider et al., 1969), the general consensus was that only the now-discounted curare animal preparations had ruled out such mediators definitively (see Roberts, 1978). Gavalas (1968) had noticed a relationship between electrodermal change and respiration but found that rewarding respiratory changes was insufficient for control of electrodermal activity because the electrodermal response to deep breathing tended to habituate.

Experiment 2 of this thesis clearly established that respiratory alterations are not necessary for the production of learned increases in electrodermal activity. Four of the five subjects tested produced very large changes in skin conductance without measureable respiratory change. The results in one case (MR01) also suggested that large increases in respiratory amplitude and volume contributed little to conductance performance on integration trials after fifteen sessions of integration-dissociation training. However, integration performance was superior to dissociation performance in all subjects early in training. This may have been because functional coupling was present at this stage but electrodermal responses to respiratory manipulation subsequently habituated, as reported by Gavalas (1968). Alternatively, the deficit may have been attributable to the greater difficulty of the dissociation task at this stage of training. Four of five subjects in Experiment 2 reported this task to be more difficult than integration.

While the findings rule out a necessary link between respiration and substantial electrodermal change, other concomitants may bear such a relation. One that persisted in Group SC-RESP was manipulation of the

volar surfaces. Subject MR01, in fact, used this strategy on both trial types while adding the respiratory concomitant on integration trials. The possible necessity of volar activities for learned electrodermal control may explain why dissociation appeared to be a harder task in Group SC-MVT. The instruction to hold movement constant may have reduced the probability that SC-MVT subjects engaged in such manipulations to the extent that SC-RESP subjects did. The persistence of finger and palmar manipulations throughout the extended training of the present study favors the view that Rice (1966) failed to dissociate GSRs and finger movements, not because of insufficient training in his experiments, but because these activities are important and perhaps necessary for learned control of electrodermal responses in feedback or operant conditioning situations. Application of dissociative procedures similar to those employed in this thesis may be necessary to directly assess the necessity of such concomitant responding for learned electrodermal control.

The data from this thesis, and from the literature, suggest that the electrodermal system may be organized in a more diverse and variable fashion than, for example, the cardiovascular system. One possible explanation for the large number of concomitants observed during conductance training in Experiment 1, in which no concomitant other than respiration showed within-subject relationships to electrodermal increases, is that a number of different concomitants may be sufficient for the production of electrodermal responding. However, none may be necessary for electrodermal responding. Furthermore, if the electrodermal response associated with a particular concomitant

habituates, as suggested by Gavalas (1968) and data from this thesis, then individual subjects have to substitute new concomitants for old ones over the course of long-term training.

There are a number of observations from the data of Experiment 2 that support this view of electrodermal organization. For example, Subject MM01 stated in his verbal report that

> "What I do from day to day changes... If my conductance changes are satisfactory I continue with them until such time as they prove ineffective, in which case I try another set."

Subject MM02 supplied a similar verbal report:

> "...for skin conductance change, with movement constant, I vary strategies within a day and over days for the simple reason that a constant strategy (with feedback present) seems to yield gradually decreasing returns."

A number of other subjects also made reference to day-to-day variability in responding, but did not clearly identify this variability with the changing effectiveness of particular concomitants. It should be noted, however, that within sessions there was a strong tendency for the largest conductance changes to be evidenced during the early trials.

This apparent variability in the relationship between conductance and concomitant activities is not found when heart rate is the autonomic target. Except under conditions of considerable stress where beta-adrenergic drive is augmented, heart rate remains very well correlated with somatomotor activity in a variety of experimental procedures (see Obrist, 1981).

The apparent persistence of localized somatomotor responding or other concomitants accompanying learned electrodermal control needs to be interpreted in the light of evidence indicating that these activities are not necessary for electrodermal changes in other situations. For example, spontaneous electrodermal responses appear to occur in the absence of measureable concomitants under resting conditions (Edelberg, 1974; Venables & Christie, 1980). Also, large increases in electrodermal activity have been demonstrated during aversive classical conditioning that are independent of somatomotor activities sufficient to influence heart rate (Roberts & Young, 1971; Roberts, 1974). The question then becomes, if specific electrodermal responses are possible, why are they not learned about in the feedback training situation?

One answer is that such specificity may be impossible because the learning processes that are engaged by feedback training do not have access to neural information that is required for specific responding. In particular, a large body of evidence indicates that proprioception arising from the striate musculature is important for the development and refinement of learned motor control. If proprioceptive feedback (which provides information on the state of the effector) is lost through surgical intervention or disease, new motor learning is difficult and, when achieved, does not show the precision that otherwise characterizes motor action (see Brener, 1984, for a review). In a similar vein, highly specific control of the electrodermal system might not be possible, because interoceptors that monitor the output of the sudomotor apparatus do not appear to exist in mammalian species (Kuno, 1980). However, failure of efforts to dissociate heart-rate changes

from somatomotor and respiratory action might not be so easily explained on this basis. Interoception deriving from the cardiovascular system exists and is prolific (Cohen & MacDonald, 1974). However, whether this interoception derives from processes that alter heart rate specifically, and whether it is distributed to those areas of the brain where learned control is developed, are unclear.

An alternative answer is that learning of highly specific electrodermal responses might be possible if a proper training procedure is used. For example, application of the present methods with forearm EMG as a concomitant might be successful. However, if special procedures are necessary, it would appear that organisms prefer to learn by mediation rather than in a more specific fashion. The explanation for this state of affairs would appear to require a better understanding of the nature of learning as well as functional systemic relations.

Learning and Concomitant Behavior Patterns

Given the rarity of specificity in the biofeedback literature, it seems appropriate to enquire into the aspects of the learning process that may result in non-specific responding, independent of whether functional coupling is a factor. Recent conceptualizations of visceral learning have gone beyond a basic operant description to stress the role of factors such as the discriminability of the response (Brener, 1974), the employment of pre-existing efferent commands (Lacroix, 1981) or the possible necessity of conscious processing of response information (Roberts et al., in press). Such models may begin to explain the apparent bias towards the acquisition of non-specific visceral responding in a feedback situation.

Brener (1974) argues that learned control of a response depends upon learning to identify the discriminable consequences of that response. If this is the case then non-specific control of electrodermal responding may develop, not because discriminable consequences of specific responses are unavailable, but because these consequences are less easily identified than those associated with movement or respiratory changes that produce electrodermal responses. Similarly, if conscious processing of response information is necessary for the development of learned control (Roberts et al., in press), then this may bias subjects towards non-specific responding. Conscious processing is likely to be facilitated by response strategies that are salient, perhaps verbally describable, or even already well learned. These factors are all likely to be more true of motor or respiratory responses than specific autonomic ones.

Lacroix (1981) specifically stressed the role of pre-existing efferent commands in the development of learned autonomic control. The framework of Roberts et al. (1982) also suggests that subjects are likely to first attempt previously learned strategies that appear relevant, on the basis of instructions or experimental environment, to the visceral learning task. Adult subjects enter the laboratory with a history of having solved performance problems that typically involve motor acts. If visceral learning involves deliberate problem solving, then it is quite plausible that subjects would initially attempt to control feedback with such responses. If successful at the outset, then these response strategies may persist unless very specific demands of

the experiment force the subject to eliminate unnecessary responding, or find a highly specific strategy.

Historically, a dissociative approach to the study of response patterns has been recommended and undertaken by several investigators (Rice, 1966; Fetz, 1974; Black, 1974; Newlin & Levenson, 1978; Schwartz, 1977; and others). The most detailed framework for understanding these response patterns is that of Schwartz (1977), who emphasized that response patterns observed during biofeedback are determined by two factors. First, one must consider system constraints, a general concept that can be seen to include physical and homeostatic limitations as well as functional coupling. For example, regulation of central arterial pressure by the baroreceptors is likely to limit the extent to which heart rate can be manipulated independently of blood pressure. Second, one must consider the precise relation that exists between exteroceptive feedback and the organism's behavior, that is the obtained response-reinforcement contingency. Other things being equal, response patterns associated with feedback will be strengthened relative to patterns not associated with reinforcing events. Much evidence in the biofeedback literature supports consideration of these factors when attempting to understand the response patterns observed during visceral learning. However, the point of the above discussion is that patterns may be shaped as well by a third factor, namely, the nature of learning itself. This factor may explain the persistence of uncoupled concomitants during learning as well as the preference of the subject for producing visceral targets through familiar behavior even though specific response strategies are achievable within the limits of system constraints.

