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City University of New York PH.D. 1983

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MOTOR SKILLS LEARNING AS A MODEL FOR VISCERAL LEARNING: AN EXPERIMENTAL INVESTIGATION

by

ALAN KLUGER

A dissertation submitted to the Graduate Faculty in Psychology in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York.

1983

This manuscript has been read and accepted for the Graduate Faculty in Psychology in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

July 28, 1983 date

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Abstract

Motor Skills Learning as a Model for Visceral Learning: An Experimental Investigation

by

Alan Kluger

Advisor: Professor Daniel V. Caputo

This study examined the hypothesis that the criteria for defining motor-skills learning are applicable to visceral learning as well. It was expected that four descriptors of motor-skills learning would apply in the learning of bidirectional peripheral skin-temperature control, an instance of visceral (vasomotor) learning. These descriptors were (1) that knowledge of results (feedback) is vital to learning, (2) that the more information provided by the feedback the better is learning, (3) that performance improves with training, and (4) that response specificity develops with training. Skin temperature, EMG, and skin conductance in the hand being trained, skin temperature in the contralateral hand, and respiration rate were recorded. The changes in temperature of the hand being trained were evaluated and were compared with the other physiological responses to assess the possible development of response specificity. This study used hand holders that served to prevent artifact in temperature recording.

The learning of temperature control was observed over 20 training sessions for three groups of six human subjects. Groups 1, 2, and 3 received analogue feedback during all, half, or none of the trials, respectively. All groups were given strategies on how to accomplish temperature change.

The results relative to the four descriptors follow. First, biofeedback trials produced greater differential temperature control than trials without biofeedback. This was due primarily to the benefit of biofeedback over no biofeedback during the decrease-temperature trials. These findings agree with the first descriptor. Second, varying the probability of biofeedback had no significant effect on control; this does not agree with the second descriptor. Third, control did not improve over quarters of training but did improve over the five minutes of a trial; this agrees, only in part, with the third descriptor. Fourth, although control did not improve over training, response specificity developed over training (especially with respect to temperature changes in the contralateral hand during decrease trials) in the biofeedback but not in the no-biofeedback conditions. These findings agree with the fourth descriptor. The results appear to support only partially the motor-skills model for visceral learning.

ACKNOWLEDGEMENTS

First and foremost I would like to acknowledge and thank my wife, Malvina, for the unconditional love, unswerving support, unlimited patience, and selfless sacrifice shown throughout my graduate education and particularly during the years required in carrying out this dissertation project. In addition, I must thank Malvina for her heroic effort in the typing and polishing of this manuscript.

I would like to express my deep appreciation to Dr. Daniel V. Caputo, my dissertation sponsor, who served as mentor, cheerleader, editor, scientific and professional model, and trusted friend throughout my dissertation research. He always made himself available for discussion and always provided wise council.

Special thanks are due to Dr. Nancy S. Hemmes and Dr. Philip H. Ramsey, the two other internal members of my dissertation committee, who contributed many valuable ideas, insights, and suggestions in the experimental design, statistical analyses and interpretation of this work. Their support and encouragement will always be appreciated.

I would like to thank Dr. Wilma A. Winnick and Dr. Paul R. Bindler, the two external members of my committee, for their much appreciated comments and fresh viewpoints that helped to mold the final version of this paper.

I would like to extend my gratitude to all of the members of the Queens College Biofeedback Laboratory including Dr. David Coleman and Camille Valentino, whose help and suggestions contributed to this study.

Acknowledgement and thanks to Roger Chung for constructing the specially designed hand holders required in this study.

I would like to express my appreciation to John Leong and the rest of the staff of the Queens College computer center for their advice and assistance in the hundreds of data manipulations and statistical tests required in this research project. The analyses of the data were aided greatly by the use of: (1) the BMDP statistical software programs which were used for all of the two-way Analyses of Variance, and (2) the SPSS statistical programs which were used for all of the Pearson Correlation analyses.

Dr. Ira Berenhaus and Dr. Gil Harris gave generously their time and advice on various aspects of the statistical analyses employed in this study.

I am deeply indebted to the 18 subjects who gave generously and cheerfully their time and cooperation.

I would like to acknowledge Dr. Julius Bell, my great-uncle, for kindling my earliest interest in and respect for science.

For their encouragement and unselfish support of my early education I would like to thank my mother and father, Joan and Simon. I would especially like to thank my mother for holding our family together, with love and devotion,

after the early death of my father.

I would like to thank especially my brother Steven for being a good and valued friend and my good and valued friend Steven for being a brother.

My mother-in-law and my father-in-law, Ilona and Walter Apfelbaum, as well as my sister-in-law and brother-in-law, Judy and Henry Karp, deserve a special thanks for always expressing sincere concern, encouragement, and good wishes.

I would like to thank my nieces, Lara and Marci, for always making me laugh.

I am grateful to and would like to acknowledge Steven, Sandy, and Joshua Richman; Ira and Sandy Berenhaus; Andrew and Barbara Glover; Richard and Rosemary Gawron; Rory and Sherill Cavaliere; and Gil Harris for their steadfast friendship, support and love.

Finally, I would like to extend sincere thanks to all of my family and friends who showed understanding and encouragement over the many years required in the training of a Neuropsychologist.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Page

CHAPTER I

The present study was designed to examine the hypothesis that the criteria for defining motor-skills learning may be applicable to visceral learning as well. Bidirectional peripheral skin-temperature control, a measure of blood flow control, was used as a model for observing the development of visceral learning over a long series of training sessions.

It has been suggested that the development of voluntary control of physiological responses, through the use of biofeedback techniques, is similar in nature to the acquisition of other skills, such as motor acts (Meichenbaum, 1978). Several investigators have specifically advocated that such a suggestion holds for the subclass of physiological responses known as visceral responses as well (Brener, 1974; Engel, 1972; Lang, 1975; Schwartz, 1974, 1976). Thus, they have felt that learning to control a visceral response through biofeedback is analogous to learning a conventional motor skill.

Although many investigators have likened the learning of visceral control to the learning of motor skills by describing visceral control learning as being similar to an individual's learning how to hit a golf ball (Engel, 1972), learning how to play darts or hit a tennis ball (Lang, 1975), or learning how to shoot fouls with a basketball (Miller, 1978), only three research groups have attempted to test aspects of this proposed analogy in any systematic way (Johnston, 1977a, 1977b, Johnston & Lethem, 1981; Lang, 1977; Schwartz, Young, & Volger, 1976).

Theoretical Underpinnings of the Analogy

The theoretical underpinnings of the view that visceral learning is analogous to conventional motor-skills learning rest on the assumption that the effectors under the control of the autonomic nervous system (which are the smooth and cardiac muscles and the glands that regulate the viscera) can be brought under voluntary control in much the same way as can the effectors under the control of the somatic nervous system (which are the striated, skeletal muscles which, for the most part, move the bones relative to each other).

This assumption has not always been considered to be a valid one. As Miller (1978, p. 375) has indicated "...on the basis of an assertion by [S.] Miller and Konorski in 1928 and two exploratory experiments incompletely reported by Skinner in 1938 and Mowrer in 1947, it was concluded that visceral responses mediated by the autonomic nervous system are not subject to instrumental learning." Of course, such assertions would argue against any motor-skills model for visceral learning.

The newer view which recognizes that visceral responses can be brought under a high degree of voluntary control is broached by Miller (1978) in the following passage:

> To the extent that a greater variety of highly specific visceral responses can be learned both singly and in various combinations, it will become more difficult to account for each of them as inextricably linked to innately organized skeletal-visceral patterns. Quite aside from the mediational issue, the theoretical and practical possibilities will be greatly increased for the flexible participation of visceral learning in normal homeostatic adjustments, in therapeutic procedures, and in the etiology of specific symptoms. Already the evidence for the specificity of learned visceral responses and their capability for being acquired in a variety of patterns has advanced the field far beyond Cannon's (1953) original notion that the sympathetic part of the autonomic nervous system always fires in undifferentiated mass action. Had he recorded the EMG from various skeletal muscles of cats exposed to barking dogs, he might have concluded that the skeletal musculature responds in the same undifferentiated way. (p. 375)

Voluntary Control of Visceral Responses

Several studies have contributed to the view that visceral responses can be brought under voluntary control. Early work by a Russian investigator named Lisina (1958) emphasized the importance of continuous exteroceptive feedback in teaching voluntary control of vasomotor responses in human subjects. In one experiment, using as feedback a light beam which was controlled by a plethysmograph that changed coincident with variations in the volume of the blood vessels in the arm, Lisina had subjects learn to vasodilate successfully in order to escape electric shock. Although many of the subjects reported using various maneuvers such as muscle relaxation, respiration changes, and efforts to reduce emotion to control the vascular response, it is interesting to note that the intentional use of such mediators reportedly diminished over trials, as the actual control increased. The success of vasodilation in these subjects is interesting in light of the fact that earlier work done by Lisina showed that subjects could not learn how to vasodilate to escape shock when exteroceptive "biofeedback" was absent. In a later experimental series the escape-conditioning paradigm was eliminated and, using a finger enclosed within a glass container to supply tactile sensations associated with the vascular response, the subjects eventually learned to control vascular changes voluntarily in response to verbal instruction of the experimenter and to self instruction, according to Lisina.

Influenced by Lisina's work, Lang used a system for training heart-rate control which similarly stressed augmented afferentation (feedback) and instruction. In these experiments, subjects were presented with a continuous display of the heart rate via a meter driven by a cardiotachometer and set up so that lateral movements of the dial provided a continuous, analogue indication of beat by beat changes in heart rate. With this feedback, Lang was successful in training subjects to restrict their heart rate to a narrow target area, marked on the meter face, varying within plus or minus 3 beats per minute of their resting rate (Hnatiow & Lang, 1965; Lang, Sroufe & Hastings, 1967). Since that time other investigators have used this same method to teach heart-rate slowing and speeding (Blanchard & Young, 1973, Young & Blanchard, 1974).

Miller and Carmona (1967) carried out one of the earliest experiments on modifying visceral responses by instrumental (operant) learning in animals. This study showed that during 40 days of 1-hour sessions thirsty dogs rewarded by water for salivating increased their rate reliably while those rewarded for reduced salivating decreased it reliably, resulting in a significant difference between the groups. In a later study, Miller (1969) attempted to control for the possible effects of overt muscular activity on visceral responses by using rats who were paralyzed by curare and who were artificially respirated. In one phase of this investigation rats were trained to control heart rate. This was accomplished by delivering electrical brain stimulation, via electrodes implanted in positive reward centers inside the medial forebrain bundle of the hypothalamus, each time the animal's heart rate exceeded a preset criterion. Using such techniques Miller demonstrated instrumental conditioning of many types of visceral responses including heart-rate acceleration and deceleration, stomach motility, and localized vasoconstriction. However, more recent studies, using curarized animals, and employing similar procedures, have failed to replicate the earlier findings (Miller, 1978). Investigations employing human subjects and instrumental conditioning procedures have proved successful in controlling such visceral responses as heart rate (Young & Blanchard, 1974) and blood pressure (Shapiro, Schwartz & Tursky, 1972).

It should be pointed out that Lang (1975) feels that there is a fundamental difference between the instrumental learning paradigm employed by Miller and others and the motor-skills paradigm employed by Lisina, Lang and others. Lang notes that Miller's instrumental learning paradigm employs feedback in binary form (i.e., here the subject is cued when his performance exceeds a preset criterion, and this signal is absent or replaced with a different cue, when the subject fails to achieve criterion), while Lang's motor skills paradigm employs feedback in analogue form (i.e., the subject attends to a signal which is in continuous covariation with the visceral condition). Lang's differentiation between instrumental conditioning and motor-skills learning does not seem to have wide acceptance among researchers since those who approached these issues from an operant framework have, nevertheless, used analogue feedback in their studies (e.g., Elder, Welsh, Longacre & McAfee, 1977; McKinney, Geller, Gatchel, Barber, Bothner & Phelps, 1980).

Motor-Skills and Visceral Learning Parallels

In order to assess whether there are parallels between motor-skills learning and visceral learning, it is necessary to ascertain first the characteristics of motor-skills learning that are widely accepted as definitive of that type of learning. These widely accepted criteria (or descriptors) of motor-skills learning will be examined in relation to visceral learning. If visceral learning appears to parallel motor-skills learning in these salient aspects, the analogy between the two may be made. Johnston (1977a) has isolated four descriptors of motor-skills learning that he avers are central or essential determinants of motor-skills learning. These four descriptors are: (1) that knowledge of results [feedback] is vital to learning, (2) that, in general, the more information provided by knowledge of results the better is learning, (3) that performance improves with training, and (4) that control changes and becomes more specific with training. His view is that if visceral learning is analagous to motor-skills learning, these descriptors (criteria) should be fulfilled in instances of visceral learning.

Other accepted criteria or descriptors of motor-skills learning which should have their counterparts in visceral learning will be examined. These include: the differentiation of early as opposed to late stages in the course of motor-skills learning, the existence of transfer of training, and the effect of a retention interval on the recall of skills.

Feedback

Perhaps the most important parallel between motor-skills and visceral learning is that both appear to rely greatly on feedback. Feedback can be divided into two types: one called intrinsic or non-augmented and the other called augmented or supplementary (Gagne, 1977; Robb, 1966). The intrinsic type of feedback is a resultant of the learner's motor activity "feeding" directly to his sensory systems (e.g., vision, audition, proprioception, interoception) without being augmented by an external agency (such as feedback supplied by a device or by an external observer). An example of intrinsic or non-augmented feedback would be trying to learn a tracking task such as the pursuit rotor while relying on the performance-related kinesthetic and visual information as feedback. The augmented type is a resultant of the learner's motor activity being transmitted to an augmenting external agency and, finally, to his sensory systems. An example of augmented or supplementary feedback would be trying to learn the pursuit rotor while, in addition to the intrinsic feedback, receiving a tone from a timer signalling every instant that the stylus is off target. Biofeedback has been defined as "...the use of modern instumentation to give a person better moment-to-moment information about a specific physiologic process that is under the control of the nervous system but not clearly or accurately perceived" (Miller, 1974, p. 684). Thus, biofeedback would clearly be a form of augmented feedback.

A learner of both visceral and somatic motor skills can make use of either or both of these types of feedback. Taub (1977) stated that the visceral learner may require more augmented feedback than the somatic motor-skills learner since it may be more difficult both to discriminate and to interpret the intrinsic feedback available from the activity of the viscera, as compared with the movements made by striate, skeletal muscles. Thus it may be much more difficult to achieve operant control of autonomic functions than of responses of the somatic musculature. This difficulty in discriminating autonomic (visceral-vascular) responses may relate in turn to the following: (1) the sensory inflow from the visceral-vascular system, although profuse, is primarily over small-diameter, unmyelinated fibers, and consequently relatively slow, and (2) the cortical representation of the visceral-vascular system, as compared with that of the somatosensory system, is sparse and not well localized, with respect to either topography or function. Thus, Taub considered autonomic response systems, at least in comparison with somatic response systems, to be partially deafferented systems. As a result of this consideration and of findings from animal research he felt that just as learning can be increased to almost normal rates by the provision of augmented feedback to somatosensory-deafferented monkeys (Taub, Perella & Barro, 1973) so too can learning be increased by the provision of feedback to visceral learners.

Evidence for the importance of feedback. One study in the field of motor-skills learning which highlighted the importance of feedback in the acquisition of motor skills was carried out by Adams, Goetz, and Marshall (1972). They tested human subjects, under what was termed augmented (i.e., heightened visual, auditory and proprioceptive feedback) or minimal (i.e., reduced visual, auditory and proprioceptive feedback) response-produced feedback conditions, on a linear self-paced positioning task consisting of a 10 inch displacement of the arm (subjects had to move a slide along a track). When feedback was augmented, the subjects received visual feedback about their movement by watching it, auditory feedback by hearing the sound of the slide moving along the track, and heightened proprioceptive feedback by having spring tension on the slide. Minimal feedback was the elimination or reduction of each of these feedback channels. The results of this study showed: (1) that the aquisition of this skill was directly related to the amount of feedback present, with augmented feedback leading to significantly more effective performance than minimal feedback and, (2) that response-produced feedback had a great impact on both learning and performance.

Another study (Smode, 1958) in the field of motor-skills learning arrived at similar conclusions. Here two groups of subjects learned to keep centered a randomly varying needle by rotating a dial. One group was given a low level of augmented feedback, in the form of a verbal report after each trial, which indicated the length of time the needle had been on target (centered). The other group was given a high level of augmented feedback by means of a counter on which their score was accumulated. The results indicated that the group receiving the high level of augmented feedback showed much higher performance than the group receiving the low level of augmented feedback.

These studies of motor-skills learning indicated: (1) response-produced feedback is important for efficient performance and learning (this is similar to Johnston's first descriptor) and, (2) that the greater the amount of response-produced feedback the more efficient the performance and learning (this is similar to Johnston's second descriptor).

Several studies in the field of visceral learning have shown similar results concerning the importance of feedback. For example, the previously mentioned work of Hnatiow and Lang (1965) showed that subjects learned to reduce cardiac-rate variability significantly when a visual display provided synchronous feedback of their own heart rate compared either with their own preceding scores without feedback, or with a control group given false feedback. Johnston and Lethem (1981) reported on a series of experiments in which subjects were trained to decrease cardiac interbeat interval (i.e., to increase heart rate) by a specific amount (e.g., reaching the 40th percentile point of the initial interbeat interval distribution within ±5 percentile points). In one of these experiments the performance of subjects trained in this task were run in a cross-over design on each of the following conditions: (1) having analogue visual biofeedback plus verbal instructions (with strategies on how to increase heart rate) and, (2) having verbal instructions alone. The results showed that biofeedback plus verbal instructions was significantly better than verbal instructions alone and that performance deteriorated when feedback was withdrawn. These studies indicated response-produced feedback is important for relatively efficient performance of a visceral control task.

Other studies have indicated that the greater the amount of response-produced feedback the more efficient the performance on a visceral control task. For example, Lang and Twentyman (1974) compared the performance of subjects trained using binary feedback (low amount of information feedback) to those using analogue feedback (high amount of information feedback) during two increase and two decrease heart-rate control sessions. The binary feedback took the form of the appearance of the word "good" on an oscilloscope screen each time the length of the interpulse interval of the R-wave of the EKG exceeded the criterion R-wave length (during heart-rate decrease trials) or was less than the criterion (during heart-rate increase trials). The word "good" was absent after each heartbeat that did not meet the criterion. The analogue feedback took the form of successive lines on the oscilloscope screen that were proportional in length to each interval between R-waves; in addition, the appearance of the word "good" was provided whenever the criterion was met. The criterion, at the start of a session, was defined as the median interpulse interval during an initial no-feedback control trial. Over trials, within sessions, the criterion was adjusted according to the subsequent level of control of the subject's heart rate during biofeedback trials. The results indicated that the analogue display prompted significantly greater heart-rate accelerations than the binary display during biofeedback trials and during no-biofeedback transfer trials for the increase heart-rate control sessions. Also the work of Gatchel (1975), a member of Lang's laboratory, showed that the frequency of information feedback affected the learning of heart-rate increases. This investigator varied the frequency of feedback for two increase and two decrease heart-rate control sessions by showing the subjects a summary of their performance in one of three ways. One group was given a summary after every 10 heartbeats (i.e., low frequency of feedback), a second group was given a summary after every 5 heartbeats (i.e., intermediate frequency of feedback) and a third group was given a continuous, analogue heart-interval display (i.e., high frequency of feedback). It should be noted that this manipulation varies not only the frequency of the feedback but also delay of the feedback. In addition, a no-biofeedback control group, involved in a tracking task, was used. The results indicated that, during increase heart-rate sessions, the feedback groups showed faster heart rates than tracking control groups. Furthermore, among the feedback groups, the analogue group showed the best performance, followed by the intermediate frequency (5-beat) group, and trailed by the low frequency (10-beat) group during increase heart-rate sessions. Thus, more frequent information resulted in better performance on a visceral learning task. A study by Brener, Kleinman, and Goesling (1969) investigated the effects of different exposures of augmented sensory feedback on the self-control of heart rate. Three groups of subjects, run over two session, were given feedback of their heart rate for either 0%, 50%, or 100% of the experimental trials. The amount of heart-rate control was measured by the mean intermedian interbeat-interval differences recorded during the increase and decrease no-biofeedback test trials interspersed among the biofeedback trials on both sessions. The results showed that heart rate control was significantly better for the group trained with feedback given 100% of the time than for the group given no feedback at all. The group given feedback on 50% of the trials showed an absolute level of control between the other two groups but was not significantly different from either. This linear relationship is at least suggestive that success in achieving visceral control is directly related to the proportion of trials on which feedback is presented.

An operant conditioning study which examined blood-pressure control in normotensive subjects (Elder, et al., 1977) is also relevant to the idea that the greater the amount of response-produced feedback the more efficient the performance. In this study subjects were trained to increase and decrease diastolic blood pressure to a criterion blood pressure change of 10% to 15% (relative to a pretraining basal blood-pressure level) for two consecutive training sessions, or until they had completed a total of 10 successive training sessions. Each session consisted of 20, 100-second runs (trials) with an interrun interval of 20 to 50 seconds. One group of subjects was called the "free operant group" and was given proportional (analogue) auditory feedback during the entire 100 seconds of each run. A second group was called the "discrete trials group" and was given the proportional feedback only during the initial and final 10 seconds of each run. There were two additional no-biofeedback control groups. The results showed that the free operant group, which obviously received more feedback than the other groups, required a mean of only 5.75 sessions to reach criterion while the discrete trials group and the two non-feedback control groups had not yet reached criterion following the the tenth training session. In addition, analysis of both increase and decrease blood pressure scores showed that the free operant group performed significantly better than the discrete trials group.

The already mentioned work of Johnston and Lethem (1981) examined the effects of varying the amount of feedback on learning to increase heart rates by a specific amount in four separate experiments. Using binary and analogue visual biofeedback displays (similar to those used by Lang and Twentyman, 1974) they compared binary to analogue feedback and compared different frequencies of analogue feedback. The frequency of analogue feedback was manipulated by varying the proportion of cardiac cycles that had feedback available (e.g., on every cycle, on every fifth cycle, on every tenth cycle, and on every fortieth cycle). The results showed that on two separate tests of binary vs. analogue feedback, the analogue feedback produced greater heart-rate control. Two out of three tests of the effects of varying the frequency of analogue feedback showed that frequent feedback was better than infrequent feedback.

Taken together, the results of these studies assessing the effects of feedback on several visceral learning tasks indicated that for the performance and therefore probably for the learning of such tasks: (1) response-produced feedback is important and, (2) the greater the amount of response-produced feedback the more efficient the learning. These results would seem to satisfy the first and second descriptors identified by Johnston (1977a) as being critical to a motor skills analogy for visceral learning. However, other findings from some of these studies and the results of other studies cast doubt on the importance of feedback as a factor in learning visceral skills.