While this thesis did not attempt to elucidate the learning process involved in biofeedback, it does suggest that the investigation of response patterns and learning should not be separated from one another. An intersection of response systems and learning processes is by no means a new idea. Traditional learning theory for a time argued that certain response systems (ie. skeletal) could only be altered by one form of learning (operant) while other response systems (ie. visceral) could only be influenced by Pavlovian methods. This particular distinction is no longer commonly asserted, but the importance of recognizing the necessary interaction between learning processes and performance remains.

APPENDIX A

This appendix is a copy of the initial screening interview form used for all subjects

Initial Interview Form

CONFIDENTIAL

STANDARD PSYCHOPHYSIOLOGICAL LABORATORY INTERVIEW FORM

NAME: SEX: M F

TELEPHONE NUMBER: AGE:

OCCUPATION: WEIGHT:

WITH WHICH HAND DO YOU WRITE: HEIGHT:

Have you ever taken part in any other experiment in which physiological recordings were made? (If biofeedback, reject. Were you trained to control the response? Were you given feedback? If so, reject).

Are you taking any medications?

antibiotics (o.k. but note)

mood altering or psychiatric drugs (reject)

antihistamines (o.k. but note)

other (if psychoactive, reject. If drug name is not recognized by interviewer subject is asked reason he is taking the medication).

Have you had any respiratory disorders? (If current, reject).

Have you had any skin conditions? (If current and on target, reject).

Are you epileptic? (If yes, reject).

Have you ever had any heart or cardiovascular problems?

high blood pressure (If yes, reject).

angina (If any cardiac problem is current and physician has restricted subject's physical activities/sports, then reject).

heart attack

Blood pressure: _____ (Taken by experimenter with standard blood pressure cuff, sphygomanometer and stethoscope) (if > 130/90, reject).

Neurological examination:

balance

finger to nose

finger to tongue

do you experience any fainting spells or spells of dizziness? (If so reject)

Do you smoke?

---

1. If a subject is rejected, experimenter must state basis on this questionnaire.

APPENDIX B

This appendix is a transcript of the instructions provided to subjects in both groups of Experiment 1.

Day One: In this experiment we are going to try to teach you to control a physiological response that is not usually thought of as being controlled voluntarily. We are not going to tell you what the response is, because we have reason to believe this will interfere with your performance. At designated times during the course of the session we will ask you to increase this response by displaying the word "INCREASE" on the videomonitor in front of you. Similarly, when the word "DECREASE" comes on, you are to decrease the response. During those times when there is no instruction word on the monitor you should sit quietly and wait for the next trial.

To help you perform this task, we will give you feedback on some trials to show you how well you are doing. Here is an example of what the feedback display looks like. The horizontal line represents your starting point at the beginning of the trial. The vertical line, on the other hand, shows changes in the response. Movements of the vertical line toward the top of the screen correspond to increases in responding. Movements of the vertical line toward the bottom of the screen correspond to decreases in responding. Your task is to keep the vertical line above the horizontal line on increase trials, and to keep it below the horizontal line on decrease trials.

There will be some trials on which feedback will be given but you will still be instructed by the videomonitor to increase or decrease the response. On these trials we want you to control the response as best you can without feedback.

Feel free to use any method you wish to control this response but please do not get out of the chair or touch the electrodes. If you need to talk to us during the experiment you can do so simply be speaking out loud. We will hear you over the intercom and will reply if we think a reply is necessary.

To provide extra incentive, we are going to pay you bonus money for responding correctly. You could earn as much as an extra dollar for every session of the experiment, were you to respond correctly all of the time. We will tell you how much bonus money you have earned at the end of each session.

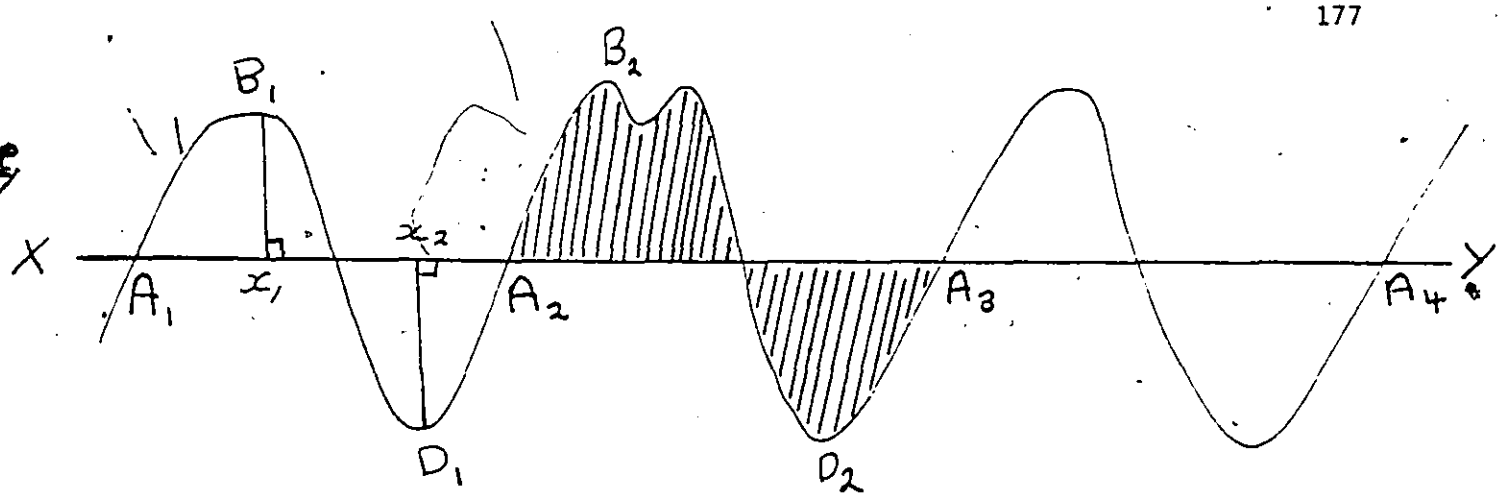
If you would like to have these instructions repeated would you please tell us now. Otherwise, we will begin the experiment in two or three minutes. Good luck.

Instructions for subsequent days were as follows:

The procedure for this session will be the same as for the last session. You may use any method you wish to perform the task but do not get out of the chair or touch the electrodes. If you need to, you can speak to us through the intercom. Remember, the amount of bonus money you earn depends upon how well you perform. Good luck.

APPENDIX C

This appendix is an explanation of the derived respiratory measures.



This figure is an idealized respiration signal recorded from a mercury strain gauge. The horizontal line XY represents the zero cursor which is computed by taking the arithmetic mean of all points. Each A_i represents a positive going zero crossing and defines the start of a new cycle. Inter-cycle-interval is calculated on the basis of the time between consecutive A_i. Amplitude is the sum of the two distances x_1B_1 and x_1D_1. B_i and D_i are the absolute maximum and minimum of the cycle. Volume is calculated by integrating the area between the signal and the cursor. The hatched area represents the volume of the second cycle.

APPENDIX D

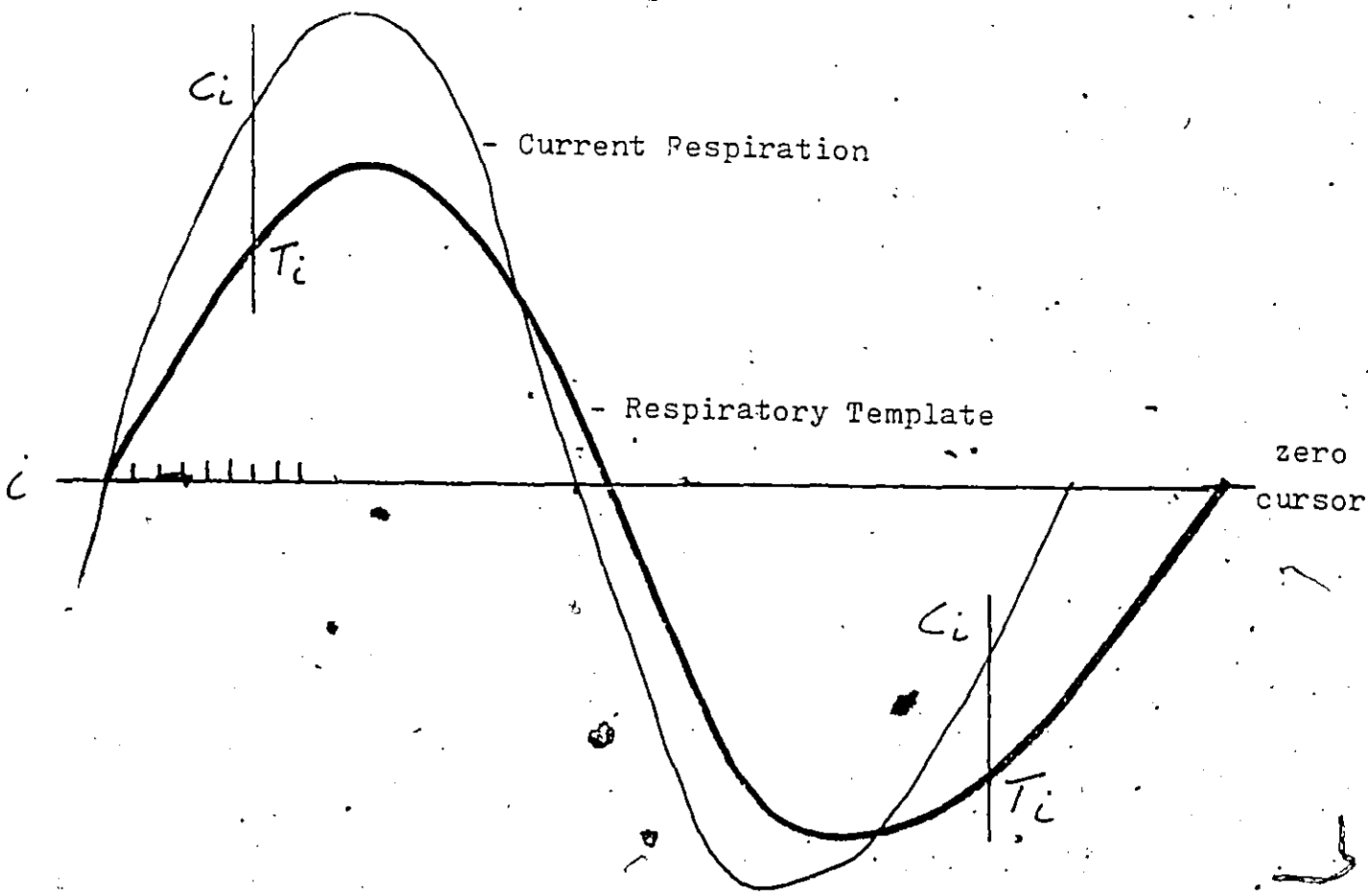
The following is an explanation of the details of the respiration feedback for group SC-RESP in Experiment 2

RESPIRATION FEEDBACK:

At the beginning of each session, once the subject had been given time to habituate, a baseline recording of the respiration signal was made by the SLI-11/03 computer. The baseline sample was 120 seconds in duration. The signal was parsed into individual respiratory cycles (see Appendix D). The amplitude and duration of each cycle was computed, and the cycles were rank ordered on both amplitude and duration. The first ten cycles that fell in the middle two quartiles on both the amplitude and duration rankings were selected and retained in a memory queue. The ten cycles were also averaged to produce a respiratory template (see Figure D1). Feedback was provided to the subject for any deviation in his current respiration from the respiratory template. The template was synchronized to the current respiratory behavior at the start of each respiratory cycle. During the 30 second period, prior to each trial in the session, respiration was recorded along with all of the other physiological variables. Following the trial the respiration data from the pretrial period was parsed and used to update the running memory queue of ten cycles that comprised the template. The cycles in the pretrial were rank ordered on the basis of amplitude and duration. The median cycle, the cycle prior to the median and the cycle folowing the median were selected and added to the queue of respiratory cycles. The oldest three cycles were dropped from the queue. The ten cycles were then averaged to produce a new template. If on any trial, the pretrial period failed to yield six analysable cycles, the template was not updated on that trial. The purpose of this was to

exclude from the template any respiratory cycles which occurred during excessive movement, or unusual breathing. The trial by trial updating allows the template to track any long term drifts in respiration, without being distorted by atypical cycles.

The above procedure was altered in the case of subject MR05. This subject had an unusually low resting respiration rate and most pretrial periods did not yield six complete cycles. For this subject only, three complete cycles during the pretrial period resulted in the addition of one cycle to the template (the median cycle, based upon amplitude), four complete cycles resulted in two cycles being added (the cycles ranked 2nd and 3rd for amplitude). This change in procedure was instituted following this subject's sixth session.



Current respiration signal synchronized to the respiratory template. The heavy curve represents the template. The thin horizontal line represents the zero cursor. The thin curved line is the current respiration signal which has been synchronized to the template on the basis of the leading positive zero crossing. The feedback at time i is based upon the absolute difference between the values of the template at that point (T_i) and the current signal (C_i).

Figure D1

APPENDIX E

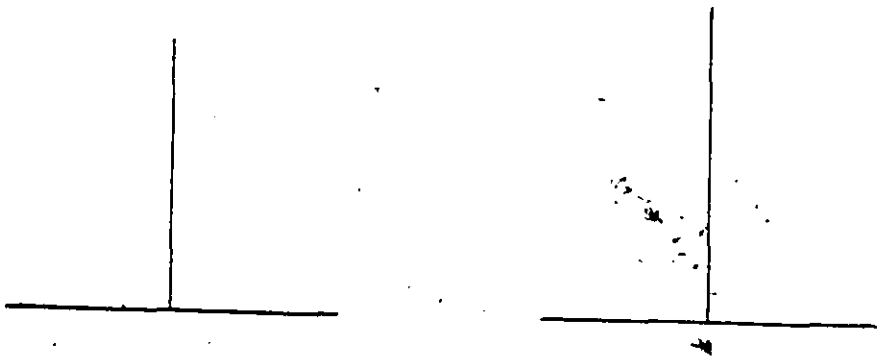
This appendix contains the text of the instructions provided, in typed form, to subjects in Experiment 2

Initial instructions given to subjects in Experiment II

Group SC-RESP

In this experiment we are going to train you to control two physiological activities. One activity is skin conductance, which we will measure with small electrodes placed on your hands. The other activity is your respiration (breathing), which we will measure with a small gauge encircling your chest. Eventually we want to train you to control both of these activities simultaneously. On some trials we will ask you to alter both skin conductance and respiration, on other trials we will ask you to alter your skin conductance while maintaining a constant level of respiration. You shuld note that when we say to keep your respiration level constant we do not mean that you should hold your breath, rather we mean that you should breathe at a constant rate and depth similar to when you are resting comfortably.

To help you perform these tasks we are going to provide you with feedback for both your skin conductance and your respiration. You will receive two visual displays side by side on a television monitor. The figure below shows what the displays on the TV monitor will look like.



The display on the left will always correspond to changes in your skin conductance and the display on the right will always correspond to changes in respiration. As you can see each display consists of a horizontal line and a vertical line projecting upwards from it. The horizontal line represents your level of responding at the start of the trial. The vertical line will increase in length in proportion to changes in the activity being monitored.

Thus, the vertical line on the left will increase in length upwards from the horizontal line when your skin conductance increases from its starting point. Similarly the vertical line on the right will increase in length when you alter your pattern of respiration in any way.

For the first few days of the experiment we are going to train you to alter these activities individually. In later sessions we will then train you to control them simultaneously.

The procedure for today will be as follows. For the first five trials we are going to ask you to increase your skin conductance. Remember, the display on the left corresponds to skin conductance. The display will appear on the TV screen in the color GREEN. Whenever a display appears in GREEN you should try to alter that response as much as possible. Thus when the left display appears in green you should try and increase the length of the vertical line as much as possible. This will correspond to increases in skin conductance. During these trials the respiration display will also be present on the screen, but it will appear in WHITE. A WHITE display indicates that you should not attempt

to control that activity in any way, either by altering it or by attempting to hold it constant. The vertical line for respiration will not be present on these trials.