Evidence against the importance of feedback. Although Lang and Twentyman (1974) reported analogue feedback to be superior to binary feedback for learning to increase heart rate they did not find this to be true for heart-rate decreases. It was found that while subjects receiving binary feedback were able to decrease heart rate on instruction relative to resting rates, these effects were not enhanced by the analogue display (Lang & Twentyman, 1974). Similarly, Gatchel (1975) found that frequency of information feedback did not affect the learning of heart-rate decreases. While feedback subjects showed greater instructed-slowing than controls, the amount of deceleration was unrelated to the frequency of information delivered by the feedback.

Young and Blanchard (1974) also studied the effects of varying the amount of information contained in a feedback signal on the self-control of heart rate. Five groups run over two sessions, were presented with auditory feedback which varied in the amount of information given to the subjects. The feedback displays in order of decreasing informational content were: (1) continuously available feedback the pitch of which was directly proportional to the subject's heart rate, (2) a similar analogue signal available continuously once the subject's heart rate exceeded the criterion level (approximately 5 beats per minute above the subject's mean heart rate for heart rate increase trials and 5 beats per minute below for heart rate decrease trials) but unavailable before the criterion level was reached, (3) binary feedback in which a tone of constant pitch was presented when the subject successfully reached the criterion heart rate level, (4) heart sounds in which an auditory presentation of the subject's amplified EKG signal was continuously available to him; there was also, (5) no feedback in which no external information was available. The results for subjects in the increase heart-rate condition showed that auditory feedback enabled subjects to raise heart rate on command more than subjects receiving no feedback. However, increasing informational content failed to yield a significant increment in control to the subjects receiving the different forms of auditory feedback. The results for subjects in the decrease heart-rate condition showed that auditory feedback did not yield a significant advantage over no feedback. Although all groups were able to lower their heart rate significantly upon command, there was a failure to find an additional advantage for feedback over no feedback in the decrease heart-rate condition.

Thus, the findings of Lang and Twentyman (1974) and Gatchel (1975) for learned heart-rate slowing and the work of Young and Blanchard (1974) for heart-rate speeding would indicate support for the notion that feedback is an important factor in learning visceral control (i.e., it would be congruent with Johnston's first descriptor), but would discredit the idea that the more information supplied by the feedback the better the learning (i.e., it would not mesh with Johnston's second descriptor). Furthermore, the findings of Blanchard and Young (1974) for heart-rate slowing would discredit the notion that feedback is an important factor in visceral learning of this type. The above results prompted Lang (1977) to conclude that the mechanisms of heart-rate speeding and slowing are different from one another, and that activating (ergotrophic) and activation reducing (tropotrophic) cardiac changes are differentially responsive to experimental manipulation. He has speculated that the information-processing demands of feedback procedures interfere with the individual's efforts to achieve a state of lowered arousal.

Lang and Twentyman (1980) ran human subjects in a study designed to test the effects of different feedback displays on instructed heart-rate speeding and slowing. Four groups of subjects were used. One of these groups served as a control and participated in a perceptual motor task in which no instructions were given to control heart rate. The other three groups were trained with biofeedback in the form of the appearance of a sweep line on an oscilloscope proportional in length to the subject's interbeat interval and with information about performance relative to a criterion (similar to biofeedback described by Lang & Twentyman, 1974). The three biofeedback groups included: (1) a group that received information about interpulse interval length (including specific information about when systole occurred), (2) a group that received information about "average" interpulse interval presented every second, and (3) a group that received information about average interpulse interval presented every six seconds (the information for the latter two groups was not triggered by systole since it represents averages). The results of this study that are relevant to the present discussion indicated that the biofeedback subjects produced greater heart-rate changes over two training sessions only during the speeding sessions. This finding, for heart-rate speeding sessions only, would be in agreement with Johnston's first descriptor. Although there was a reported general superiority of speeding over slowing performance during biofeedback trials this superiority was not found during transfer trials containing no biofeedback. The clearest comparison of manipulations of amount of feedback in this study was between the group receiving more frequent information (i.e., the group getting information averaged every second) and the group receiving less frequent and more delayed information (i.e., the group getting information averaged every six seconds). There were no significant differences found between these two groups during either heart-rate slowing or heart-rate speeding. This indicated that amount of information manipulated quantitatively in this manner did not affect visceral performance. This finding would not agree with Johnston's second descriptor.

The work of Johnston (1976, 1977a, 1977b) has brought into serious question the validity of a motor skills learning paradigm for visceral learning on several counts. For example, Johnston (1976) ran two groups of subjects over two sessions, one of which contained only heart-rate increase trials while the other contained only heart-rate decrease trials. One group was called the "instructions-only group" and received verbal instructions indicating not only the direction of desired heart-rate change but also instructions encouraging the limited use of skeletal mediators. Specifically, subjects in the increase condition were told that they could alter their breathing or tense their muscles while those in the decrease condition were informed that they would probably find it useful to sit still and breathe steadily. In both conditions subjects were encouraged to use other than purely physical means to control their heart rate. The second group was called the "biofeedback group" and received the same instructions as the "instructions-only group" with the addition of auditory binary feedback. The results of this study indicated that although there was a significant difference between increase and decrease heart-rate control trials there was no statistical evidence that the feedback used added to the control produced by instructions alone. Another study by Johnston (1977b) examined the effects of verbal instructions alone, and these verbal instructions plus analogue visual feedback, on the voluntary control of digital "pulse amplitude" (a measure of peripheral blood flow) for two groups of subjects run over eight sessions. The verbal instructions simply informed the subjects that blood flow in the skin would increase when they were relaxed and would decrease when they were tense. One group received both the verbal instructions and the visual feedback for all eight sessions while the other group received only the verbal instructions for the first four sessions and then the feedback for the remaining four. This allowed for both a between and a within subject comparison of the feedback effect. The results of this study showed that although a significant degree of control over pulse amplitude was demonstrated for both groups the feedback did not add consistently or reliably to the effect of verbal instructions alone. This was true for both the between and within subject comparisons. It should be pointed out that in other studies (e.g., Brener, et al., 1969; Elder et al., 1977; Young & Blanchard, 1974) subjects were merely instructed to exercise control of the viscera in a specific direction without supplying them with any strategies as to how to accomplish this sort of change. However, Johnston (1976, 1977b) not only supplied directional information but also gave his subjects such strategies. Lang (1977) used a control similar to Johnston's instructions-with-strategies group and he reported results comparable to those reported by Johnston. Lang compared a group given practice on Benson's mediation procedure (Benson, Rosner, Marzetta & Klemshuck, 1974), which can be considered as a strategy, with a group given heart-rate feedback on a heart-rate slowing task. The results indicated that both groups performed equally well on the heart-rate reduction task.

Keefe (1978) trained subjects to increase peripheral-skin temperature (a measure of blood flow) over five training sessions. The subjects were assigned to one of six groups in which they received: (1) response-specific instructions (i.e., being told that their task was to raise the skin temperature of their right index finger) plus feedback (consisting of a visual meter display and a variable-pitched tone which covaried with skin temperature), (2) thermal suggestions (i.e., being told that their task was to raise the skin temperature of their right index finger by repeating the phrase "my right hand is warm") plus feedback, (3) instructions to rest (i.e., being told that their task was to sit quietly in the chair) plus feedback, (4) response-specific instructions without feedback, (5) thermal suggestions without feedback, and (6) instructions to rest without feedback. The results showed that only those subjects given either feedback and response-specific instructions (Group 1), feedback and thermal suggestions (Group 2), or no feedback and thermal suggestions (Group 5) were able to produce significant increases in digital skin temperatures. However, there were no significant differences in performance among these three groups during any of the training sessions. This indicated that a group of subjects given appropriate strategies but denied biofeedback (i.e., Group 5) did as well in learning to control a visceral response as a group of such subjects who were also given biofeedback (i.e., Group 2). The results of the studies by Johnston (1976, 1977b), Keefe (1978), and Lang (1977) do not support the idea that feedback is an important factor (or, at least, not a necessary condition) in visceral learning (i.e., is not congruent with Johnston's first descriptor).

Comments. According to Johnston (1977a) the motor skills literature suggests that the information provided by feedback affects the rate at which the response is acquired (with more information leading to more rapid acquisition) rather than affecting asymptotic performance. Johnston said that studies supporting the importance of feedback in visceral learning (i.e., Gatchel, 1975; Lang & Twentyman, 1974) indicate that the absolute level of performance achieved increases with increasing information. According to Johnston, this would not be predicted from the motor skills literature since the expectation to be derived from the literature would indicate that only the rate of acquisition is affected. He felt that this suggests that information is not operating in the same way in visceral tasks as in conventional motor skills tasks and that information may be having its effects on performance rather than learning.

However, the motor skills study by Adams, Goetz and Marshall (1972) showed that increasing the information supplied by feedback affected asymptotic performance in such a way that augmented feedback led to significantly better performance than did minimal feedback. The motor skill tracking task study by Smode (1958) also showed that the absolute level of performance was significantly greater for the group learning under high levels of augmented feedback as compared to the group learning under low levels. In addition, this study seems to indicate that the superior performance evidenced by the group learning under high levels of augmented feedback was mediated largely by increases in motivation since there was a significant difference between the high and low level groups on the very first training trial. Other findings from both of these motor skills studies showed that response-produced feedback had a great impact on both learning and performance. Thus, it appears that the effects of feedback on a motor-skills task can influence the asymptotic level and, furthermore, can influence both learning and performance. This, of course, argues against Johnston's suggestion that information was not operating in the same way in visceral tasks as in motor-skills tasks. It should be noted that the learning-performance controversy has raged for decades; there is no reason to believe that the research in visceral learning will be any more successful than that done for other types of learning in settling this matter. It does seem reasonable to believe that biofeedback may serve to improve performance by increasing motivation, inducing arousal, allaying fatigue, enhancing learning, or a combination of any of these and of other possible factors. The question at hand is does performance vary as a function of feedback manipulations in similar ways for both visceral and motor-skills learning. It seems clear that the research done to this point is equivocal on this issue.

Performance Improves With Training

Johnston's third descriptor of motor-skills learning is that performance should improve with training.

Supporting evidence showing performance improves with training. The observation that performance improves with practice over trials or sessions has been long noted in the field of motor-skills learning. In fact the performance functions obtained in almost all learning experiments show a gradual course of acquisition (Kimble, 1961, p. 128). For instance, the previously mentioned studies of motor-skills learning with augmented feedback (Adams, Goetz & Marshall, 1972; Smode, 1958) showed performance improving with practice over trials.

In the field of visceral learning the previously discussed work of Miller and Carmona (1967) showed that groups of dogs rewarded for either salivation increases or decreases showed performance curves with slopes significantly different from zero for training carried out over a period of 40 sessions. Roberts, Schuler, Bacon, Zimmerman, and Patterson (1975), using auditory biofeedback, trained human subjects to control the temperature (reflecting peripheral blood flow) in one hand relative to the other, over a training period of 16 sessions. The group results showed a significant sequential change in the direction of requested performance across sessions (i.e, a significant slope for the regression line of performance). Thus, these data showed a clear-cut learning curve for all subjects combined for the 16 session training period. Taub and Emurian (1976) studied the course of learning self-regulatory control of skin temperature with analogue visual feedback derived from a single location on the dorsum of the dominant hand of human subjects. One group of subjects learned temperature increases, while a second learned temperature decreases. The results of this study were plotted as the change in skin temperature over the six training sessions. The performance curve for the group learning temperature increases seemed to improve steadily over sessions while the curve for the group learning temperature decreases showed an initial large improvement on the first session, then an abrupt decrease in performance on the second session, with a subsequent steady improvement over the next four sessions reaching levels of performance slightly greater than those shown on session one. Statistical analysis of these data showed that although the differences in performance between the two groups was highly significant, the growth in temperature control over sessions approached, but did not reach significance. Keefe and Gardner (1980) reported on two separate experiments designed to assess the effectiveness of biofeedback training combined with simple response-specific instructions (both feedback and instructions are similar to those discussed in the Keefe, 1978 study) on skin-temperature control. The first experiment trained separate groups of subjects to increase or decrease their skin temperatures over five training sessions. The second experiment trained subjects to increase their skin temperature over 20 training sessions. Both studies showed that it took about three training sessions to achieve significant within-session control. However, in the second experiment, there was no increase in temperature in any session that was significantly greater than that achieved in the third session. The study of blood pressure control by Elder et al. (1977) revealed a significant improvement in performance over sessions for both the increase and the decrease blood pressure conditions. Similarly, the study by Brener et al. (1969) which examined the effects of different exposures of augmented sensory feedback on the self-control of heart rate, found a significant improvement in performance for all groups from session one to session two, the final session. In addition, the heart-rate control study done by Gatchel (1975) reported a significant improvement in control of heart-rate increase from session one to session two for all groups receiving biofeedback.

Generally, these studies of visceral learning with biofeedback have indicated that performance improves with training and would, therefore, satisfy Johnston's third descriptor. However, there is a body of literature which suggests that, except for an initial improvement, no additional improvement occurs with training over time.

Evidence against the view that performance improves with training. Although the work by Gatchel (1975) reported a significant improvement from session one to session two in learning heart-rate increases no such improvement occurred over sessions for subjects learning heart-rate decreases. (However, the subjects who learned heart-rate decreases did show a significant improvement in performance over the five biofeedback training trials given in each training session, suggesting a tendency to improve within a session.) The work reported by Young and Blanchard (1974), on heart-rate control, showed that there was no significant change in performance from session one to session two. Johnston's (1976) study of heart-rate control showed that neither the heart-rate increase nor the heart-rate decrease group showed an improvement in performance over the single training session used for each condition in this experiment. Johnston's (1977b) study of the control of digital pulse amplitude also showed no improvement in performance over sessions for all groups (including the group receiving feedback plus instructions-with-strategies over a period of eight sessions). Surwit, Shapiro, and Feld (1976) trained two groups of subjects to either increase or decrease digital skin temperature by providing them with analogue visual feedback via a meter. Subjects were given 20, 75-second trials per session over a training period of five sessions. Results showed that although there was a significant difference in performance between the increase and the decrease groups (which was apparently due to changes primarily in the decrease group) there were no significant changes in performance from a predetermined baseline over the training sessions. However, there was evidence that control (i.e., differential temperature control) improved over blocks of trials in a session (averaged across all 5 days of training).

Comments. It appears that there are ambiguities concerning the view that performance improves with training when learning a visceral task. One observation that can be made about the studies reviewed here is that, in general, those studies which involved many training sessions or trials in the learning of visceral control tend to support this view, while those involving relatively fewer sessions or trials tend not to do so. Perhaps many of the reported findings of the studies failing to observe improvements in performance with training were due to not allowing a sufficient amount of time (or sessions, or trials) for biofeedback training to have its impact on performance.

Response Specificity Develops

Johnston's fourth descriptor of motor-skills learning is that response control changes and becomes more specific with training (i.e., that response specificity develops with training).

Evidence supporting the development of response specificity. It appears that early in the development of voluntary control of motor skills, the desired response occurs in association with other reactions, but with practice the desired response becomes dominant and the others disappear (Kimble & Perlmuter, 1970). An example of the development of such response specificity, in learning novel somatic motor skills, was described in a study on learning control over movements of the ears in human subjects (Blair, 1901, cited in Kimble & Perlmuter, 1970). It was reported that: (1) the first successful voluntary movements of the ears occurred as part of a much larger facial contortion involving a lifting of the brows and vigorous grimacing, and (2) once this occurred, and the subjects detected the movement even in a minimal way, the ear movement began to be differentiated from the general response.

After reviewing the results of a number of cognitive, verbal, and motor learning tasks Germana (1968) indicated that initial learning is accompanied by increases in many activation responses (e.g., alpha blocking, heart-rate increases, skin-conductance increments, peripheral vasoconstriction, muscle-tension increases). Nevertheless, as the learner masters the specific task, activation peaking occurs, and the activation responses return to levels adjusted to maintaining effective performance. Schwartz (1975) has interpreted Basmajian's (1972) work on learning control over single motor units in skeletal muscle via biofeedback, as evidence that control changes and becomes more specific with training. Schwartz pointed out that early in training, adjacent motor units in the muscle are also activated, but as the subject practices controlling the motor unit with feedback, the irrelevant units drop out. Schwartz has also pointed out that the studies of both Basmajian and Germana suggest that learned specificity grows out of a more generalized physiological arousal.

All of these studies have given evidence for the idea that control changes and becomes more specific with training in motor skills learning. The following discussion will review the evidence that this process occurs in visceral learning as well.

The following excerpt from Taub and Emurian's (1976) study of learned peripheral skin-temperature control apparently supports the idea of the development of response specificity when learning a visceral task:

> In the early stages of training, there is, typically, "following" by the untrained hand of temperature changes in the self-regulating hand. Subsequently, after the task has been well learned, following by the untrained hand drops out completely. Moreover, as training

> progresses, the response gradually tends to develop considerable anatomical specificity on the self-regulating hand itself. The maximum temperature control is exhibited primarily around the feedback locus and decreases with distance from that location; in some cases, there was little correlation in temperature change between points separated by as little as 2 cm on the dorsum of the hand. These phenomena appear to be typical of the "sharpening of response" or response differentiation process that normally occurs as training proceeds in other learning situations. (p. 226)

Unfortunately Taub and Emurian did not supply supporting data (regarding amount of training or extent of following) to substantiate the preceding excerpt. In a more recent report (Wand, Slattery, Haskell & Taub, 1978) Taub's group described the results of work on three subjects who were trained, via visual biofeedback, to control the temperature of a single point on the web dorsum. Temperature was recorded from that point and from four other loci on that same hand. One subject did not acquire self-regulatory temperature control; hence, in this case, the question of specificity of response was irrelevant. The other two subjects learned the response and displayed significantly greater temperature control at the feedback locus than at the other recorded locations on the hand. This anatomical specificity was reported to have developed gradually and achieved prominent and unequivocal status between sessions 16 and 20 for one subject and sessions 21 to 25 for the other. Taub (1977) also reported on a temperature-control study in which feedback was derived from the fingers. The results indicated that after learning had appeared to reach an asymptote, self-regulated temperature change was approximately only one-third as great on the hand as on the fingers. A somewhat similar finding was reported by Lynch, Hama, Kohn, and Miller (1976) who were able to train a child to control significantly temperature differences between the index and ring finger tips of the dominant hand using visual biofeedback. Although they supplied no information concerning changes in specificity over sessions this study does indicate the high degree of response differentiation capable of occurring within a visceral response system. Also, Roberts et al. (1975) reported that, for subjects successful in learning to produce a difference in skin temperature in one hand relative to the other, there were high correlations between the absolute temperatures for the two hands in the early training. Later in training when these subjects showed a high level of control they were able to vary the temperatures in the two hands independently. Unfortunately, no correlational data were given to support this contention.

Miller and Brucker (1979) have reported on training patients, paralyzed by spinal lesions, to produce increases in systolic blood pressure through the use of biofeedback procedures. The results indicated that these patients learned unusually large increases in blood pressure (about

16 mm Hg) that were performed apparently independently of skeletal responses. (This study used several control procedures to rule out the effects of skeletal and respiratory maneuvers as possible mediators of the blood-pressure control; hence, this study serves as a potential confirmation of Miller's [1969] initial findings of autonomic control without skeletal mediation observed in curarized rats.) The important finding for this discussion was the reported increase in the specificity of the blood pressure response that occurred, after prolonged practice, in two such patients. Specifically, Miller and Brucker observed that increases in blood pressure were accompanied by increases in heart rate during the first 25 training sessions; nevertheless, such blood pressure increases were not accompanied by appreciable increases in heart rate after additional periods of practice.

All of these studies support the idea that, in visceral learning, control changes and becomes more specific with training; these studies, thus tend to satisfy Johnston's fourth descriptor. The following studies have given evidence against this notion.

Evidence against the development of response specificity. The Johnston (1977b) study on voluntary control of digital pulse amplitude showed no significant differences between the trained and the contralateral finger developing over sessions or trials; hence there is to this point, no evidence for the development of specificity in pulse-amplitude control. Johnston also analyzed the changes in other physiological variables over the course of this study. He reported that early in training control was diffuse and involved changes in pulse interval, respiration rate and, to a lesser extent, muscle activity; this diffusion did not diminish significantly over eight sessions of feedback training. Surwit et al. (1976) noted that when digital skin-temperature feedback was derived from one hand, the observed temperature changes were bilateral. They did not observe any evidence of response specificity to the site of feedback even after nine days of training.

Comments. It appears that there are some studies which support and others which discredit the idea that control changes and becomes more specific with training when learning a visceral task. One important consideration is, again, the number of training sessions used by studies giving evidence for the growth of specificity. According to Wand et al. (1978), in order for temperature response specificity to develop, 16 to 25 sessions were necessary depending on the subject. Similarly, according to Miller and Brucker (1979), in order for blood-pressure increase response specificity to develop (relative to heart-rate increase), more than 25 sessions were necessary depending on the subject. On the other hand, studies failing to find evidence for specificity generally employed considerably fewer sessions. For instance Johnston (1977b) ran only 8 sessions while Surwit et al. (1976) ran only 9. It therefore seems appropriate to conclude that, for visceral learning, control does not change and become more specific with practice, unless very many sessions of practice are provided to the visceral learner.

Another factor that may have influenced the development of specificity was the set of instructions given to the biofeedback groups. Johnston (1977b), although supplying his subjects with pulse amplitude feedback from only one hand, gave them instructions (strategies) that were very general in nature (such as blood flow in the fingers would increase the more relaxed and unaroused one felt and would decrease the more alert and aroused one felt). Such instructions could tend to produce a more general response. Perhaps instructions which were more specific to the source of the biofeedback (such as blood flow in the control hand increasing if the subject were told to think of that hand as being in warm water and would decrease if the subject were to think of that hand as being in cold water) might have produced more evidence of the development of response specificity. Also, the reported finding by Surwit et al. (1976) that when digital temperature feedback was given from one hand the observed temperature changes occurred in both hands may have been due partly to the instructions. They told their subjects to think of their hands as being warm or cool. Perhaps if they were told to think of their "control hand" (i.e., the hand being measured) as being warm or cool more specificity between hands may have developed.

There appear to be at least two types of response specificity that can be measured. One is the type that develops within the response system under training. This is exemplified in motor-skills learning tasks by the dropping out of adjacent facial skeletal muscle movements when learning control over ear movements (Blair, 1901; cited in Kimble & Perlmuter, 1970), and in visceral learning tasks by the dropping out of temperature-following responses in adjacent skin areas when learning control over temperature in a specific location on the hand (Wand et al., 1978). The second type of specificity develops in response systems other than the one being trained. This type is exemplified in motor-skills learning tasks by the reduction in many activation responses after the mastery of the particular task (Germana, 1968), and in visceral learning by the reduction in heart-rate increases accompanying learned blood-pressure increases over periods of prolonged practice (Miller & Brucker, 1979).