On the next five trials we want you to alter your pattern of respiration as much as possible. Remember, the display on the right corresponds to changes in your respiration. It will now appear in green, indicating that you are to alter your breathing as much as possible. Any change in your pattern of breathing will increase the length of the vertical line. If your breathing pattern returns to normal the vertical line will decrease in length to zero. You should try to keep the vertical line as long as possible. On these trials the skin conductance display will appear in white, indicating that you should not attempt to control skin conductance in any way. The vertical line for skin conductance will not be presented.

Finally, we will give you five more trials during which we want to keep your pattern of breathing the same as your resting pattern of breathing. On these trials the respiration display will appear in ORANGE. The color ORANGE indicates that you should keep the vertical line as short as possible at all times during the trial. You can accomplish this by breathing at the same regular rate and depth as you did when you were resting. Any changes in breathing from this regular pattern will increase the length of the vertical line. Once again the skin conductance display will appear in white and its vertical line will not be present.

To summarize. The display on the left is for skin conductance. The display on the right is for respiration.

When a display appears in green you should attempt to increase the length of the vertical line towards the top of the screen as much as possible.

When a display appears in orange you should attempt to reduce the length of the vertical line to as close to zero as you can manage.

Finally, a white display indicates that you should not attempt any sort of control over that activity.

Feel free to use any strategy you wish, but please do not touch the electrodes we have attached to your body as this will create artifact in our recordings.

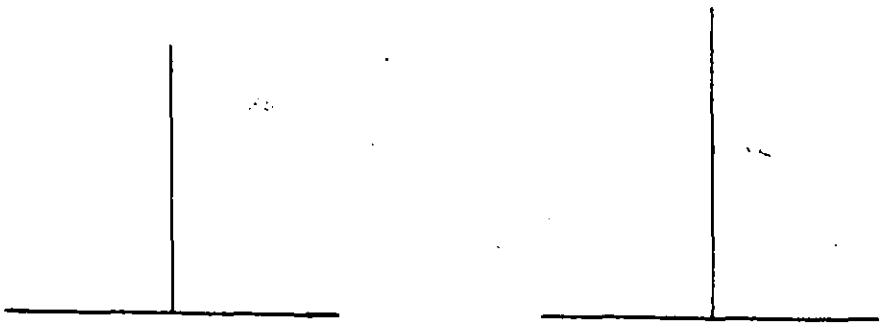
To provide extra incentive we are going to pay you bonus money for performing successfully. You could earn up to $2 in bonus money for each session if you do well. You will be told how much bonus money you have earned at the end of each session.

If you have any questions please re-read these instructions carefully. If you still have a question then ask the experimenter.

Group SC-MVT

In this experiment we are going to train you to control two physiological activities. One activity is skin conductance which we will measure with small electrodes placed on your hands. The other activity is your overall movement. Eventually we want to train you to control both of these activites simultaneously. On some trials we will ask you to alter both skin conductance and movement, on other trials we will ask you to alter your skin conductance while holding your movement constant.

To help you perform these tasks we are going to provide you with feedback for both your skin conductance and your overall movement. You will receive two visual displays side by side on a television monitor. The figure below shows what the displays on the TV monitor will look like.



The display on the left will always correspond to changes in your skin conductance and the display on the right will always correspond to changes in movement. As you can see each display consists of a horizontal line and a vertical line projecting upwards from it. The horizontal line represents your level of responding at the start of the trial. The vertical line will increase in length in proportion to changes in the activity being monitored.

Thus, the vertical line on the left will increase in length upwards from the horizontal line when your skin conductance increases from its starting point. Similarly the vertical line on the right will increase in length when you move in any way.

For the first few days of the experiment we are going to train you to alter these activities individually. In later sessions we will then train you to control them simultaneously.

The procedure for today will be as follows. For the first five trials we are going to ask you to increase your skin conductance. Remember, the display on the left corresponds to skin conductance. The display will appear on the TV screen in the color GREEN. Whenever a display appears in GREEN you should try to alter that response as much as possible. Thus, when the left display appears in green you should try and increase the length of the vertical line as much as possible. This will correspond to increases in skin conductance. During these trials the movement display will also be present on the screen, but it will appear in WHITE. A WHITE display indicates that you should not attempt to control that activity in any way, either by altering it or by

attempting to hold it constant. The vertical line for movement will not be present on these trials.

On the next five trials we want you to alter your overall movement as much as possible. Remember, the display on the right corresponds to movement. It will now appear in green, indicating that you are to alter your movement as much as possible. Any movement will increase the length of the vertical line. If your level of movement returns to normal the vertical line will decrease in length to zero. You should try to keep the vertical line as long as possible. On these trials the skin conductance display will appear in white, indicating that you should not attempt to control skin conductance in any way. The vertical line for skin conductance will not be presented.

Finally, we will give you five more trials during which we want you to keep your movement unchanged. On these trials the movement display will appear in ORANGE. The color ORANGE indicates that you should keep the vertical line as short as possible at all times during the trial. Any movement will increase the length of the vertical line. Once again the skin conductance display will appear in white and its vertical line will not be present.

To summarize, The display on the left is for skin conductanee. The display on the right is for movement.

When a display appears in green you should attempt to increase the length of the vertical line towards the top of the screen as much as possible.

When a display appears in orange you should attempt to reduce the length of the vertical line to as close to zero as you can manage.

Finally, a white display indicates that you should not attempt any sort of control over that activity.

Feel free to use any strategy you wish, but please do not touch the electrodes we have attached to your body as this will create artifact in our recordings.

To provide extra incentive we are going to pay you bonus money for performing successfully. You could earn up to $2 in bonus money for each session if you do well. You will be told how much bonus money you have earned at the end of each session.

If you have any questions please re-read these instructions carefully. If you still have a question then ask the experimenter.

APPENDIX F

This appendix contains the transcribed text of the prerecorded instructions provided to subjects in Experiment 2

Transcript of taped instructions to subjects in Dissociation Experiment

Day 1: Group SC-RESP

This experiment will train you to control both your skin conductance and your respiratory activity. To do this we will provide you with feedback for both these responses. Here is an example of the feedback displays.

The display on the left is for skin conductance. The horizontal line represents your starting point at the beginning of the trial. The vertical line, on the other hand, corresponds to changes in the response from the starting point. Increases in skin conductance will cause the vertical line of this display to increase towards the top of the screen. When this display appears in green, as it does now, you should attempt to increase your skin conductance as much as possible.

The display on the right is for respiration. The vertical line of this display will increase towards the top of the screen with any change in your pattern of breathing. At this moment the display is in green indicating that you should alter your pattern of breathing so as to increase the length of the vertical line. However, when this display is presented in orange, as it is now, you should attempt to reduce the length of the vertical line to zero, or as close to zero as you can manage. You can accomplish this by maintaining a regular, constant rate and depth of breathing, the same pattern of breathing as when you are sitting still and resting.

During the first few sessions one of these displays will appear in white, as is the case now, for the respiration display. A white

display indicates that you should not attempt to control that response, either by increasing it or by holding it constant. For today the vertical line on the white display will not be activated.

To summarize. The display on the left is for skin conductance. The display on the right is for respiration.

When a display appears in green you should attempt to increase the length of the vertical line towards the top of the screen as much as possible.

When a display appears in orange you should attempt to reduce the length of the vertical line to as close to zero as you can manage.

Finally, a white display indicates that you should not attempt any sort of control over that activity.

If you have any questions please ask to have these instructions repeated. Otherwise, the experiment will begin in two or three minutes.

Day 2: Group SC-RESP

Today's session will be very similar to the first session. Again we are going to ask you to control skin conductance and respiration separately. As before there will be five trials during which you should increase skin conductance (the left display), five trials during which you should alter your respiration (right display), and five trials during which you should maintain a constant pattern of breathing.