For visceral learning, it is possible that to interpret more adequately the idea that control changes and becomes more specific with training, these two types of response specificity should be considered carefully, and perhaps separately, since they may be affected by different factors. For instance, changes in control within the response system being trained may be due to increases in the focusing of attention on the response one is trying to control while ignoring the other responses that were originally necessary (Kimble & Perlmuter, 1970). Changes in control of responses other than the one being trained may also be due to this selective focusing of attention and ignoring of other responses, but it may be due to more general changes in activation responses (Germana, 1968), or to attempts to mediate the visceral response via skeletal or centrally integrated skeletal-visceral patterns (Miller & Brucker, 1979; Miller & Dworkin, 1977). This may really be a problem when the visceral response system being trained also takes part in the general activation response.

Other Possible Parallels

There are, at least, several other potential parallels between motor-skills learning and visceral learning. These include: (1) the identification of early as opposed to late stages in the course of learning, (2) the transfer of training, and (3) the effect of retention interval on the recall of skills.

Early vs. late stages of learning. The descriptions of the course of somatic-motor learning as having: (1) an early, cognitive phase during which time the subject needs to think about what to do next, and (2) a final, autonomous phase when such cognitive direction is no longer needed (Gagne, 1977; Kimble & Perlmuter, 1970; Meichenbaum, 1976) are strikingly similar to descriptions of the course of visceral learning during biofeedback. Here, there are reports which identify the presence of (1) an early phase during which time the subjects employ cognitive processes (e.g., self-statements, images, and feelings) as tools to enhance the training process (Meichenbaum, 1976; Ohno, Tanaka, Takeya, & Ikemi, 1977), and (2) a final stage during which the subjects find it difficult to specify exactly what they do. They simply perform the task (Taub & Emurian, 1976).

Fleishman (1966) has indicated that in the early stages of learning a motor-skills task, certain non-motor abilities (e.g., verbal, spatial) play an important role in performance. During later stages of learning, motor abilities (e.g., kinesthetic) contribute more to performance relative to these non-motor abilities. If such abilities have a similar differential influence on the performance of visceral-learning tasks, this may help to explain why studies which have used groups given feedback plus instructions (with verbal strategies) have not performed any better than groups given only the instructions (e.g., Johnston, 1977b). It might be reasoned that since Johnston trained his subjects for relatively few sessions, verbal cues (and thus the influence of verbal strategies) were contributing importantly to performance during this early phase of learning. Had Johnston allowed his subjects prolonged practice, motor or kinesthetic or non-verbal abilities may have become preeminent, while dependence on the verbal strategies may have decreased. This situation could have led eventually to better performance for the feedback group.

The transfer of training. Transfer of training means that experience or performance on one task influences performance on some subsequent task. Such transfer of training has been observed to occur in many types of learning (Ellis, 1965), including the learning of motor skills (Singer, 1975). One example, in the field of motor-skills learning, which examined a very specific type of transfer effect (or response generalization) from one anatomical training locus, was reported by Cook (1933a, 1933b). He trained all four limbs of subjects to trace the star-shaped maze. The results showed that transfer was greatest to the muscle group opposite and symmetrical, while being least to the muscle group opposite and unsymmetrical to the practiced limb. In the field of visceral learning, Taub (1977) has reported a transfer of training effect for peripheral skin-temperature control using biofeedback techniques. After the original responses developed considerable anatomic precision, Taub observed the transfer of temperature control from the originally trained hand to the subject's forehead. This study, however, had several shortcomings including the use of a small sample (only two subjects), and the failure to quantify the amount of transfer in terms of savings, in trials or in time, to reach some criterion of learning.

Schwartz, Young and Vogler (1976) have viewed the transfer of training of visceral responses in a different way. They have applied Fleishman's (1966) model of "complex motor-skill learning" to visceral (i.e., cardiac) learning. Fleishman feels that there is a fundamental difference between what he terms "abilities" and motor "skills." Abilities, according to Fleishman, refer to more general traits or response factors which the individual brings with him when he begins to learn a new task or skill. Skills, on the other hand, refer to the level of proficiency on a task or group of tasks. Fleishman's assumption is that skills involved in complex activities could be described in terms of the more basic abilities.

Schwartz et al. (1976) have pointed out that Fleishman's model predicts that a positive correlation (and therefore transfer of learning) should be found between performance on any pair of complex, integrated skills to the extent that they share a similar pattern of underlying abilities. Using this prediction made by Fleishman's model as a starting point, these researchers carried out a study examining the transfer of learning of various visceral skills. Specifically, they chose two of Fleishman's abilities, strength and endurance, which they felt could be readily translated to cardiovascular terminology. Schwartz et al. noted that the majority of cardiovascular feedback studies employed a paradigm which combines the abilities of strength and endurance. That is, the experimental task is usually to change heart rate as much as possible and to sustain it for a given interval of time.

In addition to looking at the strength-endurance abilities, they chose to study another one of Fleishman's abilities called reaction time. They felt that reaction time could also be translated into visceral skill terminology, even though it had not received empirical investigation up to that time.

Operationally, the cardiac strength-endurance task required the subject to change his heart rate (in either an increase or decrease direction) as much as possible, and to maintain this maximal change for one minute. The cardiac reaction-time task required the subject to attain a criterion heart-rate level (selected as being 50% of the change from resting level achieved on a non-feedback strength-endurance pretest of the same direction), and to maintain this criterion heart-rate level for 3 consecutive seconds with the goal of accomplishing this task as rapidly as possible. The subjects used in this study were exposed to the following experimental manipulations. During a pretest phase of this experiment all subjects were tested on the ability to perform, without feedback, first the strength-endurance task and later the reaction time task. Then the subjects were assigned to either a strength-endurance or a reaction-time biofeedback-assisted training group. During this biofeedback-assisted training phase subjects received training only in the task to which they were assigned. The final phase of the study was a non-feedback-assisted posttest of generalization which was identical to the pretest phase.

Schwartz et al. (1976) predicted that cardiac learning would be specific to the skill practiced during biofeedback-assisted training, with little transfer to the other task. This prediction was confirmed by the results of this study. The data indicated that the strength-endurance training led to significantly improved strength-endurance control, as measured from the pretest to the posttest (up

30%), accompanied by a slight decrement in reaction-time control (down 5%). Conversely, reaction-time training led to significantly improved reaction-time control (up 120%) accompanied by a small decrement in strength-endurance control (down 18%).

Effect of retention interval. According to the motor-skills literature there should be very little loss of skill related to the length of the retention interval. The amount of retention should be related to the individual differences in the original learning (Fleishman,1966). Fleishman and Parker (1962) reported on studies which gave extended practice (17 sessions) on a highly complex perceptual-motor task and which measured retention on this task after retention intervals of 1, 5, 9, 14, and 24 months. The results indicatd that the retention from original learning was independent of the length of the retention interval. Thus, for all intervals, even up to 2 years, individual differences (based on mean performance) at the end of learning correlated in the .80's and .90's with subsequent performance after periods of no practice.

In the field of visceral learning, Taub (1977) has reported that the retention of the ability to self-regulate changes in skin temperature in a single direction, after an interval of four to five months, was virtually perfect. (He has also indicated that feedback is necessary for performance of the task during the initial stages of learning, but, after sufficient training, self-regulation of skin temperature can be as good without feedback as with feedback.) Unfortunately, Taub has based these results on data from only four subjects and on what amounts to only one retention interval (i.e., 4 to 5 months). He did not report the correlations of initial learning with subsequent recall nor did he supply any measures of the degree of recall (except for showing a graph plotting the amount of temperature control as a function of sessions for the periods of initial learning and retention for one subject). The previously mentioned work of Keefe (1978) on learned control of peripheral skin-temperature increases examined retention of such learned control over time. The results indicated that subjects in the three groups showing control over temperature increases during training (two feedback groups and one no-feedback group that used thermal suggestions) retained the ability to control skin temperature both 1 and 2 weeks after training.

The Status of the Analogy

The status of the motor-skills model of visceral learning will be assessed by considering: (1) the importance of feedback in visceral learning and (2) the problems of identifying exactly what the motor-skills learning model represents and how such a model differs from other proposed models of visceral learning.

The Importance of Feedback

According to Johnston (1977a) the knowledge of results [feedback] is vital to learning a motor skill. Since Johnston found no evidence to show that the provision of biofeedback improves performance over that achieved by subjects given verbal instructions alone when learning visceral tasks (Johnston, 1976, 1977b) he indicated that biofeedback is not vital to visceral learning, and, therefore visceral learning is quite unlike motor-skills learning (Johnston, 1977a, 1977b). Aside from the problem of not running enough sessions to rule out the effects of biofeedback on learning a visceral task Johnston is, perhaps, building a straw man when he says that biofeedback should be "vital" to learning a visceral task. The word vital connotes "essential." It is improbable that even advocates of the importance of biofeedback would claim that biofeedback is essential to learning control over a visceral response since a visceral learner deprived of biofeedback (a form of augmented feedback) still has other channels of intrinsic feedback available to him. The previously mentioned motor-skills learning study of Adams, Goetz and Marshall (1972) showed that subjects deprived of augmented feedback (i.e., the minimal feedback group) did evidence signs of learning the self-paced positioning task; the subjects given augmented feedback simply displayed a higher level of learning. Thus it might, perhaps, be argued that motor-skills learners could not learn a task when deprived of all forms of feedback, but it would be incorrect to assume that motor-skills learners could not learn such a task when deprived only of augmented feedback. Hence, augmented feedback, including biofeedback, is not vital to learning. It might be that a more reasonable question to ask is whether biofeedback is an important factor when learning a visceral response. That is, can biofeedback: (1) increase the maximum level of visceral learning, or (2) increase the rate of attaining some level of performance, or (3) increase both the maximum level and the rate of learning a visceral response compared to nonbiofeedback control groups.

Relevant to this issue, Schwartz (1979) observed that if one group of visceral learners is given biofeedback plus instructions while a second group is given specific instructions alone, and if both groups show similar degrees of visceral control, it would be a mistake to conclude that there is nothing unique about biofeedback. Schwartz' view is that one should question whether the same mechanisms were used to regulate the response in both cases. He mentions the possibility that the parameters of mean, variance, and temporal patterns of the visceral response under training may change in different ways for each group, and that other physiological processes (patterns) may differ in the biofeedback and the non-biofeedback learners.

Motor-Skills Learning Models

Singer (1975) discussed at least seven different types of models of skill acquisition: (1) association theories (which subsume operant conditioning), (2) neurophysiological theory, (3) mathematical-statistical models, (4) cybernetic models, (5) information-processing models, (6) adaptive models, and (7) general descriptive models (which include both nonsystem and system subtypes). Yet, biofeedback theorists talk about "operant" as opposed to "motor-skills" models for understanding the plastic properties of the viscera, as if there were some fundamental differences, outside of terminology, between these models (Beatty, 1977; Black & Cott, 1977). In fact, certain nomenclature used by one model can be readily translated into that of the other model. For example, motor-skills theorists talk about the importance of (1) amount of feedback, (2) delay of feedback, (3) high density analogue as opposed to low density analogue feedback, and (4) the function of feedback as possibly providing: information or knowledge of results, and/or motivation or reward, and/or reinforcement (Fitts & Posner, 1967). Operant theorists discuss similarly (1) amount of reinforcement, (2) delay of reinforcement, (3) rich as opposed to lean schedules, and (4) the function of feedback stimuli as possibly providing reinforcement and/or information (Black, Cott & Pavloski, 1977). This fourth point is expressed by Black et al. (1977) in the following passage:

> The position that the principles of instrumental or operant learning (along with the related principles of classical conditioning) are adequate to describe motor skills learning, concept formation, problem solving, and language learning is held by many (Berlyne, 1975). Although we would not agree that this is a fruitful position, we do think that these principles do handle motor skills training, a form of training that, some researchers have argued, provides a prototypic model for biofeedback training. One of the main variables in motor skills training is knowledge of results. Knowledge of results is usually provided by response-contingent stimuli. Such stimuli are assumed to have two functions-providing information and reinforcement (Deese & Hulse, 1967). The feedback stimuli that occur in simple operant conditioning can of course, be described in the same manner. For example, when lever pressing is reinforced by presenting a rat with food after every response, the food can be conceived of as providing information that a correct response has occurred, as well as increasing the probability of lever pressing. From an operant point of view, information can be treated as an SD [discriminative stimulus] for the next response... Thus, knowledge of results can function to reinforce the previous response and provide an SD for subsequent responses. (pp. 92-93)

Other theorists have posited a cybernetic or systems theory approach to explaining biofeedback (Mulholland, 1979; Schwartz, 1979). Schwartz (1979) feels that many concepts from operant conditioning and motor-skills models can be readily translated into a general "systems" framework. For example, Schwartz likens the operant concept of "contingent reinforcement" to the consistent connecting of a feedback loop between an output (i.e., the behavior) and an input (i.e., back into the organism).

Certainly either of these theories would predict that the provision of feedback would affect motor-skills learning and by extension visceral learning (by describing either the reinforcing and/or information characteristics of the stimulus or by the connecting of a feedback loop). These effects could manifest themselves as changes in means, variance or in temporal or spatial patterns of the response system under training.

Consider again the overall findings of Johnston (1976, 1977a, 1977b) which showed no differences between groups receiving "feedback and instructions-with-strategies" and those given "only instructions-with-strategies" on such measures as the pattern of the course of learning, the growth of response specificity, and the absolute level of performance when learning a visceral response. Such findings would suggest that visceral learning is fundamentally different from motor-skills learning.

Johnston (1977a, 1977b) has suggested a possible explanation for the differences he found between motor-skills learning and visceral learning. He says that skill theorists define a skill as requiring a graded response, one that has both "direction" and a "specific magnitude." He points out that most biofeedback experiments on visceral learning have required subjects to control mainly "directional movements" without requiring them to produce "specific magnitudes" of control. He feels that learning to control such directional movements with no specific end point, perhaps, does not meet this definition of a skill. He proposes that: (1) laboratory visceral learning that includes the specific magnitude component typical of most skill tasks (e.g., Lang, Scroufe & Hastings, 1967), or (2) visceral learning occurring prior to the subject's ever encountering the augmented feedback situation (i.e., directional-visceral responses that presumably had to be learned early in childhood and that may have shown some of the characteristics of skill at that time), might also be sensitive to the manipulations of parameters important in the motor-skills area.

However, it should be noted that other motor-skill theorists include gross bodily movements having mainly "directional components" as being one of the specific categories of motor skills and not as being separate from them (Fitts & Posner, 1967; Singer, 1975).

In fact, if one looks at the results of practice on a motor-skills task that emphasizes a gross bodily movement stressing directional components such as simple reaction-time training, one would see that group performance continues to improve for several hundred trials spaced out over several days and that knowledge of results improves the reaction-time performance of subjects when compared to instructions which urge the subjects to react as quickly as possible (Woodworth & Schlosberg, 1954, pp. 28, 35). These findings of an improvement of performance with training and with the provision of feedback would tend to indicate a great deal of similarity in learning gross bodily skills and skills requiring greater emphasis on specific magnitude control. Hence these findings would argue against Johnston's explanation for the differences between motor-skills learning and visceral learning.

Hatch and Gatchel (1981) have recently pointed out that a major problem in choosing between the motor-skills model and the operant model of visceral learning is that these models make very few unique predictions. However, they feel that there is one area where each of these models makes differential predictions; whereas the motor-skills paradigm predicts that learning will be a direct positive function of the amount of exposure to information feedback, the operant paradigm predicts that under certain specific conditions intermittent presentations of feedback (reinforcement) leads to greater behavior change than does continuous presentation. This differential prediction of the effects of continuous as opposed to intermittent feedback will be one of the issues examined in the present study.

Methodological Considerations

The following includes a discussion of a variety of scoring techniques that have been employed to evaluate visceral learning and a discussion of a number of ways in which visceral changes can be produced.

Scoring Visceral Change

At least three different scoring techniques have been used to assess visceral learning. These include: (1) the analysis of visceral change on a particular biofeedback-training trial relative to an "initial" pre-training baseline level taken from the same session, (2) the analysis of visceral change on a training trial relative to an immediately preceding "intertrial" baseline level (this technique has also been referred to as analyzing change relative to a "running baseline"), and (3) the analysis of peak visceral change on a biofeedback-training session relative to (and corrected with respect to) the peak visceral change on a separate and previous baseline session.

An example of the use of the first two techniques for assessing visceral change, in the same study, was the work reported by Johnston (1977b). He felt that both techniques provided useful information. However, he pointed out that since many subjects displayed strong but idiosyncratic trends in the visceral response system under training (i.e., pulse amplitude) "during the training session," there would be an inflation in the error in the scores based on an initial baseline. Nevertheless, the results of this study were highly similar regardless of the scoring techniques employed. Steptoe (1977) has also assessed visceral conrol (i.e., blood pressure as represented by pulse-wave velocity) by using these first two scoring techniques in a single study. He has found that the scoring done relative to initial and to intertrial baselines may lead to rather different conclusions and, therefore, has felt that both types of analysis may be necessary for a full understanding of the nature and source of visceral change.

The third technique has been developed and used almost exclusively by Taub and his group in their work on feedback-aided self-regulation of skin temperature (Taub & Emurian, 1976). This scoring technique involves calculating a relative temperature change during (1) a separate baseline temperature session by assessing the temperature shift from the last four 65-second stabilizing intervals of that session to the peak trial during the stabilizing period, and (2) a biofeedback-training session by assessing the shift from the last four 65-second stabilization intervals of that training session to the peak training trial. The value of change is determined by subtracting step one from step two. Although Taub feels that this technique helps to correct for the tendency of certain subjects to exhibit temperature change in given direction (Taub & School, 1978) it seems that he is throwing away the data from 14 of the total 15 training trials which make up a training session when he selects only the "peak" training trial as his measure of visceral change. Johnston (1977a) has strongly criticized Taub's data reduction and reporting techniques as being idiosyncratic and, thus, incapable of being properly evaluated.

Furthermore, since Taub's technique calculates visceral change relative to trends established on previous testing days it would seem that the second scoring technique (i.e., the one that assesses change relative to the preceding intertrial interval) keeps in "closer touch" with any idiosyncratic changes that may be due to events connected to that particular biofeedback-training session.

Mediation of Visceral Responses

Miller and Dworkin (1977) have identified a number of possible ways in which visceral changes can be produced. One way is that a specific learned visceral response may be elicited directly without any necessary skeletal link (i.e., without being somatically mediated). A second possibility is that skeletal and visceral responses may be inextricably linked together as parts of a "centrally integrated pattern" that can be elicited by learning; this would indicate that the activity of the central connections of the autonomic nervous system could be modified by learning. Miller and Dworkin warn that there are several other possible ways in which visceral changes can be produced which do not indicate learning by the autonomic nervous system: (1) a learned skeletal response may have a direct mechanical effect on the transducer used to measure visceral change (any such response is pure artifact and care is required to avoid it), (2) a learned skeletal response may have a purely mechanical effect on the visceral process (e.g., changing the position of the hand relative to gravity to cause blood-flow changes to occur), (3) a learned skeletal response may affect the receptive field of an innate visceral reflex (e.g., urination can be elicited if the abdominal muscles are used to increase pressure on the partially filled bladder; sufficient pressure stimulates the stretch-reflex receptors and causes a reflex emptying).

It would seem that researchers who claim to be measuring visceral learning should guard against the influence of these three types of learned skeletal responses. Reports that visceral learning is similar to motor-skills learning would not be surprising if what the purported visceral learner is controlling are the skeletal muscles, the same muscles that are controlled in learning conventional motor skills. Unfortunately, there is great variability in the degree of control over the influences of such learned skeletal responses; they range from using elaborate control procedures (e.g., Miller & Brucker, 1979), to moderate control procedures (e.g., Johnston, 1977b), to almost no control procedures at all (e.g., Johnston & Lethem, 1981).

Outline of the Present Study

This study examined the hypothesis that the criteria for defining motor-skills learning may be applicable to visceral learning as well. It was predicted that the four descriptors of motor-skills learning used by Johnston (1977a) would apply in the learning of bidirectional peripheral skin-temperature control, an instance of visceral (vasomotor) learning.

This study observed the course of learning skin-temperature control over a long series of training sessions for three groups: Group 1 subjects were given high-probability analogue biofeedback (i.e., biofeedback given during 100% of the training trials) plus instructions including strategies on how to accomplish temperature change in both directions, Group 2 subjects were given low-probability analogue biofeedback (i.e., biofeedback during 50% of the training trials) plus instructions-with-strategies, and Group 3 subjects were given only instructions-with-strategies (i.e., biofeedback during 0% of the training trials).

Johnston's first descriptor of motor-skills learning is that knowledge of results [feedback] is vital to learning. If this descriptor is also applicable to visceral learning it should be expected that subjects using temperature biofeedback plus instructions-with-strategies should show greater skin-temperature control during training trials than subjects using instructions-with-strategies alone; this can be considered to be the first experimental hypothesis. As has been previously explained, the literature is equivocal on this point, especially regarding the influence of biofeedback on ergotrophic as opposed to tropotrophic visceral response change. The present study required subjects to attempt both to increase their peripheral skin-temperature (a tropotrophic response) and decrease their peripheral skin-temperature (an ergotrophic response) several times in each training session so that each directional temperature change could be examined separately. In addition, a measure of the ability of subjects to respond differentially to increase as opposed to decrease-temperature trials was also examined since this measure has also been used to evaluate visceral control (e.g., Brener et al., 1969). In order to reduce the possibility that the skin-temperature recordings were influenced by artifact (such as might be produced by the subject's expired air reaching the temperature sensors and by excessive hand movements) or by gross somatic mediation the present study employed specially constructed hand holders and somatically constraining instructions.

Johnston's second descriptor of motor-skills learning is that, in general, the more information provided by the knowledge of results the better is learning. If this descriptor is also applicable to visceral learning it should be expected that subjects in Group 1 will show the greatest amount of temperature control, followed by subjects in Group 2, and trailed by subjects in Group 3; this can be considered to be the second experimental hypothesis.

Johnston's third descriptor of motor-skills learning is that performance improves with training. If this descriptor is also applicable to visceral learning it should be expected that the skin-temperature control should improve over training sessions and, perhaps, also within training trials; this can be considered to be the third experimental hypothesis. In view of the fact that the visceral learning literature suggested that studies running a greater number of training sessions were more likely to report improved performance over training, the present study used a comparatively large number of training sessions (i.e., 20 training sessions) to allow for an adequate test of this descriptor.

Johnston's fourth descriptor of motor-skills learning is that response control changes and becomes more specific with training (i.e., that response specificity develops). If this descriptor is also applicable to visceral learning it should be expected that the temperature changes evidenced by the hand receiving biofeedback should correlate closely with other physiological changes early in training but that such correlations should decrease significantly late in training; this can be considered to be the fourth experimental hypothesis. As has been previously pointed out, the visceral-learning literature is equivocal on the issue of the development of response specificity. One trend seemed to be that studies using large numbers of training sessions were more likely to observe the development of response specificity than studies using relatively small numbers of training sessions. This was, again, an important reason for the present study employing a large number of training sessions. The present study examined the possible development of response specificity both within the response system being trained (i.e., temperature changes in the hand contralateral to the one which the subject was requested to control) and outside the response system being trained (i.e., electromyogram, skin-conductance, and respiration-rate responses).

CHAPTER II

Method

Subjects

Eighteen City University of New York undergraduate student volunteers were randomly assigned to one of three experimental groups; each group contained 3 males and 3 females. The mean ages of subjects in Groups 1, 2, and 3 were 22.9, 27.9, and 24.0 years, respectively. These subjects were recruited by advertisements on bulletin boards and by requests made in undergraduate Psychology courses at Queens College. Two restrictions were imposed on the subjects; they could not have had any previous biofeedback experience or any serious, chronic medical condition. One female subject assigned to Group 2, became ill early in her training and was dropped from the study; she was replaced subsequently by another female volunteer. All subjects who participated in this experiment were entitled to receive a post-experiment-bonus session during which they were exposed to progressive muscle relaxation, meditation, and biofeedback procedures.

Apparatus

An Autogen model 2000b feedback thermometer using a Yellow Springs Instrument Company model 729 thermistor supplied subjects with analogue feedback reflecting their absolute skin temperatures. This system had an absolute accuracy of ±.3 degrees F, and a time constant of .3 seconds. Subjects were supplied with temperature biofeedback via an Autogen model G-5 remote meter displaying maximal temperature excursions of ±1 degree F from the subject's initial temperature level. This meter was capable of providing visually resolvable temperature changes of approximately ±.01 degree F. If the temperature shifts exceeded ±1 degree F the meter needle could be promptly recentered to a location which reflected the subject's current temperature level.

An Autogen model 60 feedback thermometer using a Yellow Springs Instrument Company model 729 thermistor monitored the skin temperature from the hand opposite (contralateral) to that receiving the temperature biofeedback. This system had the same absolute accuracy and time constant as the Autogen model 2000b. Scotch brand hair set tape was used to apply all temperature thermistors to the skin.

An Autogen model 1700 myograph analyzer using an Autogen EMG electrode assembly (which consisted of three gold-cup electrodes, each embedded in a plastic insulator disc) was used to monitor the subject's level of muscle tension. Each electrode cup was filled with Spectra brand electrode contact medium and was attached to the skin by means of an adhesive doughnut-shaped disc. The EMG bandpass was set at

100-200 Hz.

An Autogen model 3400 feedback dermograph using an Autogen dermograph electrode assembly which was similar in construction to the EMG electrode assembly (except that the two active electrodes were silver/silver chloride while the ground electrode was gold) was used to monitor the subject's skin-conductance level. Each electrode cup was filled with Johnson and Johnson K-Y surgical jelly and was attached to the skin by the same adhesive discs used to attach the EMG electrodes. The applied electrode potential was one of constant voltage (.3 volt root-mean-square) delivered via a 10 Hz AC low distortion sine wave.

The data monitored by the Autogen models 2000b, 60, 1700, and 3400 were fed first into four separate Autogen model I5000 analogue to digital optical isolator units and then into an Autogen model 5400 multi-channel data acquisition center. The data acquisition center controlled sampling durations and inter-sample intervals. In addition, it provided integrated averages and standard deviations of the sampled physiological activity. This information was then printed out on an Autogen model P5000 alphanumeric printer.

Respiration rate was recorded via a Parks open mercury strain gauge fed first into a Parks model 271 plethysmograph and then into a Grass model 5 polygraph.

The subject was seated on a padded recliner. Specially designed adjustable, "hand holders" were mounted on top of the arm rests of this chair. These hand holders were transparent plexiglass boxes which enclosed the subject's hands and forearms so that all surfaces of the box facing the subject were closed. These shields served to prevent artifact in temperature recording such as might be produced by the subject's expired air reaching the thermistors attached to the hands. In order to permit adequate circulation of air, all the surfaces of the box that faced away from the subject were left open (Taub & School, 1978). To prevent heat from being trapped around the thermistors the hands were placed on soft screening material, suspended rather tautly, several inches above the floor of the box. To prevent undue vertical hand movement a broad adjustable screen-filled frame was designed to be lowered over the hands in such a way as to allow no more than 2 cm of vertical hand movement. To insure comfort, the entire plexiglass box could be slid along a track to accommodate various arm dimensions. In addition pillows were placed under the proximal parts of the forearms to insure that the forearms remained in a level position and to enhance comfort.

A small box with three horizontally-spaced signal lights was placed on top of the remote temperature-feedback meter.

The lights on the extreme left and right were white, and the center light was red. The light on the extreme right was labeled "increase" while the light on the left was labeled "decrease." When the light on the extreme right was lit it signaled the subject to attempt to increase skin temperature (i.e., to move the meter needle to the right). When the light on the extreme left was lit it signaled the subject to decrease skin temperature (i.e., to move the meter needle to the left). When the center light was lit it signaled the subject to stop control and just to sit quietly.

The biofeedback laboratory was a comfortably decorated, fully carpeted, dimly illuminated room in which the subject's chair faced away from the experimenter and the physiological monitoring devices. The experimenter and the physiological devices were shielded from the subject's view by an opaque fiber-board room divider.

The room temperature was thermostatically controlled; the thermostat was set at 75 degrees F throughout the experiment. This relatively high room temperature was used to guard against the "drift effect," reported by Yates (1980), from affecting the subject's baseline skin temperature. Yates noted that with colder room temperatures (e.g., 68 degrees F) there was a tendency for some subjects' skin temperatures to drift downward toward the room temperature. This effect was very markedly attenuated when room temperature was raised to 77 degrees F. In addition, Johnston (1977b) used a room temperature of 75 degrees F and reported successful bidirectional control of peripheral blood flow as measured by pulse amplitude. Room temperature was monitored by an Electrotherm (M-99) electronic digital thermometer with a sensitivity of ±.1 degree F.

Procedure

This study consisted of two stages: (1) a pre-temperature-control stage and (2) a temperature-control stage. All subjects were told that they would have to participate in from two to three sessions per week, until they completed all sessions required in this study. They were free to participate in the post-experiment-bonus session anytime after completion of these sessions.

Pre-temperature-control stage. This stage consisted of two sessions: one 10-minute session followed by one 42-minute session (i.e., Sessions 1P and 2P). These sessions were given to all of the subjects in this study. The purpose of these sessions was to allow subjects to habituate to the laboratory and to the sensor-application conditions. It also allowed the experimenter an opportunity to detect and exclude any subjects showing extremely low peripheral skin-temperature levels (i.e., below 70 degrees F). However, no such subjects were identified.

About 20 minutes before the start of the first sessison

(1P) subjects completed a questionnaire, signed a consent form, and received a brief orientation to the biofeedback laboratory and to the study.

Just before the start of each session five physiological sensors (transducers) were applied to each subject. A temperature sensor (i.e., thermistor) was placed over the central whorl of the distal phalanx of the middle finger of each hand. Each temperature sensor was secured to the hand by tape which partially encircled the finger so as not to occlude blood flow. Following the suggestions of Taub and School (1978), 5 cm of sensor-lead wire immediately adjacent to the sensor, was taped to the subject's skin in order to prevent "stem effect" artifacts.

The EMG forearm-flexor sensor, consisting of one ground and two active electrodes, was placed on the anterior surface of the forearm of the dominant hand. The EMG sensor placement was determined by measuring the distance from the medial epicondyle of the humerus to the styloid process of the radius (across the anterior surface). The first active electrode was placed one third this measured distance, distal to the medial epicondyle of the humerus, the second active electrode was placed two inches (5.08 cm) distal to the first electrode (at a point of visible contraction during flexor movement of the middle finger), and the ground electrode was placed within six inches (15.24 cm) of either of the two active electrodes. To facilitate good electrode contact, the three areas where the electrodes were to be applied were rubbed thoroughly with a gauze pad saturated with alcohol just prior to electrode application.

The skin-conductance-level sensor consisting of one reference and two active electrodes was placed on the dominant hand in such a way that the two active electrodes were attached to the palmar (i.e., anterior) surface of the hand and the reference electrode was attached to the posterior surface of the hand.

A respiration-rate sensor, consisting of a mercury strain gauge attached to an adjustable velcro belt, was wrapped around the subject's lower thorax.

Subjects were told to remove any jewelry and to loosen any sleeves that could interfere with blood flow to the hands. Subjects were seated in a semi-recumbent position in the padded reclining chair. Both hands were placed inside the hand holders; this positioned the hands approximately at heart level. The subjects were then asked to sit quietly, remain awake, avoid changing breathing from normal resting patterns, move as little as possible (especially the hands) compatible with comfort, and refrain from attempting to change peripheral-skin temperature in any direction.

During these sessions the subjects wore headphones to attenuate any environmental noise and the room lights were dimmed. The data acquisition center sampled the physiological variables during the first 50 seconds of each of the 10 or 42 minutes making up a session. The resulting means and standard deviations were printed out during the final 10 seconds of each minute of the session.

Temperature-control stage. This stage consisted of 22 sessions (Sessions 1-22) which were always 42 minutes in duration. The same physiological sensors, monitoring devices, seating conditions, and data-sampling procedures that were used during the pre-temperature-control sessions were also used for these sessions.

The general format was the same for each of these 22 temperature-control sessions. Each session was divided into an initial "pre-control-training stabilization period" and a "control-training period." As suggested by Taub and School (1978), it is extremely important to have an initial stabilization period prior to the beginning of a temperature-feedback-training period since it is vital not to confuse the effects of general relaxation (reflected by peripheral-temperature increases which often occur at the start of a session) with the effects of specific training.

The control-training period contained four, five-minute "control-training trials," with each trial being followed by a three-minute "inter-trial interval." Thus, each of these control-training periods lasted a total of 32 minutes. In

Table 1 is the standard format for all 22 temperature-control sessions. During the inter-trial intervals the subjects were given instructions similar to those given during the pre-temperature-control sessions and the pre-control-training stabililzation periods of the temperature-control sessions (i.e., not to attempt to control their peripheral-skin temperature, etc.). Two of the four control-training trials required the subjects to increase the peripheral-skin temperature of their dominant hand (which was designated as the subject's temperature-control hand) while the other two trials required them to decrease the temperature of that hand. The order of the direction of the temperature-control was randomized across sessions (i.e., the six possible orders fulfilling the requirement of two increase and two decrease trials per session were randomized across sessions). This same random order was used for all subjects. The presence of a control-training trial, the requested direction of control during that trial, and the presence of an inter-trial interval were communicated to the subject by the illumination of the appropriate signal light.

Insert Table 1 about here

Six subjects were randomly assigned to each of three experimental groups: (1) the "high-probability biofeedback plus instructions-with-strategies" group (i.e., Group 1), (2) the "low-probability biofeedback plus instructions-with-strategies" group (i.e., Group 2), and (3) the "instructions-with-strategies only" group (i.e., Group 3).

During the control-training periods of the 1st temperature-control session (Session 1) and the 22nd experimental treatment session (Session 22) the subjects in all three groups were required to attempt to control their dominant hand temperatures in the requested directions while being given only the aid of instructions-with-strategies (See Table 2). These instructions-with-strategies were similar to those used by Johnston (1977b) and advised the subjects, " ... in general, temperature in the fingers will increase the more relaxed and unaroused you feel and will decrease the more alert and aroused you feel." In addition subjects were told about the use of thermal suggestions or imagery. They were advised that temperature in the fingers will increase if they think of their fingers as being warm or in a warm situation such as being submerged in warm water, and the temperature will decrease if they think of their fingers as being cold or in a cold situation such as being submerged in icy, cold water. Subjects were told that they could use either type of strategy (i.e., relaxation-arousal or thermal suggestions) or any combination of these strategies but they should use whatever strategy they sensed was working. All subjects were reminded that at all times they were requested to use mental, non-physical methods when attempting to change their skin temperatures. They were also reminded that during the entire control-training period they should sit quietly, remain awake, avoid changing breathing from normal resting patterns, and move as little as possible (especially the hands) compatible with comfort. Although all subjects were asked to try their best to control their skin temperature it was emphasized that they should not become concerned, upset, or impatient if they sensed that they were having difficulty in controlling their temperature. They were told that skin-temperature can be a difficult task to master and this is one reason why they will be given a lot of time to learn this type of control.

Insert Table 2 about here

However, during the control-training periods of the temperature-control sessions 2 to 21 subjects in Group 1 were given analogue-temperature biofeedback that covaried with the temperature of the dominant hand during all control-training trials (i.e., during a total of 80 training-control trials made up of 40 increase and 40 decrease trials). During the control-training periods of the temperature-control sessions 2 to 21 subjects in Group 2 were given the same type of biofeedback for only one-half of the control-training trials (i.e., during only 20 of the increase and 20 of the decrease control-training trials). The order of exactly which trials received biofeedback and which did not was determined randomly for each direction. This same order was used for all subjects in Group 2. During the control-training periods of the temperature-control sessions 2 to 21 subjects in Group 3 were never given biofeedback during any of the control-trials. Group 3 subjects were given an additional session (i.e., Session 23) during which they attempted to control temperatures with biofeedback. It should be emphasized that all groups of subjects were always provided with instructions-with-strategies during every temperature-control session irrespective of the presence or absence of biofeedback.

Subjects in Groups 1 and 2 were given instructions on the use and interpretation of the remote-temperature-biofeedback meter several minutes before the start of the second experimental-treatment session. These subjects were also told that the onset of a small, dimly-glowing spotlight, which illuminated the meter face, signified that biofeedback information was available from the meter during that control-training trial. This spotlight was on during every control-training trial for subjects in Group 1. However, for subjects in Group 2, a trial without the onset of the spotlight meant that they had to attempt control without the aid of biofeedback. Of course, subjects in Group 3 were never permitted to monitor the meter. The important points of all instructions were given to the subjects in written form. Following this, all key points and elaborations were given verbally by the experimenter from a prepared outline. The subjects were free to reexamine the written instructions or ask the experimenter to explain any procedural questions before the start of each session.

Taub and School (1978) reported on the importance of the experimenter adopting a "friendly attitude" (i.e., using first names, encouraging development of a friendly relationship, frequent eye contact, etc.) as contrasted to adopting an "impersonal attitude" (i.e., using last names, discouraging extraneous conversation, avoiding eye contact, etc.) with subjects learning skin-temperture control; the friendly attitude produced very much greater skin-temperature control than did the impersonal attitude. Accordingly, the experimenter in the present study adopted a friendly attitude toward all subjects in the study.

Room temperature was monitored six times per session; readings were taken during the first minute of each session, during the baseline minute for each of the four control trials (i.e., during minutes 10, 18, 26, and 34), and during the last minute of each session (i.e., during minute 42). Outside temperature readings were obtained by calling the local weather bureau just before the start of each session.

There are various methods of assessing response change in the area of physiological feedback. The following methods were chosen to assess particular facets of the subject's response in the various experimental conditions.

Determination of temperature change. The temperature-change scores during increase or decrease temperature-control trials were determined by subtracting the integrated average temperature during the baseline minute of that control trial from the integrated average temperature achieved during control in each of the five minutes making up that trial for each subject. The most often used scores were the differences between the fifth minute of the control trial and the baseline minute of that trial. That is the "Change from baseline during increase temperature trials" = (Temperature achieved during control in minute 5 of the increase-temperature trial) - (Temperature during the baseline minute of that trial), and the "Change from baseline during decrease-temperature trials" = (Temperature achieved during control in minute 5 of the decrease-temperature trial) - (Temperature during the baseline minute of that trial). Thus, a positive value for a "Change from baseline" indicated a net increase in temperature relative to baseline, a negative value indicated a net decrease in temperature relative to baseline, and a zero value indicated no net change in temperature relative to baseline during that particular minute of the control trial.

Determination of differential temperature change. The "difference of the differences" (DOD) is a measure of the ability of a subject to respond differentially to an "increase" as opposed to a "decrease" temperature-control condition. It is expressed as DOD = (Change from baseline during increase-temperature trials) - (Change from baseline during decrease-temperature trials). Thus, a positive DOD value indicated the subject was achieving a relatively greater temperature decrease during decrease-temperature trials than during increase-temperature trials or a relatively greater temperature increase during increase-temperature trials than during decrease-temperature trials. This would suggest that the subject was responding differentially to the increase- versus the decrease-temperature conditions in the "specified" direction. A negative DOD value indicated the subject was achieving a relatively greater temperature decrease during increase-temperature trials than during decrease-temperature trials or a relatively greater temperature increase during decrease-temperature trials than during increase-temperature trials. This would suggest that the subject was responding differentially to the increase- versus the decrease-temperature conditions but in the "wrong" direction. A zero DOD value indicated the subject was not responding differentially to increase as opposed to decrease-temperature conditions.

Various group comparisons were used to assess the effects of biofeedback as opposed to no-biofeedback conditions and to assess the effects of the different probabilities of biofeedback on skin-temperature control. The following group comparisons were employed.

Biofeedback versus no-biofeedback conditions. It will be recalled that each group contained six subjects and that all temperature-control trials during which the subject was asked to increase or decrease finger temperature employed biofeedback for Group 1, one half of the trials employed biofeedback for Group 2, and none of the trials employed biofeedback for Group 3. In order to test the effects of biofeedback, over the 20 training sessions (Sessions 2-21), two types of subject comparisons were employed. The first compared all of the biofeedback trials of Group 1 plus all of the biofeedback trials of Group 2 (i.e., *n* = 12) with all of the no-biofeedback trials of Group 3 (i.e., *n* = 6). The second compared all biofeedback trials of Group 1 (i.e., *n* = 6) with all of the no-biofeedback trials of Group 2 plus all of the no-biofeedback trials of Group 3 (i.e., *n* = 12). These unequal *n* comparisons were used in order to maximize the size of the *n* in the various cells of the experimental design (i.e., analyses of variance) examining the effects of the presence or absence of biofeedback on bidirectional skin-temperature control.

Differential exposure to biofeedback. In order to test the effects of different probabilities of biofeedback, the three experimental treatment groups were compared to each other in the following way. All of the temperature-control trials of Group 1 (all of which were biofeedback trials) were compared with all of the temperature-control trials of Group 2 (half of which were biofeedback trials and half of which were no-biofeedback trials) and with all of the temperature-control trials of Group 3 (all of which were no-biofeedback trials).

All of the *p* values used in the analyses of variance and correlational analyses were based on two-tailed tests except for the comparison of the performance of trials during which subjects used biofeedback to those trials without biofeedback (i.e., Groups 1 + 2 with biofeedback vs. Group

3 and the Group 1 vs. Groups 2 no-biofeedback + 3 contrasts) during the 20 training sessions (Sessions 2-21); these comparisons used one-tailed tests. One-tailed tests were used since the literature in vasomotor learning reports either that trials with biofeedback plus instructions-with-strategies produce greater control than trials using instructions-with-strategies alone or that there is no difference between these conditions; there are no reports of the addition of biofeedback to instructions-with-strategies producing poorer performance than instructions-with-strategies alone.

CHAPTER III

Results

An overview of the results of this study indicates that trials with biofeedback produce greater differential control of peripheral skin temperature (i.e., responding differentially to increase as opposed to decrease-temperature instructions) than trials with no biofeedback. It appears that the finding of the differential control is due primarily to the benefit of biofeedback over no biofeedback during the decrease temperature-control trials. Varying the probability of biofeedback seems to have no effect on temperature control. There is no evidence that temperature control improves over training (i.e., across sessions) but some indication that control improves over the five minutes of a trial. Although, temperature control does not improve over sessions, response specificity seems to develop over training in the biofeedback condition as compared to the no-biofeedback condition. This is especially evident in the case of temperature changes in the contralateral hand and during the decrease-temperature control trials.

The statistical analysis of subjects in the biofeedback condition who are "relatively successful" and those who are "relatively unsuccessful" in learning differential temperature control (i.e., having DOD Scores greater than +.25 degrees F and less than +.25 degrees F, respectively) reveals the following. Unlike the unsuccessful subjects, the successful subjects show overall net "increases" in temperature (relative to baseline) during increase temperature-control trials. Both the successful and unsuccessful subjects show net "decreases" in temperature during decrease temperature-control trials. Furthermore, the successful subjects develop response specificity over training, especially with reference to temperature changes in the contralateral hand; this specificity is evident mainly during the decrease temperature-control trials.

Age, Ambient Temperature, and Baseline Analyses

Both the age of the subject and the ambient temperature were examined to rule out the possibility that these variables might have acted as confounding variables in the various Group comparisons. Age was examined since the study by Lynch et al. (1976) suggested that age of the subject might be related to the ability to control skin temperature (specifically, they reported that children between the ages of 6 and 12 might control temperature better than adults). Since skin temperature can be affected by outside temperature (Taub and School, 1978) and room temperature (Yates, 1980) these variables were also examined. It was particularly important to make sure that the room temperatures were substantially above 68 degrees F in order to prevent the "drift effect" and to make sure that the room temperatures were equivalent for all the groups compared in the statistical analyses. In addition, the baseline skin temperatures were examined.

Age. The mean ages (and the *SD*s of the ages) of subjects in Groups 1, 2, and 3 were 22.9 (6.8), 27.9 (9.4), and 24.0 (4.3) years, respectively. There were no significant between-group differences in the ages of subjects in Groups 1, 2, and 3, *F* (2, 15) = .79, *p* > .10. There were also no significant differences in the ages of Groups 1 + 2 versus Group 3, *t* (16) = .38, *p* > .10, or in Group 1 versus Groups 2 + 3, *t* (16) = -.84, *p* > .10.

Ambient temperatures. The mean outside temperatures (and *SD*s) in degrees F during the 20 training sessions (i.e., Sessions 2 - 21) for Groups 1, 2 and 3 were 61.18 (13.32), 59.71 (19.00), and 50.86 (15.32) degrees F, respectively. These did not differ significantly, *F* (2, 15) = .73, *p* > .10; nor did those of Groups 1 + 2 versus Group 3, *t* (16) = 1.22, *p* > .10, or of Group 1 versus Groups 2 + 3, *t* (16) = .74, *p* > .10.

The mean room temperatures (and mean *SD*s), made up of six observations per session, during the 20 training sessions for Groups 1, 2, and 3 were 75.29 (.79), 75.42 (.96), and 75.68 (.54) degrees F, respectively. In Table 3 (top panel) is a summary of a 3 x 6 (Groups: 1, 2, 3 x Room Temperature: 1 - 6) mixed design analysis of variance on the data. There were no significant main effects or interactions. Similar analyses of variance contrasting Groups 1 + 2 with 3 (see Table 3, middle panel) and Groups 1 with 2 + 3 (see Table 3, bottom panel) also showed no significant main effects or interactions. These analyses indicate that all groups were trained under equivalent room temperatures and that these temperatures were well above those described as causing "drift effect" (i.e., 68 degrees F). The six within-session mean room temperatures in degrees F averaged over all groups and sessions were 75.47, 75.45, 75.46, 75.46, 75.47, 75.47, respectively; this indicates no trend for the room temperature warming or cooling over the course of a temperature-training session.