The only difference is that today the non-target display will be activated. It will still appear in white, indicating that you should not try and manipulate it, but the vertical line will be present to show you what is happening to one activity as you control the other.

Day 3: Group SC-RESP

Today's session will be the same as the last session except that, instead of giving you blocks of five trials consecutively for one task, the trials will be arranged randomly.

Remember that a GREEN display indicates that the response should be altered as much as possible. An ORANGE display indicates that the response should be maintained at a constant level, and a WHITE display should not be manipulated in either fashion.

In addition, today, we are going to give you some trials during which no feedback will be available. Instead we will present colored patches on the screen where the feedback display would normally have appeared. As was true of the feedback displays the patches will be either GREEN, ORANGE or WHITE. Also as before, the left patch will refer to skin conductance and the right patch to respiration. Thus if a green patch is presented on the left side you should attempt to alter skin conductance as much as possible even though you will not have the feedback available to tell you how well you are doing. Similarly if a green patch appears on the right side you should attempt to alter respiration as much as possible. Finally if an orange patch appears on the right side you should attempt to maintain a constant pattern of breathing. In all cases the other (non-target) side will appear white.

You will receive these test trials both at the beginning and end of today's session.

Day 4: Group SC-RESP

We are now ready to begin training you to control both skin conductance and respiration at the same time. Starting with today's session both displays will always be active and both will appear in color.

On half of the trials both displays will appear in green. On these trials you should attempt to alter both skin conductance and respiration as much as possible.

On the remaining trials the skin conductance display will appear in green and the respiration display will appear in orange. On these trials you should attempt to alter skin conductance as much as possible while at the same time maintaining a constant pattern of breathing.

You may find controlling both responses at once somewhat difficult but you should try as hard as possible to comply with the task. You will receive plenty of practice and training.

We are also going to continue to include test trials at the beginning and end of each session. On these trials the color code will be the same as always but patches of color will be presented in place of the feedback displays. You should do the best you can on these trials even though you do not have feedback to guide your performance.

Days 5 to 18: Group SC-RESP

Today's session will be just like the previous one. When both displays are green you should alter both skin conductance and respiration at the same time.

When the skin conductance display is green and the respiration display is orange you should alter skin conductance as much as possible while maintaining a constant pattern of respiration. On test trials you should do as best you can even though feedback is unavailable.

Day 1: Group SC-MVT

This experiment will train you to control both your skin conductance and your overall movement. To do this we will provide you with feedback for both these responses. Here is an example of the feedback displays.

The display on the left is for skin conductance. The horizontal line represents your starting point at the beginning of the trial. The vertical line, on the other hand, corresponds to changes in the response from the starting point. Increases in skin conductance will cause the vertical line of this display to increase towards the top of the screen. When this display appears in green, as it does now, you should attempt to increase your skin conductance as much as possible.

The display on the right is for movement. The vertical line of this display will increase towards the top of the screen with any change in your overall movement. At this moment the display is in green indicating that you should alter your movement so as to increase the length of the vertical line. However, when this display is presented in orange, as it is now, you should attempt to reduce the length of the vertical line to zero, or as close to zero as you can manage. You can accomplish this by not changing your level of movement.

During the first few sessions one of these displays will appear in white, as is the case now, for the movement display. A white display

indicates that you should not attempt to control that response, either by increasing it or by holding it constant. For today the vertical line on the white display will not be activated.

To summarize. The display on the left is for skin conductance. The display on the right is for movement.

When a display appears in green you should attempt to increase the length of the vertical line towards the top of the screen as much as possible.

When a display appears in orange you should attempt to reduce the length of the vertical line to as close to zero as you can manage.

Finally, a white display indicates that you should not attempt any sort of control over that activity.

If you have any questions please ask to have these instructions repeated. Otherwise, the experiment will begin in two or three minutes.

Day 2: Group SC-MVT

Today's session will be very similar to the first session. Again we are going to ask you to control skin conductance and movement separately. As before there will be five trials during which you should increase skin conductance (the left display), five trials during which you should alter your movement (right display), and five trials during which you should not change your level of movement.

The only difference is that today the non-target display will be activated. It will still appear in white, indicating that you should

not try and manipulate it, but the vertical line will be present to show you what is happening to one activity as you control the other.

Day 3: Group SC-MVT

Today's session will be the same as the last session except that, instead of giving you blocks of five trials consecutively for one task, the trials will be arranged randomly.

Remember that a GREEN display indicates that the response should be altered as much as possible. An ORANGE display indicates that the response should be maintained at a constant level, and a WHITE display should not be manipulated in either fashion.

In addition, today, we are going to give you some trials during which no feedback will be available. Instead we will present colored patches on the screen where the feedback display would normally have appeared. As was true of the feedback displays the patches will be either GREEN, ORANGE or WHITE. Also as before, the left patch will refer to skin conductance and the right patch to movement. Thus if a green patch is presented on the left side you should attempt to alter skin conductance as much as possible even though you will not have the feedback available to tell you how well you are doing. Similarly if a green patch appears on the right side you should attempt to alter movement as much as possible. Finally if an orange patch appears on the right side you should attempt to maintain an unchanging level of movement. In all cases the other (non-target) side will appear white. You will receive these test trials both at the beginning and end of today's session.

Day 4: Group SC-MVT

We are now ready to begin training you to control both skin conductance and movement at the same time. Starting with today's session both displays will always be active and both will appear in color.

On half of the trials both displays will appear in green. On these trials you should attempt to alter both skin conductance and movement as much as possible.

On the remaining trials the skin conductance display will appear in green and the movement display will appear in orange. On these trials you should attempt to alter skin conductance as much as possible while at the same time holding movement constant.

You may find controlling both responses at once somewhat difficult but you should try as hard as possible to comply with the task. You will receive plenty of practice and training.

We are also going to continue to include test trials at the beginning and end of each session. On these trials the color code will be the same as always but patches of color will be presented in place of the feedback displays. You should do the best you can on these trials even though you do not have feedback to guide your performance.

Days 5 to 18: Group SC-MVT

Today's session will be just like the previous one. When both displays are green you should alter both skin conductance and movement at the same time.

When the skin conductance display is green and the movement display is orange you should alter skin conductance as much as possible

while holding movement constant. On test trials you should do as best you can even though feedback is unavailable.

APPENDIX G

Questionnaires administered to the subjects in Experiment II following sessions 13 and 18

Respiratory Version

Subject Questionnaire

Please answer all questions in as much detail as possible.

Answer the questions in the order presented.

Do not go on to the next question until you have finished the question you are answering.

*Note: In the actual questionnaire each question was presented on a separate page. To conserve space they are presented consecutively here.

1) Describe, in as much detail as possible, what it is that you do to alter your skin conductance on those trials when you also alter respiration.

2) Describe in as much detail as possible, what it is that you do to alter your skin conductance on those trials when you hold respiration constant.

3) What exactly do you do to alter your respiration?

4) What exactly do you do to hold your respiration constant?

5) Describe how you went about finding out how to alter your responding in the correct manner.

6) If you had to write a set of instructions to allow another subject to do this task without feedback, what would you instruct the subject to do on trials when he is to alter both skin conductance and respiration?

7) If you had to write a set of instructions to allow another subject to do this task without feedback, what would you instruct the subject to do on trials when he is to alter skin conductance and hold respiration constant?

8) How difficult do you find those trials when you are to alter both skin conductance and respiration?

very easy impossible
1 2 3 4 5 6 7 8 9 10

9) How difficult do you find those trials when you are to alter skin conductance but hold respiration constant?

very easy impossible
1 2 3 4 5 6 7 8 9 10

10) How well do you feel you are doing on those trials when you do not have the feedback available and you are trying to alter both skin conductance and respiration?

Not nearly as well as when feedback is present. | As well as when feedback is present. | Much better than when feedback is present.
1 2 3 4 5 6 7 8 9 10

11) How well do you feel you are doing on those trials when you do not have the feedback available and you are trying to alter skin conductance but hold respiration constant?

Not nearly as well as when feedback is present. | As well as when feedback is present. | Much better than when feedback is present.
1 2 3 4 5 6 7 8 9 10

12) Does anything about your behavior in this situation, either in terms of what you do or how you use the feedback, change from day to day? Why? Please be as specific as possible.