Insert Table 3 about here

Baseline. The mean skin temperatures (and _SDs_) of the control hand (the hand whose skin temperature the subject is trying to control) during the running baselines over the 20 training sessions combining all increase and decrease temperature-control trials for Groups 1, 2, and 3 were 91.60 (4.47), 91.03 (3.23) and 90.44 (5.53) degrees F, respectively. There were no significant differences in these baseline temperatures $F\ (2, 15) = .10$, $p > .10$. There were also no significant differences in the baseline temperatures of Groups 1 + 2 (with biofeedback) versus 3, $t\ (16) = .35$, $p > .10$, or in Group 1 versus Groups 2 (no biofeedback) + 3, $t\ (16) = .34$, $p > .10$.

Hypothesis 1 - That Knowledge of Results (Feedback) is Vital to Learning

Johnston's first descriptor of motor-skills learning is that knowledge of results (feedback) is vital to learning. If this descriptor is also applicable to visceral learning it should be expected that subjects using temperature biofeedback plus instructions-with-strategies should show greater skin-temperature control during training trials than subjects using instructions-with-strategies alone. It will be recalled that this was assessed by two types of analyses. The first analysis compared all of the biofeedback trials of Group 1 plus all of the biofeedback trials of Group 2 with all of the no-biofeedback trials of Group 3. The second alternate analysis compared all of the biofeedback trials of Group 1 with all of the no-biofeedback trials of Group 2 plus all of the no-biofeedback trials of Group 3. Both types of analyses were applied to the three temperature-control scores that were employed in the present study: difference of the differences (DOD), changes from baseline during increase-temperature control trials, and changes from baseline during decrease-temperature control trials.

DOD scores. Figure 1 plots DOD scores for temperature change in the control hand, over all 20 training sessions, based on the differences between the fifth minute of control trials and the baseline minute of these trials. The left panel of Figure 1 contrasts the DOD scores for the "biofeedback" (i.e., Groups 1 + 2 with biofeedback) and the "no-biofeedback" (i.e., Group 3) conditions. The alternate, similar analysis is seen in the right panel of Figure 1 which contrasts the DOD scores for the "biofeedback" (i.e., Group 1) and the "no-biofeedback" (i.e., Groups 2 no-biofeedback + 3) conditions. The means (and SDs) for the DOD scores in degrees F for Groups 1 + 2 with biofeedback were +.49 (.60), for Group 3 were -.12 (.36), for Group 1 were +.46 (.81), and for Groups 2 no-biofeedback + 3 were -.08 (.44).

Insert Figure 1 and Table 4 about here

In Table 4 is a summary of two, 2 x 4 (Groups x Quarters of Training) mixed design analyses of variance on the DOD acores. The first analysis in Table 4 contasts Groups 1 + 2 (biofeedback) with Group 3 and shows a main effect of Groups that is significant beyond the .05 level. The second analysis in Table 4 contrasts Group 1 with Groups 2 (no-biofeedback) + 3 and shows a main effect of Groups that is also significant beyond the .05 level. This indicates that subjects with biofeedback achieved significantly greater DOD scores than those without biofeedback. Thus as evaluated by the DOD scoring method, it would appear that knowledge of results provided by visual biofeedback is vital to learning. As such, the acquisition of an apparently visceral response follows the same principles noted for motor-skills learning.

Changes from baseline. In the left panel of Figure 2 are the "changes from baseline" during increase and decrease temperature trials in the control hand, over the 20 training sessions, based on the differences between the fifth and baseline minutes of each trial for the biofeedback (i.e., Groups 1 + 2 with biofeedback) as opposed to the no-biofeedback (i.e., Group 3) conditions. In the right panel of Figure 2 is the same information for the biofeedback (i.e., Group 1) as opposed to the no-biofeedback (i.e., Groups 2 no-biofeedback + 3) conditions. In Table 6 (Minute 5) are the means (and *SD*s) for all of these Group contrasts.

Insert Figure 2, Table 5 and Table 6 about here

In Table 5 is a summary of four, 2 x 4 (Groups x Quarters of Training) mixed design analyses of variance on the changes from baseline during either "increase" or "decrease" temperature-control trials for the two different group contrasts. Both of the main Groups effects for the decrease condition are significant beyond the .05 level. This indicates that, during decrease temperature-control trials, subjects with biofeedback achieve significantly greater temperature decreases than those without biofeedback. All other main effects and interactions for the decrease trials as well as all of the main effects and interactions for the increase trials are not significant. Thus, while knowledge of results may be vital for learning to control temperature decreases it is of no benefit in learning to control temperature increases. Therefore, the findings for the DOD scores and the changes from baseline during decrease temperature-control trials but not during increase temperature-control trials support the first hypothesis.

Hypothesis 2 - That in General the More the Information Provided by Knowledge of Results the Better is Learning

Johnston's second descriptor of motor-skills learning is that, in general, the more information provided by knowledge of results the better is learning. If this descriptor is also applicable to visceral learning it should be expected that subjects in Group 1 will show the greatest amount of temperature control, followed by subjects in Group 2, and trailed by subjects in Group 3. The DOD scores and the changes from baseline during increase and during decrease temperature-control trials were considered separately.

Effects of probability of biofeedback on DOD scores. In Figure 3 are the DOD scores in the control hand, averaged over the 20 training sessions, based on the differences between the fifth and baseline minutes of each trial for the three groups receiving different probabilities of biofeedback (i.e., Group 1 with 100%, Group 2 with 50%, and Group 3 with 0% of the temperature-conrol trials containing biofeedback). The DOD scores for Group 2 combined all of the biofeedback trials and all of the no-biofeedback trials. The means (and SDs) for the DOD scores in degrees F of Group 1, 2, and 3 were +.46 (.81), +.24 (.35), and -.12 (.36), respectively. An analysis of variance of these DOD scores indicated that although the direction of differences in the DOD scores among Groups 1, 2 combined, and 3 is in the expected direction, these differences were not significant, F (2, 15) = 1.77, p > .10.

Insert Figures 3 and 4 about here

Changes from baseline. In Figure 4 are the changes from baseline during increase and decrease temperature-control trials in the control hand, averaged over the 20 training sessions, based on the differences between the fifth and baseline minutes of each trial for the three groups receiving different probabilities of biofeedback. There seem to be no clear cut differences among the three groups in the changes from baseline during increase trials but the direction of differences among the groups during decrease trials appears to be in the expected direction. However, a separate analysis of variance for each direction indicates that there are no significant differences among Groups 1, 2 combined, and 3 in the changes from baseline during increase trials, F (2, 15) = .17, $p > .10$ or during decrease trials, F (2, 15) = 2.53, $p > .10$.

Hypothesis 3 - That Performance Improves with Amount of Training

Johnston's third descriptor of motor-skills learning is that performance improves with training. If this descriptor is also applicable to visceral learning, skin-temperature control should improve over training sessions and, perhaps, also within training trials. Changes over training sessions were evaluated by examining changes in performance over the four quarters of training while changes within trials were evaluated by examining the changes in performance over the five minutes making up a temperature-control trial.

Over quarters of training. In Figure 5 are the DOD scores in the control hand for successive quarters of training based on the differences between the fifth and baseline minutes of each trial contrasting biofeedback (i.e., Groups 1 + 2 with biofeedback and Group1) and no-biofeedback (i.e., Group 3 and Groups 2 no-biofeedback + 3) conditions. The already mentioned analyses of variance on these DOD scores (see Table 4) show that although there are significant Groups effects there are no significant Quarter of Training main effects or Quarter of Training x Groups interactions in both Group contrasts. This indicates that there are no differences in the DOD scores in any of the quarters of training for the average of the biofeedback and the no-biofeedback conditions or for either of these conditions alone.

Insert Figure 5 about here

The already mentioned analyses of variance on the changes from baseline during increase and decrease temperature-control trials (see Table 5) show that although there are significant Groups effects for the decrease trials, there are no significant Quarter of Training main effects or Quarter of Training x Groups interactions in either the increase or decrease directions for both Group contrasts.

In Figure 6 are the changes from baseline during increase and decrease temperature-control trials in the control hand for successive quarters of training based on the differences between the fifth and baseline minutes of each trial, contrasting Group 1, Group 2 (plotting separately biofeedback and no-biofeedback trials) and Group 3.

Thus it appears, unlike the case of motor-skills learning, additional training does not seem to have a durable effect on the acquisition of a visceral skill.

Insert Figure 6 about here

Over the five minutes of a trial. In Figure 7 are the DOD scores in the control hand, averaged over the 20 training sessions based on the differences between each of the five consecutive minutes of a trial and the baseline minute of that trial for both group contrasts of the with-biofeedback and the no-biofeedback conditions. This shows a steady growth of correct differential responding over the five minutes of a trial for subjects with biofeedback but not for those without biofeedback. In Table 7 is a summary of the mean DOD scores (and _SD_s) averaged over the 20 training sessions for each of the five consecutive minutes for both group contrasts of the biofeedback and no-biofeedback conditions.

Insert Figure 7, Table 7, and Table 8 about here

In Table 8 is a summary of two, 2 x 4 x 5 (Groups x Quarters of Training x Minutes in a Trial) mixed-design analyses of variance on the DOD scores, contrasting the five consecutive minutes of a trial for each consecutive quarter of training for both group contrasts separately. The top panel of Table 8 contrasts Groups 1 + 2 with biofeedback with Group 3 and shows a Groups main effect that is significant beyond the .05 level and a Minutes x Groups interaction that is significant beyond the .001 level. The significant Groups main effect indicates that, averaged over the four quarters of training and the five minutes of a trial, subjects with biofeedback showed higher DOD scores than those without biofeedback. To identify the meaning of the significant Minutes x Groups interaction "planned comparisons" (using contrast codings) were made for each of the five mean DOD scores for each minute of a trial averaged over quarters for Groups 1 + 2 with biofeedback and for the five means for Group 3. Since it had been predicted that there would probably be significantly greater Group differences between the late minutes of a trial compared to the early minutes of a trial, the interaction comparisons chosen were between the first minute and each of the successive four minutes of a trial. Such contrasts showed significant Groups x Minutes interactions for minutes 1 vs. 5, F (1,64) = 16.48, $p < .001$, for minute 1 vs. 4, F (1,64) = 15.16, $p < .001$, for minutes 1 vs. 3, F (1,64) = 8.64, $p < .01$, but not for minutes 1 vs. 2, F (1,64) = 2.17, $p > .10$. This pattern of interaction indicates that there were significantly greater group differences in the DOD scores for minutes 5, 4, and 3 than there were for minute 1 but that there were no significantly greater Group differences for the minute 2 scores than there were for the minute 1 scores (this agrees quite closely with what is shown visually in the left half of Figure 7). Another examination of the Minutes x Groups interaction combined the late minutes (i.e., minutes 2 + 3 + 4 + 5) vs. minute 1 and showed a significant interaction, F (1,64) = 15.29, $p < .001$. This reinforces the notion that there were significantly greater group differences during the late minutes of a trial than there were during the first minute. The bottom panel of Table 8 contrasts Group 1 with Group 2 no-biofeedback + 3 and shows a Groups main effect that is significant beyond the .05 level and a Minutes x Groups interaction that is also significant beyond the .05 level. These findings are similar to those in the previously discussed group contrast and are open to similar interpretation. To identify the meaning of the significant Minutes x Groups interaction planned comparisons were again made for each of the five mean DOD scores for each minute of a trial averaged over quarters for Group 1, and for the five means for Group 2 no-biofeedback + 3. The interaction comparisons chosen were again between the first minute of a trial and each of the successive four minutes of a trial. Such contrasts showed significant Groups x Minutes interactions for minutes 1 vs. 5, F (1,64) = 10.48, $p < .01$, for minutes 1 vs. 4, F (1,64) = 7.40, $p < .01$, but not for minutes 1 vs. 3, F (1, 64) = 3.22, $p > .05$ or for minutes 1 vs. 2, F (1,64) = .87, $p > .25$. This pattern of interaction indicates that there were significantly greater Group differences in the DOD scores for minutes 5 and 4 than there were for minute 1 but that there were no significantly greater Group differences in the DOD scores for minutes 3 and 2 than there were for minute 1 (this agrees quite closely with what is shown visually in the right half of Figure 7). The other examination of the Minutes x Groups interaction which combined the late minutes (i.e., minutes 2 + 3 + 4 + 5) versus minute 1 also showed a significant interaction, F (1,64) = 7.54, $p < .01$. This again reinforces the notion that there were significantly greater Group differences during the late minutes of a trial than there were during the first minute. This Groups contrast also shows a significant Minutes x Quarters interaction, F (12, 192) = 1.89, $p < .05$. However, since the other Groups contrast did not find this interaction to be significant, F (12, 192) = .60, $p > .25$, and since this interaction did not involve any "Group" differences, the exact nature of this interaction was not examined.

In Table 6 is a summary of the mean changes from baseline (and SDs) during increase and decrease temperature-control trials averaged over the 20 training sessions for each of the five consecutive minutes of a trial for both group contrasts of the biofeedback and no-biofeedback conditions. The only steady growth of control over the five minutes of a trial is in the biofeedback conditions in the "decrease" direction.

Insert Table 9 and Table 10 about here

In Tables 9 and 10 are summaries of four, 2 x 4 x 5 (Groups x Quarters of Training x Minutes in a trial) mixed design analyses of variance on the changes from baseline during increase (Table 9) and during decrease (Table 10) temperature-control trials for both group contrasts separately. Table 9 indicates that there were no significant main effects or interactions for the changes from baseline during increase temperature trials for both group contrasts.

However, the top panel in Table 10 contrasting Groups 1 + 2 with biofeedback vs. 3 for the changes from baseline during decrease-temperature trials indicates that there is a Groups main effect that is significant beyond the .05 level, a Minutes main effect that is significant beyond the .05 level, and a Minutes x Groups interaction that is significant beyond the .01 level. The significant Groups main effect shows that averaged over the four quarters of training and the five minutes of a trial, the subjects with biofeedback decreased their skin temperatures more than those without biofeedback when instructed to do so. The significant Minutes effects shows that averaged over both groups and over quarters of training there is a significant difference in the temperature changes from baseline among the five minutes of a decrease-temperature trial. To obtain a clearer meaning of exactly where these changes occurred the Shaffer-Welsch Stepwise Multiple Comparison Procedure (Ramsey, 1981; Welsch, 1977) was used. It indicated that the mean temperature change for Minute 5 (mean = -.47 degrees F) was significantly lower than for Minute 1 (mean = -.20 degrees F), $p < .05$ and that Minute 4 (mean = -.41 degrees F) was significantly lower than Minute 1, $p < .05$. None of the other paired-minute comparisons were significant. To identify the meaning of the significant Minutes x Groups interaction the "planned comparisons" already described for the DOD scores were used for the changes from baseline during decrease temperature-control trials. Such comparisons showed significant Minutes x Groups interactions for minutes 1 vs. 5, F (1,64) = 10.03, $p < .01$, for minutes 1 vs. 4, F (1, 64) = 11.06, $p < .01$, for minutes 1 vs. 3, F (1, 64) = 9.37, $p < .01$, for minutes 1 vs. 2, F (1, 64) = 5.32, $p < .05$, and for minutes 1 vs. 2 + 3 + 4 + 5, F (1, 64) = 14.07, $p < .001$. This pattern of interaction indicates that there were significantly greater Group differences in the changes from baseline during decrease-temperature trials for the late minutes of a trial than for the initial minute of a trial.

The bottom panel in Table 10 contrasting Group 1 vs. Groups 2 no-biofeedback + 3 for the changes from baseline during decease-temperature trials indicates that there is a significant Groups main effect that is significant beyond the .05 level, a significant Minutes main effect that is significant beyond the .001 level and a significant Minutes x Groups interaction that is significant beyond the .01 level. As was the case in the previous groups contrast for the decrease scores the meaning of the Groups and Minutes main effects are open to similar interpretations. Again, to obtain a clearer meaning of where the Minutes differences occurred, the Shaffer-Welsch Stepwise Multiple Comparison Procedure was used. It showed that the mean temperature change for Minute 5 (mean = -.39 degrees F) was significantly lower than Minute 1 (mean = -.17 degrees F), $p < .05$ but none of the other paired-minute comparisons were significantly different. To identify the meaning of the significant Minutes x Groups interaction planned comparisons were again employed. Such comparisons showed significant Minutes x Groups interactions for minutes 1 vs. 5, $F(1, 64) = 14.29$, $p < .001$, for minutes 1 vs. 4, $F(1, 64) = 9.89$, $p < .01$, for minutes 1 vs. 3, $F(1, 64) = 5.09$, $p < .05$, for minutes 1 vs. 2 + 3 + 4 + 5, $F(1, 64) = 11.14$, $p < .01$, but not for minutes 1 vs. 2, $F(1, 64)$ $p > .10$. Again this pattern of interaction indicates that there were significantly greater Group differences in the changes from baseline during decrease-temperature trials for the late minutes of a trial than for the initial minute of a trial.

Taken together these analyses indicate that performance improves with training over the five minutes of a trial for the DOD scores and for the changes from baseline during decrease-temperature trials but not during increase-temperature trials. This could be taken as agreeing, in part, with Johnston's third descriptor.

Descriptor 4 - That Control Changes and Becomes More Specific with Training

Johnston's fourth descriptor of motor-skills learning is that control changes and becomes more specific with training (i.e., that response specificity develops). If this descriptor is also applicable to visceral learning it should be expected that the temperature changes evidenced by the hand receiving biofeedback should correlate closely with other physiological changes early in training but that such correlations should decrease significantly late in training.

In the present study the possible development of response specificity was evaluated by assessing the changes in correlation from early to late stages of training for temperature changes (the response being trained) in the control hand (TP1) versus the changes in the four other physiological variables being monitored. These other variables were (1) temperature in the contralateral hand (TP2), (2) muscle tension in the control hand (EMG), (3) dermograph or skin conductance in the control hand (DER), and (4) respiration rate (RESP). For all of the physiological variables the measures employed are the DOD scores based on the differences between the fifth minute of the control trials and the baseline minute of these trials for the biofeedback (i.e., Groups 1 + 2 with biofeedback) and the no-biofeedback (i.e., Groups 2 no biofeedback + 3) conditions. The changes in correlation from early to late stages of training were evaluated in two analyses. One compared the changes in correlation between TP1 and the other variables for the "first" and "fourth" _quarter_ of training for each condition separately. The second analysis compared these changes in correlation for "first" and the "last" _twentieth_ of training for each condition separately. Since the scoring of respiration rate (by hand) was extremely time consuming it was decided to score only the first and last twentieth of training. Therefore, the changes in correlation for respiration rate were evaluated solely by the first to last twentieth analysis. All of the other variables were examined in both analyses.

To assess whether a significant change in correlation has occurred from the first to the fourth quarter or from the first to the last twentieth of training in the biofeedback and the no-biofeedback conditions separately a technique for comparing two coefficients of correlation, in dependent samples, with no subscripts in common was employed (Johnson & Jackson, 1959, 353-356). This technique yields a "normal deviate" (i.e., z - score value) that is used as the test of significance of the difference between the two correlations.[1]

TP1 versus TP2. In Table 11 is a summary of the correlations of the DOD scores between TP1 and TP2, EMG, and DER for each of the four quarters of training for the with-biofeedback and the no-biofeedback conditions separately. Probability values are shown for the correlations in each quarter if that correlation is significantly greater than zero. In addition, Table 11 shows the normal deviate (z) scores which determine whether a significant "change in correlation" has occurred between the first and the fourth quarters of training for each condition. The top row of Table 11 shows that the correlations between changes in temperature of the control and the contralateral hand are high and positive in the first quarter but clearly drop over quarters for subjects with biofeedback. The reduction in correlations from the first to the fourth quarter is highly significant, $p < .0001$. However, the situation is quite different for subjects without biofeedback; their correlations between TP1 and TP2 remain high and positive over all four quarters of training and there is no significant reduction in correlation from the first to the last quarter. The significant "reduction" in correlations seen in the biofeedback condition indicates that response specificity is developing over training within the response system (peripheral-skin temperature) being trained.

Insert Table 11 about here

In an attempt to assess whether the reduction in correlations of the DOD scores is due primarily to changes in correlations during increase or during decrease temperature-control trials, a separate analysis was performed. Specifically, correlations of changes from baseline during increase and during decrease temperature-control trials were done for the first and fourth quarters of training for subjects in the biofeedback condition. The correlations for the increase direction for quarters one and four were +.98 and +.97, respectively. There was no significant difference between these correlations, normal deviate (z) = .32. The correlations for the decrease direction for quarters one and four were +.98 and +.46, respectively. There was a significant reduction in correlations, normal deviate (z) = 3.43, $p <$ .001. This indicates that the response specificity seems to be developing with training during decrease but not during increase temperature-control trials.

In Table 12 is a summary of the correlations of the DOD scores between TP1 and TP2, EMG, DER, and RESP for the first and last twentieth of training for the biofeedback and the no-biofeedback conditions separately. In addition, Table 12 shows the normal deviate (z) scores which assess whether a significant "change in correlation" has occurred between the first and last twentieth of training for each condition. The top rows of the top and bottom panels of Table 12 show that the correlations between TP1 and TP2 drop significantly for subjects with biofeedback, *p* < .01, but not for subjects without biofeedback. These findings are very similar to those comparing the correlations of the first and fourth quarters of training and are, therefore, open to similar interpretations.

Insert Table 12 about here

TP1 versus EMG. The middle rows of the top and bottom panels of Table 11 show that correlations of DOD scores between temperature of the control hand and muscle tension of that hand do not change systematically over the four quarters of training and that there is no significant change in correlation from the first to the last quarter for either condition.

The second rows of the top and bottom panels of Table 12 show no significant change in the correlation of the DOD scores between TP1 and EMG from the first to the last twentieth of training for subjects with biofeedback. There does seem to be a significant change in correlations between TP1 and EMG for subjects without biofeedback, *p* < .05, but the change is not toward specificity (i.e., the correlation values increase rather than decrease over training).

TP1 versus DER. The bottom rows of the top and bottom panels of Table 11 show that correlations of the DOD scores between temperature of the control hand and skin conductance of that hand do not change systematically over the four quarters of training. Furthermore, there is no significant change in correlation from the first to the last quarter for both the with-biofeedback and the no-biofeedback conditions.

The third rows of the top and bottom panels of Table 12 show a significant reduction in the correlations of the DOD scores between TP1 and DER from the first to the last twentieth of training for subjects with biofeedback, $p < .01$, but not for subjects without biofeedback. This may indicate the emergence of response specificity developing in a system outside the one being trained. However, this indication must be viewed with reservation since the analysis of changes over quarters does not support the growth in specificity between TP1 and DER.

TP1 versus RESP. The bottom rows of the top and bottom panels of Table 12 show a reduction in the correlation of the DOD scores between temperature of the control hand and respiration rate from the first to the last twentieth of training for subjects with biofeedback, however, this reduction is not significant. There is an increase in the correlations between TP1 and RESP for subjects in the no-biofeedback condition from the first to the last twentieth of training, but this increase is not significant either (and not in the direction of specificity). Thus, there is little evidence for response specificity developing between TP1 and RESP over training.