Movement Version

Subject Questionnaire

Please answer all questions in as much detail as possible.

Answer the questions in the order presented.

Do not go on to the next question until you have finished the question you are answering.

1) Describe, in as much detail as possible, what it is that you do to alter your skin conductance on those trials when you also alter movement.

2) Describe in as much detail as possible, what it is that you do to alter your skin conductance on those trials when you hold movement constant.

3) What exactly do you do to alter your movement?

4) What exactly do you do to hold your movement constant?

5) Describe how you went about finding out how to alter your responding in the correct manner.

6) If you had to write a set of instructions to allow another subject to do this task without feedback, what would you instruct the subject to do on trials when he is to alter both skin conductance and movement?

7) If you had to write a set of instructions to allow another subject to do this task without feedback, what would you instruct the subject to do on trials when he is to alter skin conductance and hold movement constant?

8) How difficult do you find those trials when you are to alter both skin conductance and movement?

very easy impossible.
1 2 3 4 5 6 7 8 9 10

9) How difficult do you find those trials when you are to alter skin conductance but hold movement constant?

very easy impossible
1 2 3 4 5 6 7 8 9 10

10) How well do you feel you are doing on those trials when you do not have the feedback available and you are trying to alter both skin conductance and movement?

Not nearly as well as when feedback is present. | As well as when feedback is present. | Much better than when feedback is present.

1 2 3 4 5 6 7 8 9 10

11) How well do you feel you are doing on those trials when you do not have the feedback available and you are trying to alter skin conductance but hold movement constant?

Not nearly as well as when feedback is present.			As well as when feedback is present.					Much better than when feedback is present.
1	2	3	4	5	6	7	8	9	10

12) Does anything about your behavior in this situation, either in terms of what you do or how you use the feedback, change from day to day? Why? Please be as specific as possible.

APPENDIX H

The following two tables present the t-statistics for Experiment 2. The first table is for group SC-RESP; the second is for group SC-MVT.

The following abbreviations are used:

SC - Skin conductance

RA - Respiratory amplitude

RC - Respirator cycle duration

RC - Respirator volume

MVT - Gross body movement

EMG - Forearm EMG

IBI - Cardiac Inter-beat-interval

Table H-1

Group SC-RESP

Comparison	Dependent measure	df	t values					
			MR01	MR02	MR03	MR04	MR05	
Integration training vs. dissociation training (sessions 4-18)	SC	(14)	6.31^{+}	3.90^{+}	4.98^{+}	4.37^{+}	5.16^{+}	
	RA	"	10.04^{+}	11.16^{+}	9.16^{+}	7.98^{+}	17.57^{+}	
	CD	"	.39	3.57^{+}	-.53	-3.91^{+}	.78	$^{*}p < .05$
	RV	"	9.87^{+}	9.54^{+}	10.07^{+}	8.20^{+}	18.08^{+}	$^{+}p < .01$
Dissociation vs. blank trials (sessions 4-18)	SC	"	4.72^{+}	3.22^{+}	6.22^{+}	4.79^{+}	13.83^{+}	
	RA	"	.68	.10	2.05	-1.06	1.91	
	CD	"	.32	-1.13	.31	-7.14^{+}	.04	
	RV	"	1.42	.63	1.75	.90	2.41*	
	EMG	"	2.58*	3.24^{+}	1.02	3.51^{+}	11.82^{+}	
	MVT	"	.69	-.67	1.32	1.44	4.52^{+}	
	IBI	"	-.97	-2.55*	-.83	-7.53^{+}	-11.76^{+}	
Integration transfer vs. training trials (sessions 4-18)	SC	"	.30	-3.14^{+}	2.17*	.09	1.53	
	RA	"	1.40	-2.29*	-.23	-1.12	-1.71	
	CD	"	-1.13	2.22*	-.23	1.79	.94	
	RV	"	1.24	-3.41^{+}	-2.79*	-1.48		
Dissociation transfer vs. training trials (sessions 4-18)	SC	"	-.46	-.41	-1.36	-4.07^{+}	.10	
	RA	"	2.30*	-.44	.47	1.24	2.04	
	CD	"	2.46*	3.72^{+}	.05	3.82^{+}	1.87	
	RV	"	2.39*	-1.16	.84	.39	1.56	
Terminal Performance (sessions 14-18) Integration vs. dissociation Dissociation vs. blank	SC	4	4.42^{+}	1.28	1.41	2.82*	2.60	
	RA	"	.67	-1.48	1.26	-.77	-.41	
	CD	"	-.87	-.87	1.92	-3.29*	-.03	
	RV	"	.96	-.71	1.13	1.09	.65	

Table H-2

Group SC-MVT

Comparison	Dependent measure	df	t values				
			MM01	MM02	MM03	MM04	MM05
Integration training vs. dissociation training (sessions 4-18)	SC	(14)	8.29^{+}	9.77^{+}	8.19^{+}	4.69^{+}	5.01^{+}
	MVT	"	131.28^{+}	40.56^{+}	52.78^{+}	93.64^{+}	18.32^{+}
Dissociation vs. blank trials	SC	"	6.26^{+}	14.09^{+}	10.91^{+}	18.96^{+}	10.73^{+}
	MVT	"	.62	2.82^{*}	3.06^{+}	.49	1.52
	EMG	"	.81	7.06^{+}	5.41^{+}	6.98^{+}	3.21^{+}
	RA	"	-1.99	-2.83^{*}	-4.98^{+}	4.17^{+}	5.47^{+}
	RC	"	.58	-5.03^{+}	-5.94^{+}	-.83	3.97^{+}
	RV	"	-2.43^{*}	-.91	-3.40^{+}	3.89^{+}	5.92^{+}
	IBI	"	.95	-5.16^{+}	-7.77^{+}	-8.01^{+}	-2.88^{*}
Transfer vs. training: (sessions 4-18)							
Integration trials	SC	"	3.01^{*}	4.41^{+}	5.15^{+}	.75	1.58
	MVT	"	.96	-.36	1.21	4.21^{+}	-.46
Dissociation trials	SC	"	-3.22^{+}	3.13^{+}	.14	-.17	1.11
	MVT	"	-.97	2.44^{*}	-2.64^{*}	2.09	.81
Terminal Performance: (sessions 14-18)							
Integration vs. dissociation	SC	4	6.86^{+}	7.35^{+}	4.10^{+}	.95	3.75^{+}
Dissociation vs. blank	MVT	"	.44	3.16^{+}	1.63	-1.63	0

$^{*}p < .05$
$^{+}p < .01$

REFERENCES

Barlow, D.H., Agvas, W.S., Abel, G.G., Blanchard, E.B., & Young, L.D. Biofeedback and reinforcement to increase heterosexual arousal in homosexuals. Behaviour Research and Therapy, 1975, 13, 45-40.

Basmajian, J.V. Learned control of single motor units. In G.E. Schwartz and J. Beatty (Eds.), Biofeedback: Theory and Research. New York: Academic Press, 1977, 415-432.

Beatty, J. & O'Hanlan, J.F. Operant control of posterior theta rhythms and vigilance performance: Repeated treatments and transfer of training. In N. Birbaumer and H. Kimmel (Eds.), Biofeedback and Self Regulation. Hillsdale: Erlbaum, 1979, 247-258.

Black, A.H. Heart rate changes during learned avoidance in dogs. Canadian Journal of Psychology, 1959, 13, 229-242.

Black, A.H. Transfer following operant conditioning in the curarized dog. Science, 1967, 155, 375a, 201-203.

Black, A.H. The operant conditioning of central nervous system electrical activity. In G.H. Bower (Ed.), The psychology of learning and motivation. Vol. 6. New York: Academic Press, 1972.

Black, A.H. Operant autonomic conditioning: The analysis of response mechanisms. In P.A. Obrist, A.H. Black, J. Brener, & L.V. DiCara (Eds.), Cardiovascular psychophysiology: Current issues in response mechanisms, biofeedback, and methodology. Chicago: Aldine, 1974. (a)

Black, A.H. Operant conditioning of central nervous system electrical activity and the neural basis of learning. In M. Chase (Ed.), Operant control of brain activity. Los Angeles: UCLA Press, 1974. (b)

Black, A.H., Cott, A., & Pavloski, R. The operant learning theory approach to biofeedback training. In G.E. Schwartz & J. Beatty (Eds.), Biofeedback: Theory and research. San Francisco: Academic Press, 1977.

Blanchard, E.B. & Young, L.D. Self-control of cardiac functioning: A promise as yet unfulfilled. Psychological Bulletin, 1973, 79, 143-162.

Brener, J. A general model of voluntary control applied to the phenomena of learned cardiovascula rchange. In P.A. Obrist, A.H. Black, J. Brener, & L.V. DiCara (Eds.), Cardiovascular psychophysiology. Chicago: Aldine, 1974.

Brener, J. Operant reinforcement, feedback and the efficiency of learned motor control. In M. Coles, E. Donchin and S. Porges (Eds.), Psychophysiology: Systems, Processes and Applications (Vol. II. New York: Guilford Press, 1984.

Brener, J. & Hothersall, D. Heart rate control under conditions of augmented sensory feedback. Psychophysiology, 1966, 3, 23-28.

Brener, J. & Hothersall, D. Paced respiration and heart rate control. Psychophysiology, 1967, 4, 1-6.

Brener, J., Kleinman, R.A., & Goesling, W.J. The effects of different exposures to augmented sensory feedback on the control of heart rate. Psychophysiology, 1969, 5, 510-516.

Brener, J., Phillips, K., & Connally, S. Energy expenditure, heart rate and ambulation during shock-avoidance conditioning of heart rate increases and ambulation in freely moving rats. Psychophysiology, 1980, 17, 64-74.

Clemens, W. & Shattock, R. Voluntary heart rate control during static muscular effort. Psychophysiology, 1979, 16(4), 327-332.

Clifton, R.K. The relation of infant cardiac responding to behavioral state and motor activity. In W.A. Collins (Ed.), Minnesota Symposium on Child Psychology, 1978, 11, 64-97.

Comper, P. & Lacroix, J.M. Further evidence of lateralization in the electrodermal system as a function of relative hemispheric activation. Psychophysiology, 1981, 18, 149. (abstract)

Cornsweet, T.N. & Crane, H.D. Training the visual accommodation system. Vision Research, 1973, 13, 713-715.

Crider, A., Schwartz, G.E., & Shnidnan, S. On the criteria for instrumental autonomic conditioning. Psychological Bulletin, 1969, 71, 455-461.

Crider, A., Shapiro, D., & Tursky, B. Reinforcement of spontaneous electrodermal activity. Journal of Comparative and Physiological Psychology, 1966, 61, 20-27.

Culp, W.E. & Edelberg, R. Regional specificity in the electrodermal reflex. Perceptual and Motor Skills, 1966, 23, 623-627.

DeBacher, G. & Basmajian, J.V. EMG feedback strategies in rehabilitation of neuromuscular disorders. In J. Beatty and H. Legewie (Eds.), Biofeedback and Behaviour, p. 439-448. New York: Plenum, 1977.

DiCara, L.V. & Miller, N.E. Transfer of instrumentally learned heart-rate changes from curarized to non-curarized state. Journal of Comparative and Physiological Psychology, 1969, 68, 159-162. (a)

Edelberg, R. Electrical activity of the skin. In N. Greenfield and R. Sternbach (Eds.), Handbook of Psychophysiology, Ch. 9. New York: Holt, 1972.

Edelberg, R. Mechanisms of electrodermal adaptations for locomotion, manipulation, or defense. In E. Stëller & J.M. Sprague (Eds.), Progress in physiological psychology Vol. 5. New York: Academic Press, 1975.

Edelberg, R. & Beaver, W. Laterality of the skin potential response to tactual activity (personal communication).

Edelman, R. Effects of differential afferent feedback in instrumental GSR conditioning. Journal of Psychology, 1970, 74, 3-14.

Elliott, R. The motivational significance of heart rate. In P.A. Obrist, A.H. Black, J. Brener and L.V. DiCara (Eds.), Cardiovascular Psychophysiology, p. 505-537. Chicago: Aldine, 1974.

Engel-Sitterfeld, P. Biofeedback in the treatment of neuromuscular disorders. In J. Beatty and H. Legewie (Eds.), Biofeedback and Behavior. New York: Plenum Press, 1977, 427-438.

Engel, B.T., Chism, R.A. Operant conditioning of heart rate speeding. Psychophysiology, 1967, 3, 418-426.

Engel, B.T., Nikoomanesh, P., & Schuster, M.M. Operant conditioning of rectosphincteric responses in the treatment of fecal incontinence. New England Journal of Medicine, 1974, 290, 646-649.

Fetz, E.E. Operant control of single unit activity and correlated motor responses. In M. Chase (Ed.), Operant control of brain activity. Los Angeles: UCLA Press, 1974.

Fowler, R.L. & Kimmel, H.D. Operant conditioning of the GSR. Journal of Experimental Psychology, 1962, 63, 563-567.

Freyschuss, U. Cardiovascular adjustment to somatomotor activation: The elicitation of increments in heart rate, aortic pressure and venomotor tone with the initiation of muscle contraction. Acta Physiological Scandanavica, 1970 (Supple. 342), 1-63.

Gavalas, R.J. Operant reinforcement of a skeletally mediated autonomic response: Uncoupling of the two responses. Psychonomic Science, 1968, 11, 195-196.

Grignolo, A., Light, K.C., & Obrist, P.A. Beta-adrenergic influence on the canine myocardion: A behavioral and pharmacological study. Pharmacology, Biochemistry, and Behavior, 1981, 5.

Jarrett, A. & Morimoto, T. Heat exchange between animals and their environment. In A. Jarrett (Ed.), The physiology and pathophysiology of the skin. London: Academic Press, 1978.

Johnson, H.J., & Schwartz, G.E. Suppression of GSR activity through operant reinforcement. Journal of Experimental Psychology, 1967, 75, 307-312.

Katkin, E.S. & Murray, E.N. Instrumental conditioning of autonomically mediated behavior: Theoretical and methodological issues. Psychological Bulletin, 1968, 70, 52-68.

Kimmel, H.D. Instrumental conditioning of autonomically mediated behavior. Psychological Bulletin, 1967, 67, 337-345.

Kimmel, H.D. Instrumental conditioning of autonomically mediated responses in human beings. American Psychologist, 1974, 29, 325-335.

Kimmel, E. & Kimmel, H.D. A replication of operant conditioning of the GSR. Journal of Experimental Psychology, 1963, 65, 212-213.

Kimmel, H.D. & Hill, F.A. Operant conditioning of the GSR. Psychological Reports, 1960, 7, 555-562.

Klinge, V. Effects of exteroceptive feedback and instructions on control of spontaneous galvanic skin responses. Psychophysiology, 1972, 9, 305-317.

Kuno, Y. Human perspiration. Springfield: Charles C. Thomas Publishers, 1956.

Lacroix, J.M. & Cooper, P. Lateralization in the electrodermal system as a function of Cognitive/Hemispheric manipulations. Psychophysiology, 1979, 16, 2, 116-129.

Lacroix, J.M. & Roberts, L.E. A comparison of the mechanisms and some properties of instructed sudomotor and cardiac control. Biofeedback and Self-Regulation, 1978, 3, 105-132.

Lader, M.H. & Montagu, J.D. The psycho-galvanic reflex: A pharmacological study of the peripheral mechanism. Journal of Neurology, Neurosurgery and Psychiatry, 1962, 25, 126-133.

Landis, Psychology and the psychogalvanic reflex 1930.

Levenson, R.W. Feedback effects and respiratory involvement in voluntary control of heart rate. Psychophysiology, 1976, 13, 108-114.

Levenson, R. Cardiac-Respiratory-Somatic Relationships and Feedback effects in a multiple session heart rate control experiment. Psychophysiology, 1979, 16, 4, 367-373.

Levy, M.N. Sympathetic parasympathetic interactions in the heart. Circulation Research, 1971, 29, 437-445.

Levy, M.N. Parasympathetic control of the heart. In W.C. Randall (Ed.), Neural Regulation of the heart. New York: Oxford University Press, 1977, 97-129.