Taken together these results indicated that response specificity seemed to develop over training within the response system being trained (i.e., between TP1 and TP2) but not between the response system being trained and the other physiological response systems (i.e., between TP1 and EMG, DER, or RESP) in the biofeedback but not in the no-biofeedback condition.

Summary of Statistical Tests

A summary of the statistical tests done to evaluate each of the four hypotheses during the twenty temperature-control training sessions follows.

Hypothesis 1. Four of the five Groups comparisons using DOD scores and four of the five Groups comparisons using changes from baseline during decrease-temperature control trials indicated that the biofeedback condition produced significantly greater control of skin temperature than the no-biofeedback condition (see Anovas in Tables 4, 5, 8, 10 and the Anovas contrasting Groups 1, 2, and 3). However, all of the five Groups comparisons using changes from baseline during increase temperature-control trials indicated no difference in control of skin temperature between the biofeedback and no-biofeedback conditions (see

Anovas in Tables 5, 9 and the Anovas contrasting Groups 1, 2, and 3).

Hypothesis 2. All three of the Anovas using DOD scores, changes from baseline during increase temperature-control trials, and changes from baseline during decrease temperature-control trials indicated no difference in control of skin temperature among the three Groups trained under different probabilities of biofeedback (see Anovas contrasting Groups 1, 2, and 3).

Hypothesis 3. All of the twelve Quarters comparisons and all of the twelve Quarters x Groups interactions using DOD scores, and changes from baseline during both increase and decrease temperature-control trials indicated no differences in temperature control over the quarters of training.

Both of the two Minutes x Group interactions for the DOD scores (see Table 8) and both of the two Minutes x Group interactions for the changes from baseline during decrease temperature-control trials (see Table 10) indicated significantly greater temperature control for the feedback compared to the no-feedback groups during the late minutes of a trial than during the initial minute of a trial. However, both of the two Minutes x Groups interactions for the changes from baseline during increase temperature-control trials (see Table 9) showed no significant difference in temperature control for the feedback compared to the no-feedback groups during the late minutes of a trial than during the initial minute of a trial.

Hypothesis 4. Both of the two tests of correlation changes using DOD scores from early to late stages of training between TP1 and TP2 indicated significant reductions in correlations over training for the biofeedback but not for the no-biofeedback groups scores (see Tables 11 and 12). The two tests for reductions in correlation from the first to the last quarter of training between TP1 and TP2 using changes from baseline during increase and decrease temperature-control trials indicated a significant reduction during decrease trials but not during increase trials for the biofeedback group.

Only one of the five tests of changes in correlation between TP1 and EMG, DER, or RESP using DOD sscores (see Tables 11 and 12) indicated a significant reduction in correlation; this significant reduction was noted between the first and last twentieth of training for TP1 versus DER in the biofeedback but not in the no-biofeedback condition.

Successful versus Unsuccessful Biofeedback Subjects

Since there seemed to be a great range in the ability of the 12 subjects in the biofeedback condition (i.e., Groups 1 + 2 with biofeedback) to respond differentially in the increase and decrease temperature directions (i.e., DOD scores ranging from +2.10 to -.13 degrees F) it was decided to identify, within this augmented group, a subgroup that was relatively " successful" versus a subgroup that was relatively "unsuccessful" in learning differential temperature control. DOD scores that were equal to or greater than +.25 degrees F (approximately the median DOD score) were used to select the successful subjects in the biofeedback condition; this resulted in six subjects being designated as successful and six as unsuccessful. The DOD scores in the control hand, averaged over the 20 training sessions, based on the differences between the fifth and baseline minutes of each trial were +.87 for the successful, and +.11 for the unsuccessful subjects. A Groups (successful vs. unsuccessful subjects) x Quarters of Training mixed-design analysis of variance confirmed that this selection produced a successful group that showed significantly greater DOD scores than the unsuccessful group, $F(1,10) = 7.99$, $p < .05$; there was no significant main effects for Quarters and no significant Quarters + Groups interactions. (It should be noted that only one of the 12 subjects in the no-biofeedback condition had mean DOD scores greater than +.25 degrees F).

Insert Figure 8 about here

In Figure 8 are the changes from baseline during increase and decrease temperature-control trials, averaged over the 20 training sessions, based on the differences between the fifth and baseline minutes of each trial for successful and unsuccessful subjects in the biofeedbck condition. It is clear that only successful subjects show a net "increase" in skin temperature relative to the running baseline.

In Table 13 (top panel) is a summary of the correlations of the DOD scores between TP1 and TP2, EMG, and DER for the first and the fourth quarters of training for the successful and the unsuccessful biofeedback subjects. In addition, Table 13 shows the normal deviate (*z*) scores which assess whether a significant "change in correlation" has occurred between the first and fourth quarters of training for each group separately. There is only one significant reduction in the correlation of the DOD scores; this is between TP1 and TP2 for the successful biofeedback subjects, $p < .05$. In order to assess whether the reductions in correlations of the DOD scores between TP1 and TP2 are due primarily to changes in correlations during increase or during decrease temperature-control trials separate analyses on the changes from baseline for each direction were done (see Table 13, the forth and fifth rows of the top and bottom panels). The only significant reduction in correlation is seen in the "decrease direction" for the successful biofeedback subjects.

Insert Table 13 and Table 14 about here

In Table 14 is a summary of the correlations of the DOD scores between TP1 and TP2, EMG, DER, and RESP for the first and last twentieth of training for the successful and the unsuccessful biofeedback subjects separately. In addition, Table 14 shows the normal deviate (*z*) scores which assess whether a significant "change in correlation" has occurred between the first and last twentieth of training for each condition. The significant changes in correlation are between TP1 and TP2, $p < .05$, and between TP1 and DER, $p < .001$, for the successful biofeedback subjects only. Thus successful subjects but not unsuccessful biofeedback subjects seem to develop response specificity over training, especially with respect to the contralateral hand; this development in specificity is evident mainly during the decrease temperature-control trials.

Other Findings

Other findings not directly related to the four experimental hypotheses are reported here.

Pre-training changes. Session 1 was a pre-training test of the ability of all subjects to control temperature using instructions-with-strategies alone (but without biofeedback) prior to differential treatment. In Table 15 is a summary of nine, one-way analyses of variance on the DOD scores, changes from baseline during increase-temperature trials and changes during decrease-temperature trials in the control hand, based on the differences between the fifth and baseline minutes of each trial for Session 1. Three different group contrasts were used: (1) Group 1, Group 2, Group 3, (2) Groups 1 + 2 vs. Group 3, and (3) Group 1 vs. Groups 2 + 3. There were no significant differences in the DOD scores, in the changes from baseline during increase-temperature trials or during decrease-temperature trials. Thus, there was no difference in the ability of the subjects to control temperature prior to the 20 training sessions.

Insert Table 15 about here

Post-training changes. Session 22 was a post-training test of the ability of all subjects to control temperature without biofeedback after differential treatment. This session could be viewed as a transfer test from biofeedback to non-biofeedback conditions for Groups 1 and 2. In Table 16 are the means and standard deviations for the performances on Session 22 of the combined groups (1 + 2, and 2 + 3) and individual groups (1, 2, 3) on the DOD scores, changes from baseline during increase-temperature trials and during decrease-temperature trials in the control hand, based on the differences between the fifth and baseline minutes of each trial. In Table 17 is a summary of nine, one-way analyses of variance on the DOD scores, changes from baseline during increase-temperature trials and changes during decrease-temperature trials in the control hand, based on the differences between the fifth and baseline minutes of each trial for Session 22. Three different group contrasts were used: (1) Group 1, Group 2, Group 3, (2) Groups 1 + 2 vs. 3, and (3) Group 1 vs. Groups 2 + 3. The only significant difference among groups was in the changes from baseline during increase-temperature trials for Group 1, Group 2, Group 3, F (2, 15) = 4.92, $p < .05$. The Shaffer-Welsch Stepwise Multiple Comparison Procedure was used to assess the meaning of this significant Groups main effect. It showed that Group 2 (mean = +.72) produced significantly greater changes during increase-temperature trials than Group 1 (mean = -.39), and Group 3 (mean = -.17), $p < .05$; however Group 1 was not significantly different from Group 3. Thus only subjects who had exposure to both biofeedback and no-biofeedback trials during training (i.e., Group 2) were able to increase their temperature relative to the other groups during this no-biofeedback transfer session.

Insert Table 16 and Table 17 about here

Since there were no significant differences found between subjects trained with biofeedback as opposed to those without biofeedback (analyses of Groups 1 + 2 vs. 3, and 1 vs. 2 + 3) during this no-biofeedback transfer session it appears that the continuous presence of the feedback signal during control is necessary for the improved performance that was shown by subjects with biofeedback (compared to those without biofeedback) during the 20 training sessions. Perhaps the most dramatic erosion in performance from the 20 training sessions (Sessions 2 - 21) to the no-biofeedback control session (Session 22) was that of Group 1. This group showed average DOD scores of +.47 during training; the DOD scores dropped to -.28 during Session 22. This represents a turnaround in performance of +.75 degrees F. This erosion in performance probably accounts for the lack of difference between biofeedback and no-biofeedback subjects (especially in the Groups 1 + 2 vs. 3 analysis) during Session 22.

Session 23. Session 23 gave subjects in Group 3 an opportunity to try to control temperature with biofeedback.

It allowed for a test for any evidence of "latent learning" in the group trained with instructions plus strategies alone. The mean temperature changes (and standard deviations) based on the differences between the fifth minute of the control trial and the baseline minute of that trial during Session 23 for the DOD scores, the changes from baseline during increase-temperature trials, and the changes from baseline during decrease-temperature trials were +.05 (.55), -.62 (.72), -.67 (1.03), respectively. There were no significant differences between mean temperature changes during Session 22 (the last session during which Group 3 subjects tried to control temperature without biofeedback) and those during Session 23 (with biofeedback) for the DOD scores, $\underline{t}$ (5) = .36, $\underline{p} > .70$, for changes during increase-temperature trials, $\underline{t}$ (5) = 1.88, $\underline{p} > .10$, or for changes during decrease-temperature trials, $\underline{t}$ (5) = .45, $\underline{p} > .60$. Thus, there seem to be no signs of latent learning for Group 3 subjects.

Absolute baseline values. The mean absolute baseline values for the variables over all trials of the 20 training sessions for biofeedback (i.e., Groups 1+2 with biofeedback) and no-biofeedback (i.e., Groups 2+3 no biofeedback) conditions follow. For the biofeedback condition, the baseline values for TP1, TP2, EMG, and DER were 91.22 degrees F, 91.81 degrees F, .47 microvolts, and 11.88

micromhos, respectively. For the no-biofeedback condition, the baseline values for TP1, TP2, EMG, and DER were 90.86 degrees F, 91.79 degrees F, .50 microvolts, and 13.69 micromhos, respectively.

The mean baseline value for respiration rate avereged over the first and last twentieth of training for the biofeedback condition was 17.09 cycles/minute and for the no-biofeedback condition was 16.08 cycles/minute.

Effects of the Law of Initial Value. To assess whether the Law of Initial Value may have affected temperature control, correlations were calculated beteween the absolute baseline temperatures and their respective (1) DOD scores, (2) changes from baseline during the increase-temperature trials, and (3) changes from baseline during the decrease-temperature trials. These calculations were based on the differences between the fifth minute of the control trials and the baseline minute of these trials, averaged over all 20 training sessions for subjects with biofeedback (i.e., Groups 1 + 2 with biofeedback) and subjects without biofeedback (i.e. Groups 2 no-biofeedback + 3) separately. The correlations between baseline temperatures and the DOD scores, changes during increase-temperature trials and changes during decrease trials, for subjects with biofeedback were +.20, +.52, and +.23, respectively. These same correlations for subjects without biofeedback were

+.08, +.11, and -.04, respectively. None of these correlations were significantly greater than zero. In fact, the correlation with the greatest magnitude (i.e., between baseline and changes during increase-temperature trials for subjects with biofeedback) was positive indicating the higher the baseline temperature the greater the increase in temperature. This runs counter to the relationship predicted by the Law of Initial Value which would expect a negative correlation. Therefore, the Law of Initial Value does not appear to be an important factor in determining the temperature control exhibited in the present study.

Review of Major Results

The results of this experiment can now be reviewed with respect to the four experimental hypotheses. The finding that trials with biofeedback produced greater differential control of peripheral skin temperature than trials without biofeedback indicates that biofeedback is important and perhaps vital in learning to control a visceral response. This finding is in accord with Johnston's first descriptor which states that knowledge of results (feedback) is vital to motor-skills learning. However, the finding that varying the probability of biofeedback had no significant effect on temperature control indicates that varying the amount of information provided by the biofeedback (at least in the case of varying the ratio of training trials provided with biofeedback to the total number of training trials) is not an important factor in visceral learning. These findings do not support Johnston's second descriptor which states that in general the more information provided by knowledge of results the better is motor-skills learning. The finding that there was no evidence that temperature control improved over the four quarters of training but there was indication that control improved over the five minutes of a trial indicates that, in visceral learning, performance does not improve over long periods (sessions) but does improve within short periods (trials). These findings support, only in small part, Johnston's third descriptor which states that performance improves with training in motor-skills learning. The finding that response specificity seemed to develop over training in the biofeedback but not in the no-biofeedback condition (especially in the case of temperature changes in the contralateral hand) indicates that the response does become more specific with training in visceral learning. These findings support Johnston's fourth descriptor which states that control changes and becomes more specific with training in motor-skills learning.

Footnotes

[1] The author found an error in the final equation for the normal deviate (Zo) reported by Johnson and Jackson (1959, 356). The equation shows that $Zo = 0.2413/0.1102$ indicating that $Zo = r/SD1'$. The numerator of this equation should be $Z'12 - Z'34$ (not r). This error and its correction were confirmed by Dr. Philip H. Ramsey of Queens College.

CHAPTER IV

Discussion

This study examined the hypothesis that the criteria for defining motor-skills learning may be applicable to visceral learning as well. It was predicted that the four descriptors of motor-skills learning used by Johnston would apply in the learning of bidirectional peripheral skin-temperature control.

A more detailed discussion of each of the four experimental hypotheses, the performance of successful vs. unsuccessful biofeedback subjects, the performance during the no-biofeedback post-training transfer session, and the general conclusions of the present study will follow.

Biofeedback and Visceral Control

The finding that there were no significant differences in the ages of the subjects, outside temperatures, room temperatures, baseline skin temperatures during training, and in the ability to control temperature without biofeedback prior to differential group treatment (i.e., performance in Session 1) for any of the group contrasts implies that the group differences in skin-temperature control observed during training were due to the differential group treatment (i.e., biofeedback vs. no biofeedback).

The present finding that trials with biofeedback produced significantly greater visceral control than those without biofeedback agrees with the studies by Hnatiow and Lang (1965) for reduced cardiac-rate variability, and by Johnston and Lethem (1981) for decreased (by a specific amount) cardiac interbeat interval control. However, these findings do not agree with studies by Johnston (1976) for bidirectional heart-rate control, by Johnston (1977b) for bidirectional pulse-amplitude control, and by Lang (1977) for heart-rate slowing; these studies indicate that trials with biofeedback do not produce significantly greater visceral control than trials without biofeedback.

Johnston (1977a, 1977b), and Johnston and Lethem (1981) have tried to explain these discrepant findings by pointing out that visceral tasks that seem to benefit by the addition of biofeedback to instructions alone are tasks requiring a "graded" response (i.e., a response having both direction and specific magnitude). On the other hand, visceral tasks requiring mainly "directional" movements without requiring the production of specific magnitudes do not seem to benefit by the addition of biofeedback. Examples of visceral responses requiring mainly directional changes would include such tasks as simple heart-rate speeding or slowing, and skin-temperature cooling or warming. Tasks requiring a graded response would include decreasing heart rate by a specific amount or reducing cardiac-rate variability.

The findings of the present study do not support this explanation since they indicated the benefit of the addition of feedback to instructions alone in a task that required subjects to control mainly directional movements. However, this task is a more demanding task than is usually required of subjects learning directional temperature control (or, for that matter, learning directional control of other visceral responses) since subjects had to change the direction of the temperature control, randomly, several times in a single session (this point will be elaborated upon later). Most other studies requiring directional control ask subjects to control in only one direction; such a response is much less demanding than one requiring unpredictable changes in the direction of control several times in each session. Perhaps it might be that the more demanding and complex a visceral task is, the more it will be aided by the addition of biofeedback to simple instructions or to instructions-with-strategies. If this turns out to be the case it could reconcile the results of the present study with the results of Hnatiow and Lang (1965), and Johnston and Lethem (1981) since visceral tasks like theirs which require both direction and specific magnitude might also be considered to be more demanding or complex than one requiring only directional movements.

The present study found that the ability to respond differentially to increase as opposed to decrease temperature instructions was due mainly to the benefit of biofeedback over no biofeedback during the "decrease" temperature trials. Thus, trials with biofeedback seemed to produce greater control of peripheral skin temperature than trials without biofeedback when the response was one that was associated with heightened activation or arousal (i.e., decreasing temperature) but not when the response was associated with reduced activation or increased relaxation (i.e., increasing temperature). This finding, for skin-temperature control, is in accord with Lang's (1977) contention that the mechanisms of heart-rate speeding and slowing are different from one another, and that ergotrophic (activation increasing) and tropotrophic (activation decreasing) cardiac changes are differentially responsive to biofeedback. The findings of the present study would add credence to the notion that the information processing demands of feedback procedures may help with the individual's efforts to achieve a heightened state of arousal but interfere with (or at least not help with) his efforts to achieve a lowered state of arousal.

From both the perspectives employed in assessing change, the differential temperature response (i.e., the difference of the differences) and the baseline comparison, biofeedback had a significant impact in the decrease temperature condition as compared with the increase condition but yielded effects of considerably smaller magnitude than reported in other studies of biofeedback-assisted bidirectional temperature control.

In reviewing data from the perspective of the difference of the differences scores, it is clear that although the differences between the changes from baseline during increase trials and during decrease trials for finger temperature were significantly greater for subjects using biofeedback (average DOD score of about +.5 degrees F for the fifth minute of a trial, see Table 6) than for those without biofeedback (average DOD score of about -.10 degrees F for the fifth minute of a trial) the magnitude of these differences is much smaller than those reported in other studies examining biofeedback-assisted bidirectional temperature control. For example studies by Surwit et al. (1976) and Keefe and Gardner (1979) reported temperature differences between increase and decrease conditions for subjects using biofeedback of 4.05 degrees F and 5.04 degrees F, respectively.

The Taub and Emurian (1976) study which used biofeedback to train separate groups to increase or decrease temperature requires mention since they reported significant differences between the two conditions of at least several degrees. In fact, two subjects who had mastered the unidirectional temperature control task were given bidirectional training and showed evidence of strong bidirectional control. However, the results of this study are vitiated by Taub and Emurian's data reduction and reporting techniques which have been strongly criticized as being idiosyncratic and thus, incapable of being evaluated (Johnston, 1977a). The problem with their data reduction is that the reported magnitudes of skin-temperature changes are always made relative to and thus dependent upon the temperature changes occurring during an initial pre-biofeedback training session. The meaning of the magnitude of the temperature changes is therefore, difficult to compare with most other temperature control studies which evaluate "within session" changes.

Examining the data in terms of changes from baselines, subjects given biofeedback in the present study were again found to be more responsive during the decrease trials (mean change of -.64 degrees F for the fifth minute of a trial, see Table 6) than during increase trials (mean change of -.16 degrees F for the fifth minute of a trial). This finding agrees with the majority of biofeedback studies in bidirectional skin-temperature control which showed that changes during decrease trials were of greater magnitude than during increase trials (King & Montgomery, 1980a). For example, Surwit et al. (1976) reported that the change from the first to the last five-trial block was -2.0 degrees C (-3.6 degrees F) for control in the decrease-temperature condition, and +.25 degrees C (+.45 degrees F) for control in the increase-temperature condition. (In fact, the change during the increase-temperature condition was -.18 degrees F relative to an initial, pre-control stabilization point. This small temperature change in the wrong direction is very similar to the change reported in the present study for the increase temperature condition). The study by Keefe and Gardner (1979) reported overall mean changes of -2.9 degrees F for the decrease group and +2.5 degrees F for the increase group on the final day of training. Although these studies have in common the finding of greater change during decrease than during increase temperature trials when using biofeedback, the reported absolute changes in skin temperature are quite different in each of them. Most of the other studies reported changes of considerably greater magnitude than found in the present study.

There are, at least, three possible reasons why the present study generated such relatively small differences between the increase and decrease temperature conditions (i.e., DOD scores), and such relatively small absolute changes from baseline for increase and for decrease trials. The first is that the task in the present study was more demanding of the subjects than any previously reported temperature-control study since subjects had to change the direction of the temperature control several times in a single session. It will be recalled that each session was made up of two increase and two decrease trials, and that furthermore the order of these directions changed randomly for each of the twenty training sessions. Previously reported bidirectional temperature-control studies had separate groups in an increase and decrease condition (e.g., Keefe & Gardner, 1979; Surwit et al., 1976). In such studies individual subjects had the responsibility of controlling skin temperature in only one direction; thus, the comparisons between increase and decrease conditions were always between groups.

The only other studies in biofeedback-aided peripheral-vasomotor control that required subjects to change direction within a training session were those by Johnston (1977b) and Roberts et al. (1975). The work of Roberts et al. (1975) required subjects to control the temperature of one hand relative to the other. There are several reasons why it is difficult to discuss the import of the temperature differences reported by them. One is that the subjects were selected on the basis of extreme scores on tests of hypnotic susceptibility and absorption. Another reason is that their obtained difference scores were the result of several complex response patterns, such as both hands being warmed or cooled together but at different rates, one hand being held constant and the other changing in the correct direction, hand temperatures converging or diverging, and the temperature differential going in the wrong direction. The occurrence of these different patterns contributing to the difference scores makes their meaning confusing for a discussion of differences between increase and decrease trials. The other study in vasomotor control that required subjects to change direction within a training session utilized a finger-positioner to help control for finger movements (Johnston, 1977b). This study required bidirectional pulse-amplitude control. However, Johnston's subjects received, in each session, a block of three increase and three decrease trials, the order being balanced within and across subjects. This sequence required subjects to change direction only one time per session. Once a subject received the first trial, the directions of the rest of the trials in a session were quite predictable since each direction was run in blocks. This situation seems to be more predictable and less demanding than the present study but less predictable and more demanding than the temperature control studies requiring subjects to control in one direction only. It would have been interesting if Johnston had reported on the skin-temperature changes that accompanied the pulse-amplitude changes. Unfortunately, although temperature probes were applied to the skin they proved unsatisfactory and no reports of skin temperature were given.

Thus, the difference in the amount of demand on the subjects in the present study and the demand on subjects in previous temperature-control studies requiring change in one direction only, might be viewed as being analogous to: (1) the differences between the demand in a conditional-discrimination task as opposed to a simple-discrimination task or (2) between the demand in a discriminative reaction-time task as opposed to a simple reaction-time task. In both cases the discrimination tasks, as opposed to the simple tasks, are generally considered more demanding, resulting in differences in performance.

Second, this study used stringent controls in attempting to prevent artifact from affecting the skin-temperature responses. For instance, all subjects were instructed that during the entire control-training period that they should sit quietly, remain awake, avoid changing breathing from normal resting patterns, and move as little as possible (especially the hands) compatible with comfort. In addition, this study used specially constructed hand holders designed to prevent artifact in temperature recording such as might be produced by the subjects' expired air reaching the temperature sensors, by excessive hand movements, and by hand position changes relative to gravity. The study by Surwit et al. (1976) neither instructed subjects to refrain from movement nor used hand holders or hand restraints. Although Keefe and Gardner (1979) did tell their subjects to avoid unnecessary movement and irregular respiration they did not employ hand holders or hand restraints. The importance of restricting movement is highlighted by a recent study in temperature control by King and Montgomery (1980b). In the second of two experiments several groups of subjects were trained to increase their hand temperatures. All subjects were given strategies which instructed them on the possible use of Autogenic phrases and thermal imagery for controlling temperature increases. The only subjects that could significantly increase their temperatures were those subjects who received biofeedback and who were also encouraged to use "somatic maneuvers" (respiratory changes, muscle tension, relaxation) to effect the change. Subjects using contingent feedback but denied, by specific instruction, the use of such maneuvers, as well as subjects using noncontingent feedback or Autogenic instructions alone, could not increase their temperatures significantly. This finding of King and Montgomery complements the finding of the present study which indicates that when somatic maneuvers are severely restricted by instructions and by physical restraints, subjects show little indication of being able to increase their hand temperatures.

A third possible reason why the present study showed relatively small differential temperature control is the comparatively short length of the temperature-control period. The control trials were always five minutes in duration. The study by Surwit et al. (1976) ran 20, 75-second trials (all in the same direction) with 10 second intertrial intervals. For statistical analysis the trials were divided into 4, 5-trial blocks. The scores indicating temperature change reflected changes from the first to the last 5-trial block (an interval of about 20 minutes). The study by Keefe and Gardner (1979) used a ten minute control period with temperatures recorded at the start of the period and at the fifth and tenth minute. In both of these studies there was indication of increasing differential temperature control with increasing duration of the control period. The present study also indicates that control with biofeedback was growing over a trial with little evidence of an asymptote (see Figure 7). Perhaps, if the trials were longer than five minutes, larger DOD scores and changes from baseline would have been obtained. Short trial durations were chosen in the present study in order that enough trials could be presented per session to insure that the subjects could not predict easily which temperature control direction would be required next. This was done so that subjects would be unlikely to manipulate the baseline periods during the intertrial intervals in some way that could affect the temperature control.

However, the purpose of the study was not to try to produce the largest possible levels of temperature control but to assess the differences in control between subjects using instructions-with-strategies alone and those using biofeedback plus instructions-with-strategies in order to test aspects of the motor-skills model of visceral learning.

Quantity of Information

The present study manipulated the "amount" of feedback by exposing different groups to different probabilities (proportions) of analogue biofeedback. Group 1 was provided with biofeedback during every trial of the 20 training sessions, Group 2 was provided with biofeedback during one half of these trials, and Group 3 was not provided with biofeedback during any of these trials. Since the results showed that there were no significant differences among these three groups on the DOD scores, and on the changes from baseline during increase and during decrease trials it would indicate that the manner in which the amount of information was manipulated in the present study did not affect the performance on temperature control. This finding does not agree with Johnston's second descriptor which states that, in general, the more information provided by the knowledge of results the better is the learning. (Furthermore this finding also represents the only test in which subjects using biofeedback did not perform significantly better on differential temperature control than those not using biofeedback).

These results agree with such studies as those by Gatchel (1973), and by Lang and Twentyman (1974) for heart-rate decrease control, by Lang and Twentyman (1980), and by Young and Blanchard (1974) for heart-rate increase and decrease control all of which indicated that increasing the amount of biofeedback did not affect performance on a visceral control task.

However, these results do not agree with such studies as those by Brener et al. (1969) for heart-rate increase and decrease control, by Gatchel (1975), and Lang and Twentyman (1974) for heart-rate increase control, by Elder et al. (1977) for blood-pressure increase and decrease control, and by Johnston and Lethem (1981) for heart-rate increase by a specific amount all of which showed that the greater the amount of feedback the better the performance on a visceral task.

Of all of these studies which examined the effect of varying the amount of feedback on the performance of a visceral control task, the one which varied amount of feedback in a manner most similar to that employed in the present study was the work of Brener et al. (1969). They varied the amount of feedback by varying the proportion of the training trials during which biofeedback was present on two successive bidirectional heart-rate training sessions. Three groups were used; one was provided with biofeedback during 100% of the training trials, a second during 50% of the trials, and a third during 0% of the trials. The measure used in the statistical analyses was the difference between the mean intermedian inter-heartbeat intervals for the decrease and increase heart-rate control trials (this measure of visceral control is very similar to the DOD scores reported in the present study). Brener et al. sampled heart-rate control for all groups by interspersing non-biofeedback test trials among the training trials during both training sessions. The graphed results indicated that the amount of the heart-rate control on non-biofeedback test trials, especially during the second session, was a direct function of the percentage of training trials on which feedback was given. In fact, their second session results which plotted heart-rate control as a function of proportion of feedback are very similar to the results of the present study which plotted both DOD scores and decrease temperature scores as a function of probability of feedback, (see Figures 3 and 4). However the statistical evidence they used to justify the claim that the amount of learned heart-rate control is a function of the amount of feedback provided during training is equivocal at best. Brener et al. (1969, pp.514-515) reported that an analysis of variance of these data indicated a significant Sessions effect that showed greater heart-rate control during the second of the two sessions. They further reported that "no other significant effects" were observed (this would imply that there was no significant Groups effect or Groups x Sessions interaction). In spite of this finding, they proceeded to run a Duncan's "Multiple Comparison Test" which indicated that the 100% feedback group displayed significantly greater heart-rate differences than the 0% group. They also stated that although the differences in the heart-rate control between the 50% and 100% groups, and the 50% and 0% groups were in the predicted directions, these differences were not significant. It would seem that without obtaining a significant omnibus F for the Groups main effect they had little justification for performing additional statistical tests on the data. It would have probably been more appropriate to conclude that proportion or probability of feedback did not affect heart-rate control. Even if they had some justification for using the multiple comparison test it would appear that the only reasonable conclusion they could draw from it was that subjects with biofeedback showed greater heart-rate control than subjects without biofeedback, not that the amount of control was a function of the amount of feedback. If the work of Brener et al. is assessed in terms of this alternate interpretation, their results would agree quite well with the results of the present study which indicate that feedback is better than no feedback but that amount of feedback is not important in visceral control.

The other studies which varied the amount of biofeedback did so by markedly different procedures than by varying the probability of trials having feedback. Lang and Twentyman (1974) varied amount of feedback by comparing binary (low amount of information) to analogue (high amount of information); Lang and Twentyman (1980), and Gatchel (1975) varied the relative frequency of analogue feedback (this manipulation actually varied both frequency and delay of feedback, the Gatchel study also employed contingent monetary reward). Elder et al. (1977) varied the proportion of time in each training trial during which feedback was present (i.e., feedback provided during all 100 seconds of each trial, feedback during only the initial and final 10 seconds of each 100 second trial, and no feedback during the entire trial); Young and Blanchard (1974) varied the amount of feedback by comparing binary, continuous analogue, binary followed by analogue, heart sounds, and no feedback conditions. Johnston and Lethem, in a group of experiments, varied the amount of feedback by comparing analogue vs. binary, and by comparing different frequencies of analogue feedback (i.e., varying the ratio of cardiac cycles receiving biofeedback to those not receiving biofeedback).

One can readily appreciate the difficulty of trying to compare the results of the present study with the results of these other visceral control studies when one takes into account the many different ways in which they manipulated amount of information. The difficulty of such a comparison is compounded by the use of different scoring procedures, visceral response systems, trial durations, number of training sessions, degrees of restraint on somatic maneuvers (often including no restraints at all), directions of requested visceral change, sensory modalities through which feedback is supplied and so on.

One trend that seems to emerge from these studies is that varying the amount of feedback is more likely to affect the performance on an activating than on a tropotrophic response. A second trend is that qualitative manipulations of the amount of feedback such as comparing binary with continuous analogue are more likely to affect performance than quantitative manipulations such as varying the frequency of analogue feedback. For example, Johnston and Lethem (1981), training interbeat interval decreases by a specific amount, reported strong evidence that analogue feedback was superior to binary feedback on two separate tests of this manipulation. However, their examination of the effect of frequency of feedback was less consistent; it showed that frequent was better than infrequent feedback in only two of the three tests made on this manipulation of the amount of feedback. This suggests that the effect of varying the amount of feedback in some quantitative way (as was done in the present study) might produce a relatively weak effect on visceral-control performance. Perhaps it is necessary to use relatively large numbers of subjects to test adequately such quantitative manipulations of the amount of feedback.

Since the present study used only six subjects per group to explore the issue of manipulating the amount of feedback by varying the feedback in a quantitative way (i.e., probability of feedback), it could be argued that a larger number of subjects per group may have been required to test this manipulation adequately. This seems to be a possibility for the changes from baseline during decrease temperature trials (an activating response) but not for the changes from baseline during increase-temperature trials (a tropotrophic response, see Figure 4). Of course, the statistical evidence from the present study used to assess Johnston's second descriptor indicated that the general way in which the amount of information provided by the biofeedback was manipulated here did not lead to better learning. This finding presents difficulties for a motor-skills learning model of visceral learning.

Performance and Training

As was true for the other hypotheses, the literature is mixed as to whether performance improves with training as would be required by the motor-skills paradigm. There was a trend in this literature which suggested that studies using a greater number of training sessions were more likely to report changes over training than those using fewer sessions. The present study attempted to allow adequate opportunity for any such changes to occur by giving extended training. However, even with the 20 training sessions used, no changes in performance were noted over the four quarters of training for all of the types of scores examined.

The finding that changes in temperature control improved over minutes of a trial is in agreement with other studies in bidirectional skin control such as that by Keefe and Gardner (1979) showing improvement over the ten minutes of a trial, and by Surwit et al. (1976) over the four blocks of trials. This improvement over minutes might be taken as partial evidence for Johnston's requirement that performance improves with training. However since temperature control did not seem to improve over quarters of training (i.e., no significant Minute x Quarter x Group interactions, see

Tables 8, 9, and 10), such evidence must be considered as weak and again does not provide strong support for the motor-skills paradigm.

Response Specificity

Again, the literature was equivocal as to whether the response changes and becomes more specific with training. There was a trend in the literature which indicated that response specificity was more likely to be observed in studies using many more training sessions. The present study, which employed a large number of training sessions, found strong evidence for response specificity developing within the response system under training (i.e., specificity developing in temperature changes in each hand, see Tables 11 and 12) and rather weak evidence for such development in response systems outside of the one being trained (the only significant reduction in correlation was between skin-temperature changes and skin-conductance changes of the control hand in the first to last twentieth analysis, see Table 12) for subjects using biofeedback. There was no evidence of specificity developing for subjects without biofeedback either within or between response systems. The significant reduction in correlation between the control and contralateral hand for the DOD scores and the changes from baseline during decrease trials are particularly interesting since there appeared to be no significant changes in the ability of subjects to improve temperature control over these same training periods. However, it would appear that the "pattern" of the temperature control changed over training. Early in training the temperature changes in the contralateral hand followed those in the control hand quite closely while later in training this relationship was significantly reduced. These findings lend credence to Schwartz's (1979) notion that when one is comparing a group of visceral learners using biofeedback plus instructions to a second group given specific instructions alone, one should not only compare mean performance but should also compare variance and temporal "patterns" of the visceral response under training and of other physiological patterns. If any of these measures differ it could indicate that different mechanisms are involved in regulating the response in the two groups. The present study found differences between such groups on both mean performance and on temporal patterns of the response under training. Thus, it may indicate that different mechanisms are involved in the regulation of temperature control by subjects using biofeedback compared to those without biofeedback.

Virtually all of the earlier reports on the development of response specificity within the response system being trained were of an anecdotal nature lacking quantitative support. The present study supplies such quantitative support.

It is also interesting to note that for the subjects using biofeedback the specificity occurred during the changes from baseline during decrease trials but not during increase trials. This lack of development in response specificity during increase temperature trials paralleled the lack of temperature control evidenced during these trials.

The finding of the present study that response specificity developed within the response system being trained supports the motor-skills paradigm.

Individual Differences

The identification of the six relatively successful as opposed to the six relatively unsuccessful biofeedback subjects (based on DOD scores) permitted a more refined examination of those biofeedback subjects who were adequately effecting the changes from baseline in each direction and those subjects who were showing the strongest signs of the development of response specificity.

Knowledge of results. Looking at the changes from baseline during increase trials for the biofeedback subjects as a whole (Groups 1 + 2 with biofeedback) it appears that these subjects, on average, were not reinforced for their responses via the biofeedback signal since they were shown information indicating an absolute mean decrease in skin temperature of -.16 degrees F (see Figure 2). It could be argued that it is difficult to understand how such subjects who, on average, did not receive knowledge of results on what the proper response was (or, in operant terms, did not receive reinforcement) could have learned to respond differentially to increase as opposed to decrease temperature trials. But, looking at the changes from baseline during increase trials for the successful as opposed to the unsuccessful biofeedback subjects (see Figure 8) it is clear that the subjects who were most successful in differential control of skin temperature were those subjects who, on average, were successful on *increase* trials. That is, these were the subjects who did receive knowledge of results (or reinforcement) as to what the proper response was during increase temperature trials.

Since there were no changes over quarters of training for the successful biofeedback subjects it indicates that these subjects were able to exhibit differential skin-temperature control early in training.

It is not clear why some subjects might be considerably more successful than others in learning biofeedback-aided temperature control. The finding of great individual differences in performance has been reported in many visceral learning studies. These individual differences may be attributable to many factors including innate abilities, learned response patterns, and so on. Attempts to identify such factors have not been fruitful (e.g., Roberts et al., 1975). Perhaps it may turn out to be as difficult to identify the unique characteristics of successful visceral learners (i.e., autonomic athletes) as it has been in trying to identify the unique characteristics of successful conventional motor-skills athletes (e.g., baseball players).

Response Specificity. It is also apparent that the successful but not the unsuccessful biofeedback subjects showed a significant reduction in correlations between the temperatures in the two hands over training (i.e., showed response specificity within the skin-temperature modality) for both the *DOD* scores and the changes from baseline during *decrease* temperature trials (see Table 13 and 14). There was also a greater reduction over training in these correlations during increase trials for the successful subjects compared to the unsuccessful subjects, but the magnitude of these decreases was not statistically significant. These findings indicate that only the successful visceral controllers showed the development of response specificity within the response system being trained. These changes in response specificity for the successful but not for the unsuccessful biofeedback subjects would provide support for the motor-skills model.

Although this study was not designed to measure the possible degree of somatic mediation of the subjects' temperature control, an examination of Tables 13 and 14 supplies some information on this issue. In both of the response systems largely under the control of the somatic nervous system that were monitored in the present study, muscle tension (EMG) and respiration rate, the correlations between those responses and skin-temperature (TP1) responses on DOD scores, and changes from baseline during increase and decrease temperature-control trials were lower for the successful as compared to the unsuccessful subjects during both early and late stages of training. Considering these findings, it would be difficult to argue that the relatively higher temperature control evidenced by subjects with biofeedback compared to subjects without biofeedback was due to any gross control exerted by the skeletal muscles since the temperature responses of the successful temperature controllers covaried less with the somatic responses than did the temperature responses of the unsuccessful subjects. Of course this does not mean that somatically mediated musculature responses not measured in this study (e.g., muscle changes in the upper arm or shoulder, or respiration amplitude changes) did not significantly affect the temperature control reported in the present study. It would be difficult to measure all possible sources of somatic mediation in any study since it would require measuring the activity of an almost infinite number of skeletal responses. However, the correlations between the somatic response systems measured in this study and the visceral response system being trained indicate little evidence for the presence of any gross levels of somatic mediation. Thus, as far as can be assessed in this study, visceral response control seemed to occur independent of somatic mediators.

Response Transfer

The finding that subjects trained with biofeedback (especially Groups 1 + 2 combined) did no better than those without biofeedback (especially Group 3) during the no-biofeedback post training transfer session (Session 22) indicated that the continued presence of the feedback signal seemed to be critical for the maintainance of this bidirectional temperature-control task. This may indicate that biofeedback is mainly a controlling factor in performance but that it does not aid in visceral "learning". This finding is in line with Johnston and Lethem's (1981) report that for subjects trained to control heart-rate increases by a specific amount, the withdrawal of the feedback led to a significant deterioration in such performance. Johnston and Lethem concluded that feedback is guiding the performance of subjects but subjects do not acquire a new response that can function in the absence of the guiding feedback. Johnston and Lethem suggested that perhaps learning heart-rate control is more akin to learning an open task (e.g., tracking) rather than a closed task (e.g., lever moving) in motor-skills learning. Poulton (1957) was the first to define open and closed skilled movements. According to Poulton a closed skill depends on internal feedback alone (i.e., kinesthetic feedback from the execution of the response); augmented feedback is not required in performing closed skills. However, an open skill is one that is performed either in an unpredictable series of environmental requirements or in an exacting series, predictable or not; both internal and augmented sources of feedback are important in performing open skills. The key distinction between these two motor-skills tasks, according to Johnston and Lethem, is that in an open task, feedback performs a vital control function; it determines the level of performance that can be achieved and this level of performance is attained rapidly. They further suggested that if controlling heart rate is similar to an open task like tracking then one would expect that feedback would have its main effect on asymptotic levels of performance rather than on acquisition (changes over training), and that the continued presence of feedback would be vital. This idea that learning visceral control is similar to learning to perform an open task in motor skills could explain the lack of changes in performances over quarters of training, and the drop-off in performance once biofeedback was withdrawn in the present study. However, it is doubtful whether such an idea could explain the observation of the development of response specificity or the ability in this study of subjects given feedback on 50% of the trials (i.e., Group 2) to control temperature increases during Session 22 compared to those given feedback on 100% of the trials (i.e., Group 1) and those given feedback on none of the trials (i.e., Group 3). In addition, the appeal of the motor-skills model for visceral learning is that it is based on a large body of empirical findings. If one now has to qualify the proposed analogy by specifying that visceral learning appears to be similar to a certain subset of motor-skills tasks, the appeal and power of the analogy is diminished, and one must wonder whether such an analogy is worth bothering with at all.

The finding that in Session 22, subjects in Group 2 (50% biofeedback group) were able to show significantly greater increases of skin temperature during increase-temperature trials compared to subjects in Group 1 and Group 3 may indicate that these subjects may have learned something about how to increase temperature during training but were not able to demonstrate this learning until they were removed from the possible information processing demands of the feedback trials. Perhaps the reason subjects in Group 1 did not show such an improvement is that they did not get an opportunity to rehearse control without biofeedback during training as the subjects in Group 2 did. It may be that the best strategy for training subjects to control a tropotrophic visceral response eventually in the absence of feedback is to expose the subjects to some trials with biofeedback and some trials without biofeedback during training. That this might be so is strongly suggested by the recent work of McKinney et al. (1980) on heart-rate deceleration training (an example of a tropotrophic cardiac response). These researchers randomly assigned normal human subjects to one of two yoked groups: (1) a contingent faded feedback group or (2) a continuous feedback group. Subjects in the former group received compensation based on performance level, while subjects in the latter group were given the identical amount of compensation their yoked partners received, but noncontingently. Although both groups started training with continuous beat-by-beat analogue biofeedback, subjects in the contingent faded feedback group were asked to decrease heart rate 15% from baseline and were then trained using only 75%, 50%, and 25% of beat-by-beat feedback (i.e., they were weaned from a continuous to an increasingly more intermittent schedule). It was hypothesized that the immediate reinforcement of appropriate behavior and the contingent fading (following mastery) of feedback would aid in the generalization of the response to a no-biofeedback, no-contingent reinforcement post training transfer session (i.e., an extinction session). The results indicated that the group receiving contingently faded feedback training showed a significantly greater heart-rate decrease in the training sessions and in the post training extinction session compared to the group receiving continuous feedback throughout training. In fact the group receiving contingently faded feedback showed higher mean heart-rate deceleration during the post-training extinction session than they did during the biofeedback training sessions; the group receiving continuous feedback showed an erosion in performance during the post-training extinction session compared to the performance during the training session. These findings are very similar to those reported in the present study for the performance during temperature-increase trials of Group 2 (50% feedback being somewhat analogous to the intermittent reinforcement received by the contingently faded group) and Group 1 (100% feedback being somewhat analogous to the continuous reinforcement received by the continuous feedback group). Of course the study by McKinney et al. confounds intermittent feedback with contingent reinforcement.

Hatch and Gatchel (1981) have used the results of such studies as McKinney et al. to argue for an operant theory as opposed to a motor-skills theory of heart-rate control. Hatch and Gatchel admitted that a major problem in choosing between these two theories is that they make relatively few "unique" predictions. However, they noted that one area where differential predictions can be made by the two models is the way in which the gross amount of information (amount of feedback) a subject is exposed to during training should affect learning. Whereas the motor-skills paradigm predicts that learning will be a direct positive function of the amount of exposure to information feedback (Johnston's second descriptor), the operant paradigm predicts that under certain specific conditions intermittent presentation of feedback (reinforcement) leads to greater behavior changes than does continuous presentation.

Since the results of the study by McKinney et al. (1980) and the results of the present study (which did not employ contingent reinforcement or fading) showed that training a tropotrophic visceral response using intermittent presentation of biofeedback led to greater behavior change in a no-biofeedback post training transfer (or extinction) session than training using a continuous presentation of biofeedback, it would tend to indicate a superiority of the operant model compared to the motor-skills model in predicting these results.

General Conclusions

This study was designed to test the proposal that the motor-skills learning paradigm adequately defines visceral learning. It was expected that four descriptors of motor-skills learning used by Johnston (1977) would apply in the learning of bidirectional peripheral skin-temperature control, an instance of visceral (vasomotor) learning. The results of this visceral learning study only partially support the general hypothesis that the criteria for defining motor-skills learning define visceral learning as well.