Lott, G.G. & Gatchel, R.J. A Multi-Response Analysis of Learned Heart Rate Control. Psychophysiology, 15(6), 578-581.

Magnusson, E. The effects of controlled muscle tension on performance and learning of heart-rate control. Biological Psychology, 1976, 4, 81-92.

Mandler, G., Preven, D., & Kuhlman, C. Effects of operant reinforcement on the GSR. Journal of the Experimental Analysis of Behavior, 1962, 5(3), 317-321.

Martin, I. & Venables, P. Techniques in Psychophysiology, Chichester: Wiley and Sons. 1980.

McCanne, T.R. & Sandeman, C.A. Determinants of human operant heart rate conditioning: A systematic investigation of several methodological issues. Journal of Comparative and Physiological Psychology, 1975, 88, 609-618.

Miller, N.E. Learning of visceral and glandular responses. Science, 1969, 163, 434-445.

Miller, N.E. & DiCara, L.V. Instrumental learning of heart rate changes in curarized rats: Shaping, and specificity to discriminative stimulus. Journal of Comparative and Physiological Psychology, 1967, 63, 12-19.

Miller, N.E. & DiCara, L.V. Instrumental learning of urine formation by rats: changes in renal blood flow. American Journal of Physiology, 1968, 215, 677.

Monnier, M. Functions of the nervous system: Vol. 1 General physiology, autonomic functions. Amsterdam: Elsevier Publishing Co., 1968.

Newlin, D.B. & Levenson, R.W. Efficacy of pattern feedback for the dissociation of heart rate and respiration rate. Biological Psychology, 1978, 7, 277-285.

Obrist, P.A. The cardiovascular-behavioral interaction - As it appears today. Psychophysiology, 1976, 13(2), 95-107.

Obrist, P.A. Cardiovascular psychophysiology: A perspective. New York: Plenum Press, 1981.

Obrist, P.A., Lawler, J.E., Howard, J.L., Smithson, , Martin, & Manning, Sympathetic influences on cardiac rate and contractility during acute stress in humans. Psychophysiology, 1974, 11, 405-427.

Obrist, P.A., Galosy, R.A., Lawler, J.E., Gaebelein, C.J., Howard, J.L., & Shanks, E.M. Operant conditioning of heart rate: Somatic correlates. Psychophysiology, 1975, 12, 445-455.

Perski, A. & Engel, B. The role of behavioural conditioning in the cardiovascular adjustment to exercise. Biofeedback and Self-Regulation, 1980, 5(1), 91-103.

Plotkin, W.B. On the Self-Regulation of the Occipital Alpha Rhythm: Control Strategies, Stages of Consciousness and the Role of Physiological Feedback. Journal of Experimental Psychology: General, 1976, 105(1), 66-99.

Plotkin, W.B. & Cohen, R. Occipital Alpha and the Attributes of the "Alpha Experience". Psychophysiology, 1976, 13(1), 16-21.

Provine, R. & Enoch, J. On voluntary ocular accommodation. Perceptions and Psychophysics, 1975, 19(2), 209-212.

Rice, D.G. Operant GSR conditioning and associated electromyogram responses. Journal of Experimental Psychology, 1966, 71, 908-912.

Roberts, A.H., Schuler, J., Bacon, J.R., Zimmerman, R.L., & Patterson, R. Individual differences and autonomic control absorption, hypnotic susceptibility and the unilateral control of skin temperature. Journal of Abnormal Psychology, 1974, 84, 272-279.

Roberts, L.E. Comparative psychophysiology of the electrodermal and cardiac control systems. In P.A. Obrist, A.H. Black, L.V. DiCara, & J. Brener (Eds.), Cardiovascular psychophysiology: Current issues in response mechanisms, biofeedback, and methodology. Chicago: Aldine, 1974, 332-352.

Roberts, L.E. The role of exteroceptive feedback in learned electrodermal and cardiac control: Some attractions of and problems with discrimination theory. In J. Beatty & H. Legewie (Eds.), Biofeedback and behavior. New York: Plenum Press, 1977.

Roberts, L.E. Operant conditioning of autonomic responses: One perspective on the curare experiments. In G.E. Schwartz & D. Shapiro (Eds.), Consciousness and self regulation (Vol. 2). New York: Plenum Press, 1978.

Roberts, L.E. & Marlin, R.G. Some comments on the self-description and discrimination of visceral response states. In N. Birbaumer & H.D. Kimmel (Eds.), Biofeedback and self-regulation. Hillsdale, New Jersey: Lawrence Erlbaum Associates, 1979, 79-97.

Roberts, L.E., Marlin, R.G., Keleher, B., & Williams, R. Visceral learning as problem solving. To appear in N. Miller & E. Richter Heinrich (Eds.), Biofeedback: Basic issues, clinical aspects. Berlin GDR: UEB Deutscher Verlag der Wissenschaften (1981).

Roberts, L.E. & Young, R. Electrodermal responses are independent of movement during aversive conditioning in rats, but heart rate is not. Journal of Comparative and Physiological Psychology, 1971, 77, 495-512.

Schwartz, G.E. Voluntary control of human cardiovascular integration and differentiation through feedback and reward. Science, 1972, 175, 90-93.

Schwartz, G.E. Toward a theory of voluntary control of response patterns in the cardiovascular system. In P.A. Obrist, A.H. Black, J. Brener, & L.V. DiCara (Eds.), Cardiovascular Psychophysiology. Chicago: Aldine, 1974.

Schwartz, G.E. Biofeedback and patterning of autonomic and central processes: CNS - cardiovascular interactions. In G.E. Schwartz & J. Beatty (Eds.), Biofeedback: Theory and research. New York: Academic Press, 1977.

Shapiro, D., Crider, A.B., & Tursky, B. Differentiation of an autonomic response through operant reinforcement. Psychonomic Science, 1964, 1, 147-148.

Shapiro, D., Tursky, B., Gershen, E., & Stern, M. Effects of feedback and reinforcement on the control of human systolic blood pressure. Science, 1969, 163, 585-589.

Shean, G. Instrumental modification of the galvanic skin response: Conditioning or control? Journal of Psychosomatic Research, 1970, 14, 155-160.

Shearn, D.W. Operant conditioning of heart rate. Science, 1962, 137, 530-531.

Steptoe, A. Blood pressure control: A comparison of feedback and instructions using pulse wave velocity measurements. Psychophysiology, 1976, 13(6), 528-535.

Stern, R. Detection of one's own spontaneous GSRs. Psychonomic Science, 1972, 29, 354-356.

Stern, R.M. & Anschel, C. Deep inspirations as stimuli for responses of the autonomic nervous system. Psychophysiology, 1968, 5, 132-141.

Stern, R.M. & Kaplan, B.E. Galvanic skin response: Voluntary control and externalization. Journal of Psychosomatic Research, 1967, 10, 349-353.

Taub, E. Self-Regulation of Human Tissue Temperature. In G.E. Schwartz and J. Beatty (Eds.), Biofeedback: Theory and research. New York: Academic Press, 1977, 265-300.

Vandercar, D.H., Feldstein, M.A., & Solomon, H. Instrumental conditioning of human heart rate during free and controlled respiration. Biological Psychology, 1977, 5, 222-231.

Van Twyver, H.B. & Kimmel, H.D. Operant conditioning of the GSR with concomitant measurement of two somatic variables. Journal of Experimental Psychology, 1966, 72, 841-846.

Wang, G.H. The neural control of sweating. University of Wisconsin Press, Madison, Wisconsin, 1964.

Welgan, P.R. Learned control of gastric acid secretions in ulcer patients. Psychosomatic Medicine, 1972, 36(5), 411-419.

Wilcott, RC. Effects of high environmental temperature on sweating and skin resistance. Journal of Comparative and Physiological Psychology, 1963, 56, 778-782.

Willer, J.C. Anticipation of pain-produced stress: Electrophysiological study in man. Physiology and Behavior, 1980, 25, 49-51.

Zeir, & Kocher, Concomitant physiological reactions of EEG Alpha enhancement training with Biofeedback. In N. Birbaumer and H. Kimmel (Eds.), Biofeedback and Self Regulation. Hillsdale: Erlbaum, 1979, 225-236.