The finding that subjects trained with biofeedback plus instructions with strategies controlled skin temperature significantly better than those using instructions-with-strategies alone during training would not be surprising if what was really being controlled was the somatically mediated striated, skeletal musculature which is clearly responsive to feedback. The present study employed shielded hand holders and instructions in an attempt to reduce the possibility that the temperature recordings were influenced by artifact or gross somatic mediation. The study tried to measure skin-temperature control that was perhaps more purely visceral in nature than responses measured in the earlier studies. It appears that reducing possible somatic mediators and artifacts not controlled in the earlier temperature studies reduced the magnitude of temperature changes produced in this study. An examination of the correlations between the temperature changes in the control hand with the somatically controlled response changes measured in this study (EMG and Respiration Rate) indicated a lower correlation for successful compared to unsuccessful biofeedback subjects. This suggests that there was little evidence that gross somatic mediation was responsible for the ability of subjects to control the temperature response. However, it is virtually impossible to rule out all potential somatic mediators and artifacts; all that can be done is to reduce them as much as is reasonably possible. Whether the temperature control reported in this study represents control that is relatively purely visceral or simply represents a reduced somatically mediated response is difficult to answer. Furthermore, it is possible that both visceral and somatic changes are inextricably tied together by some central control system producing concomitant changes in both. The finding that response specificity seemed to develop within the vasomotor system for the subjects using biofeedback (and principally in the successful subjects) suggests that something visceral was learned over training but this could also be explained by response specificity developing in the somatic mediators which could in turn effect the vasomotor responses.

It should be recalled that the present study maintained relatively high room temperatures to try to prevent the drift effect (Yates, 1980). The findings that subjects using biofeedback were able to decrease their skin-temperature more during decrease temperature-control trials than during increase temperature-control trials, and that subjects using biofeedback were able to decrease their skin temperature more than those without biofeedback during decrease-temperature trials imply that the temperature decreases noted in the present study were not due to the drift effect. If only the drift effect were operative, it should have produced an equal magnitude of temperature decrease in all groups and all conditions.

The instructions given to all subjects in the present study contained strategies on how they might accomplish the bidirectional temperature responses. The strategies included the relationship of relaxation and arousal to temperature increases and decreases; in addition, subjects were instructed in the use of thermal suggestions (imagery). Subjects were told that it would be difficult to know which strategy or group of strategies might work for them individually but that they should try to use the strategies they sensed were working best. One could argue that perhaps this is not the optimal set of instructions to employ in addition to biofeedback. However, since both relaxation vs. arousal, and thermal suggestions have been reported to be effective in vasomotor control in previous studies (Johnston, 1977b; Keefe 1978), it was felt that these strategies were as valid as any. But the present finding that subjects using biofeedback plus instructions with strategies controlled temperature more effectively than those using instructions-with-strategies alone does not mean that biofeedback is always better than no biofeedback. Perhaps future research may identify such strategies.

The two most often discussed models of visceral learning are the motor-skills learning model and the operant learning model. The fact that both models lead to few "unique" predictions of results renders the validation of either difficult. For example, the finding that response specificity seems to develop within the vasomotor system is clearly predicted by the motor-skills model. However response specificity could be explained by operant theory as well. Hatch and Gatchel (1981) pointed out that one area where the two models lead to differential predictions is in the effect of amount of exposure to information feedback on performance. The present study found that subjects trained on what amounts to an intermittent schedule showed greater control of temperature increases during the no-biofeedback post training transfer session than did those on a continuous schedule. This outcome could not be predicted from motor-skills theory but could be predicted from operant theory. However the finding that, during training, biofeedback seems to aid in the control of temperature decreases but not in temperature increases is perhaps more easily explained by motor-skills (or information-skills) theory by describing feedback as being an arousing, information-processing state that could aid in ergotrophic but not tropotrophic responses.

Perhaps the most reasonable conclusion that can be drawn from the present study is that it shows partial support for a motor-skills model. Additional well-constructed research is needed to close gaps in the present study and to resolve inconsistencies in the literature, especially with respect to the effects of amount of feedback on learning. Much more research must be done on varying the amount of information in different ways, and measuring the changes in control during both training (with the biofeedback signal present) and post training or transfer (without the biofeedback).

Several of the findings in the present study may have clinical implications. The finding that, over extended training, response specificity developed in differential temperature control in subjects using biofeedback suggests that if the interest of the clinician is to induce generalized peripheral blood-flow changes it might be important to train subjects with temperature feedback derived and averaged from both hands or all four limbs at the same time or use different feedback loci on different trials. This should produce a more widespread peripheral blood-flow change than would be expected if only a single feedback locus was used. Also, the finding that Group 2 subjects who were trained with exposure to controlling temperature during trials with and without biofeedback, seemed to be able to control temperature increases when all feedback was withdrawn compared to Group 1 subjects who were exposed only to trials with biofeedback, suggests that clinicians interested in patients transferring learned visceral control to real world (no biofeedback) situations might consider interspersing trials with and without biofeedback during training (fading procedures might be particularly useful).

It could very well be the case that the relatively small magnitude temperature changes (especially in the increase direction) reported with normal subjects using biofeedback in the present study may not predict the magnitude of changes possible in patients exhibiting abnormally low temperatures. The baseline temperatures of subjects in the present study averaged in the low nineties (degrees F) while patients with severe anxiety and Raynaud's disorder may have temperatures ten to twenty degrees cooler than this.

The findings of the present study suggest further research ideas. In order to try to get a clearer idea of which factors were responsible for the small magnitude temperature changes reported in the present study one could train subjects with and without hand holders and instructions in predictable unidirectional and unpredictable bidirectional biofeedback-aided temperature control. In addition, trial length could be varied. Such a study could indicate if it were the hand holders and instructional controls, the demands of the unpredictable bidirectional task, the trial lengths, or some combination of these conditions that produced such relatively small temperature changes.

The present study used less than ideal (alternate, unequal N) analyses of variance in comparing the biofeedback and the no-biofeedback conditions in order to maximize the size of the N. Since these were not the standard types of comparisons future research in bidirectional skin-temperature control might involve running more subjects over fewer training sessions in a larger, equal N design. Future research should also attempt to replicate the finding that subjects exposed to both biofeedback and no-biofeedback during training show greater temperature-increase control during extinction than those always receiving biofeedback during training. Such results would aid in choosing more adequately between an operant and motor-skills model of visceral learning.

Other research possibilities, to which reference has already been made, involve the comparison of groups of temperature-control subjects trained by having biofeedback derived from only one peripheral locus and those having biofeedback derived from many peripheral-skin loci. In order for a more reasonable choice to be made between the motor-skills and operant theories additional research is needed in comparing subjects trained on continuous as opposed to intermittent feedback schedules; such studies should also compare contingent as opposed to non-contingent reinforcement techniques as well as investigating fading procedures.

In summary, it was found that a motor-skills model predicted only some of the results of bidirectional temperature control reported in this study. The results of the present study along with findings in the extant visceral learning literature do not currently show enough consistency to allow for a choice to be made, with confidence, between a motor-skills and an operant model of visceral learning.

Table 1

Standard format for all temperature-control sessions

Period	Time Epoch	Duration (minutes)	Events
Pre-Control-Training Stabilization Period	1	10	Subjects did not try to control skin-temperature. The final (i.e., tenth minute) of this period served as a baseline for Trial 1.
Control-Training Period	2	5	Subjects tried to control skin temperatue--Trial 1.
	3	3	Subjects did not try to control skin temperature--Intertrial interval. The final (i.e., third) minute of this interval served as a baseline for the next trial.

Note. Time epochs 2 and 3 were repeated three times in sequence (with time epoch 2 representing Trials 2, 3, and 4 on each subsequent repitition).

Table 2

Outline of Treatment of the Experimental Groups

Groups	Session #s	Treatment
1 & 2	1P & 2P*	No Control
	1 **	Instructions Only
	2 - 21**	Instructions + Biofeedback
	22 **	Instructions Only
3	1P & 2P*	No Control
	1 **	Instructions Only
	2 - 21**	Instructions Only
	22 **	Instructions Only
	23 **	Instructions + Biofeedback

* Pre-temperature-control stage sessions
** Temperature-control stage sessions

Table 3

Analyses of Variance: Six Room Temperatures Per Session

Groups Contrasted	Source	df	MS	F
1,2,3	Group (G)	2	1.391	.38
	Error	15	3.641	
	Room Tp. (R)	5	.002	.23
	R x G	10	.005	.75
	Error	75	.007	
1+2 vs. 3	Group (G)	1	2.477	.72
	Error	16	3.432	
	Room Tp. (R)	5	.003	.37
	R x G	5	.005	.68
	Error	80	.007	
1 vs. 2+3	Group (G)	1	1.602	.46
	Error	16	3.487	
	Room Tp. (R)	5	.002	.26
	R x G	5	.010	1.52
	Error	80	.007	

Table 4

Analyses of Variance:
Mean DOD Scores of Skin Temperature in the Control Hand
(Minute 5 - Baseline Minute)

Groups Contrasted	Source	df	MS	F	p (2-tails)
1+2 with BF vs. 3	Group (G)	1	5.947	5.22	.036*
	Error	16	1.139		
	Quarters (Q)	3	.255	.85	.476
	Q x G	3	.122	.40	.752
	Error	48	.302		
1 vs. 2 no-BF+3	Group (G)	1	4.623	3.45	.082*
	Error	16	1.341		
	Quarters (Q)	3	.743	2.13	.108
	Q x G	3	.318	.91	.440
	Error	48	.348		

* $p < .05$ (1-tail)

Table 5

Analyses of Variance:
Mean Changes from Baseline Scores of Skin Temperature in the Control Hand During Increase and Decrease Temperature-Control Trials
(Minute 5 - Baseline Minute)

Groups Contrasted	Source	*df*	*MS*	*F*	*p* (2-tails)
Increase Temperature-Control Trials					
1+2 with BF vs. 3	Group (G)	1	.129	.16	.690
	Error	16	.786		
	Quarters (Q)	3	.012	.12	.947
	Q x G	3	.101	.90	.404
	Error	48	.102		
1 vs. 2 no-BF+3	Group (G)	1	.014	.02	.899
	Error	16	.858		
	Quarters (Q)	3	.174	1.55	.213
	Q x G	3	.135	1.20	.319
	Error	48	.112		
Decrease Temperature-Control Trials					
1+2 with BF vs. 3	Group (G)	1	4.322	4.11	.060*
	Error	16	1.052		
	Quarters (Q)	3	.211	.87	.466
	Q x G	3	.128	.52	.668
	Error	48	.244		
1 vs. 2 no-BF+3	Group (G)	1	5.150	5.33	.035*
	Error	16	.966		
	Quarters (Q)	3	.231	.93	.433
	Q x G	3	.197	.79	.503
	Error	48	.248		

* $p < .05$ (1-tail)

Table 6

Change from Baseline (degrees F) for Each Minute of a Temperature-Control Trial Showing Means (*M*) and *SD*s.

Minute	Score	Biofeedback		No-Biofeedback	
		Increase	Decrease	Increase	Decrease
Of Trial		Temp.	Temp.	Temp.	Temp.
		Gps. 1+2 with BF		Gp. 3	
1	*M*	-.21	-.23	-.11	-.13
	(*SD*)	(.10)	(.11)	(.06)	(.11)
2	*M*	-.31	-.46	-.13	-.05
	(*SD*)	(.25)	(.26)	(.10)	(.17)
3	*M*	-.22	-.53	-.16	-.03
	(*SD*)	(.36)	(.39)	(.14)	(.21)
4	*M*	-.16	-.59	-.20	-.05
	(*SD*)	(.44)	(.49)	(.17)	(.27)
5	*M*	-.16	-.64	-.25	-.12
	(*SD*)	(.55)	(.58)	(.17)	(.31)
		Gp. 1		Gps. 2+3 No BF	
1	*M*	-.23	-.23	-.14	-.14
	(*SD*)	(.09)	(.10)	(.08)	(.11)
2	*M*	-.27	-.42	-.17	-.15
	(*SD*)	(.19)	(.24)	(.11)	(.23)
3	*M*	-.26	-.52	-.18	-.14
	(*SD*)	(.35)	(.43)	(.20)	(.29)
4	*M*	-.26	-.64	-.23	-.15
	(*SD*)	(.49)	(.58)	(.29)	(.33)
5	*M*	-.30	-.77	-.27	-.20
	(*SD*)	(.58)	(.73)	(.40)	(.33)

Table 7

DOD Scores for Each Minute of a Temperature-Control Trial
(degrees F)

Minute Of Trial	Score	Gps. 1+2 With BF	Gp. 3 No BF	Gp. 1 With BF	Gps. 2+3 No BF
1	*M*	.02	.02	.00	-.01
	(*SD*)	(.09)	(.11)	(.04)	(.11)
2	*M*	.14	-.08	.15	-.01
	(SD)	(.27)	(.17)	(.27)	(.19)
3	*M*	.31	-.13	.26	-.04
	(*SD*)	(.43)	(.23)	(.48)	(.29)
4	*M*	.43	-.15	.38	-.07
	(*SD*)	(.52)	(.32)	(.66)	(.36)
5	*M*	.49	-.12	.46	-.08
	(*SD*)	(.60)	(.36)	(.81)	(.44)

Table 8

Analyses of Variance: DOD Scores
(Mins. 5,4,3,2,& 1) - (Min. of Baseline)

Groups Contrasted	Source	df	MS	F	p (2-tails)
1+2 with BF vs. 3	Group (G)	1	11.008	5.15	.0375*
	Error	16	2.138		
	Minute (M)	4	.298	1.67	.1676
	M x G	4	1.070	6.00	.0004****
	Error	64	.178		
	Quarter (Q)	3	.468	.97	.4141
	Q x G	3	.302	.63	.6017
	Error	48	.482		
	M x Q	12	.036	.60	.8428
	M x Q x G	12	.022	.36	.9756
	Error	192	.061		
1 vs. 2 no-BF+3	Group (G)	1	6.801	3.20	.0928*
	Error	16	2.128		
	Minute (M)	4	.378	1.74	.1513
	M x G	4	.741	3.42	.0135**
	Error	64	.217		
	Quarter (Q)	3	.924	1.59	.2047
	Q x G	3	.700	1.20	.3189
	Error	48	.582		
	M x Q	12	.113	1.89	.0382**
	M x Q x G	12	.030	.50	.9111
	Error	192	.060		

* p < .05 (1-tail)
** p < .05 (2-tail)
*** p < .01 (2-tail)
**** p < .001 (2-tail)

Table 9

Analyses of Variance: Increase-Temperature Scores
(Mins. 5,4,3,2,& 1) - (Min. of Baseline)

Groups Contrasted	Source	df	MS	F	p (2-tails)
1+2 with BF vs. 3	Group (G)	1	.151	.10	.7524
	Error	16	1.462		
	Minute (M)	4	.029	.23	.9203
	M x G	4	.196	1.57	.1941
	Error	64	.125		
	Quarter (Q)	3	.072	.35	.7901
	Q x G	3	.249	1.22	.3143
	Error	48	.205		
	M x Q	12	.007	.37	.9738
	M x Q x G	12	.014	.75	.7008
	Error	192	.019		
1 vs. 2 no-BF+3	Group (G)	1	.350	.29	.5956
	Error	16	1.192		
	Minute (M)	4	.091	.66	.6246
	M x G	4	.017	.13	.9727
	Error	64	.138		
	Quarter (Q)	3	.368	1.92	.1382
	Q x G	3	.262	1.37	.2639
	Error	48	.191		
	M x Q	12	.018	1.05	.4073
	M x Q x G	12	.019	1.09	.3693
	Error	192	.017		

Table 10

Analyses of Variance: Decrease-Temperature Scores
(Mins. 5,4,3,2,& 1) - (Min. of Baseline)

Groups Contrasted	Source	df	MS	F	p (2-tails)
1+2 with BF vs. 3	Group (G)	1	13.887	6.84	.0188*
	Error	16	2.008		
	Minute (M)	4	.348	2.53	.0498*
	M x G	4	.535	3.87	.0070**
	Error	64	.138		
	Quarter (Q)	3	.200	.59	.6215
	Q x G	3	.186	.55	.6484
	Error	48	.336		
	M x Q	12	.045	.94	.5068
	M x Q x G	12	.019	.41	.9590
	Error	192	.047		
1 vs. 2 no-BF+3	Group (G)	1	10.234	5.40	.0337*
	Error	16	1.896		
	Minute (M)	4	.817	6.44	.0002***
	M x G	4	.560	4.42	.0032**
	Error	64	.127		
	Quarter (Q)	3	.126	.30	.8264
	Q x G	3	.307	.73	.5418
	Error	48	.424		
	M x Q	12	.064	1.51	.1225
	M x Q x G	12	.033	.77	.6788
	Error	192	.042		

* $p < .05$ (2-tail)
** $p < .01$ (2-tail)
*** $p < .001$ (2-tail)

Table 11

Pearson Correlation (*r*) of DOD scores (Min.5-Baseline Min.) for each Quarter of Training (correlating TP1 vs. TP2, EMG, and DER) for Biofeedback (i.e., Groups 1+2 with BF) and No-Biofeedback (i.e., Groups 2+3 no BF) conditions

Variables vs. TP1	Q1 (*r*)	Q2 (*r*)	Q3 (*r*)	Q4 (*r*)	Q1 vs.Q4 (*z*)
Biofeedback Condition					
TP2	.9890**	.4981	.5347	.3011	4.9554***
EMG	-.0937	-.3643	-.5353	-.0170	-.1610
DER	-.3345	-.0999	.2423	-.4085	.1755
No-Biofeedback Condition					
TP2	.8610**	.9546**	.9455**	.8179**	.3234
EMG	.2096	.5233	-.4066	.4388	-.6990
DER	-.1632	-.2942	-.3006	-.2287	.1609

* $p < .05$
** $p < .01$
*** $p < .0001$
(All tests are two-tailed)

Table 12

Pearson Correlation (*r*) of DOD scores (Min.5-Baseline Min.) for the "first twentieth" and the "last twentieth" of training for Biofeedback (Gps. 1+2 BF) and No-Biofeedback (Gps. 2+3 No BF) Conditions

Variables vs. TP1	First 1/20th (*r*)	Last 1/20th (*r*)	First vs. Last 1/20th (*z*)
	Biofeedback Condition		
TP2	.9467**	.2373	3.2829**
EMG	-.0124	-.1750	.3581
DER	-.8750**	-.0461	-2.7784**
RESP	-.4072	.0525	-1.0147
	No-Biofeedback Condition		
TP2	.9160**	.9872**	-1.2779
EMG	-.2259	.8524**	-2.4857*
DER	.1871	-.2064	.8725
RESP	.0673	.6210*	-1.3678

* $p < .05$
** $p < .01$

Table 13

Pearson Correlation for the "first" and "fourth" quarters of training (Min.5-Baseline Min.) for successful and unsuccessful biofeedback subjects

Score (*n*=6)	Variables vs. TP1	Q1 (*r*)	Q4 (*r*)	Q1 vs. Q4 (*z*)
Successful Biofeedback Subjects				
DOD	TP2	.9201**	-.0067	2.1268*
DOD	EMG	-.3714	.1705	-.5970
DOD	DER	.0540	-.3367	.4616
Inc.	TP2	.9933**	.9340**	.8662
Dec.	TP2	.9841**	-.1608	3.2200**
Unsuccessful Biofeedback Subjects				
DOD	TP2	.9948**	.9734**	.5917
DOD	EMG	.7978	.2105	1.5524
DOD	DER	-.3807	-.5420	.2060
Inc.	TP2	.9697**	.9648**	.1037
Dec.	TP2	.9876**	.9916**	-.0715

* *p* < .05 (2-tails)
** *p* < .01 (2-tails)

Table 14

Pearson Correlation (*r*) for DOD Scores during the "First" and "Last" Twentieth of Training (Min.5-Baseline Min.) for Successful and Unsuccessful Biofeedback Subjects

Variables vs. TP1	First 1/20th (*r*)	Last 1/20th (*r*)	First vs. Last 1/20th (*z*)
Successful Biofeedback Subjects			
TP2	.9550**	-.0745	2.3176*
EMG	.1371	.0217	.1330
DER	-.9489**	.5273	-3.7364***
RESP	-.0136	-.0015	-.0156
Unsuccessful Biofeedback Subjects			
TP2	.8818*	.7501	.4465
EMG	.6878	-.2482	1.2097
DER	-.5788	-.3726	-.4286
RESP	-.5641	.3931	-1.6250

* $p < .05$
** $p < .01$
*** $p < .001$
(All tests are two tailed)

Table 15

One-Way Analyses of Variance -- Changes During *Pre* Training Session (i.e., Session 1) Min.5-Baseline Min.

Groups Contrasted	Score	Source	df	MS	F	p (2-tails)
1,2,3	DOD	Group	2	.283	.50	.6159
		Error	15	.565		
	Inc.Tp.	Group	2	.259	1.12	.3518
		Error	15	.232		
	Dec.Tp.	Group	2	.121	.40	.6802
		Error	15	.306		
1+2 vs. 3	DOD	Group	1	.393	.73	.4065
		Error	16	.540		
	Inc.Tp.	Group	1	.047	.19	.6684
		Error	16	.247		
	Dec.Tp.	Group	1	.168	.58	.4584
		Error	16	.291		
1 vs. 2+3	DOD	Group	1	.002	.00	.9513
		Error	16	.565		
	Inc.Tp.	Group	1	.237	1.01	.3300
		Error	16	.235		
	Dec.Tp.	Group	1	.194	.67	.4255
		Error	16	.290		

Table 16

Scores During Post Training No-Biofeedback Session
(i.e., Session 22)

Groups	DOD Scores		Increase Tp.		Decrease Tp.	
	M	(*SD*)	*M*	(*SD*)	*M*	(*SD*)
1+2	.38	(1.40)	.16	(0.94)	-.22	(0.67)
3	.26	(1.00)	-.17	(0.26)	-.43	(0.93)
1	-.28	(0.43)	-.39	(0.51)	-.11	(0.35)
2+3	.65	(1.42)	.27	(0.82)	-.37	(0.88)
2	1.04	(1.76)	.72	(0.97)	-.32	(0.92)

Table 17

One-Way Analyses of Variance -- Changes During *Post* Training Session (i.e., Session 22) Min.5-Baseline Min.

Groups Contrasted	Score	Source	df	MS	F	p (2-tails)
1,2,3	DOD	Group	2	2.634	1.85	.1913
		Error	15	1.426		
	Inc.Tp.	Group	2	2.064	4.92	.0228*
		Error	15	.420		
	Dec.Tp.	Group	2	.155	.26	.7777
		Error	15	.608		
1+2 vs. 3	DOD	Group	1	.054	.03	.8596
		Error	16	1.660		
	Inc.Tp.	Group	1	.431	.69	.4182
		Error	16	.625		
	Dec.Tp.	Group	1	.181	.31	.5839
		Error	16	.578		
1 vs. 2+3	DOD	Group	1	3.466	2.39	.1413
		Error	16	1.447		
	Inc.Tp.	Group	1	1.787	3.31	.0876
		Error	16	.540		
	Dec.Tp.	Group	1	.276	.48	.4976
		Error	16	.572		

* $p < .05$

Figure Caption

Figure 1. Mean difference of the differences (DOD) scores (i.e., Minute 5 - Baseline Minute) for biofeedback (BF) and no-biofeedback (no-BF) conditions in both types of subject comparisons. Horizontal markings indicate ±1 standard error of the mean.

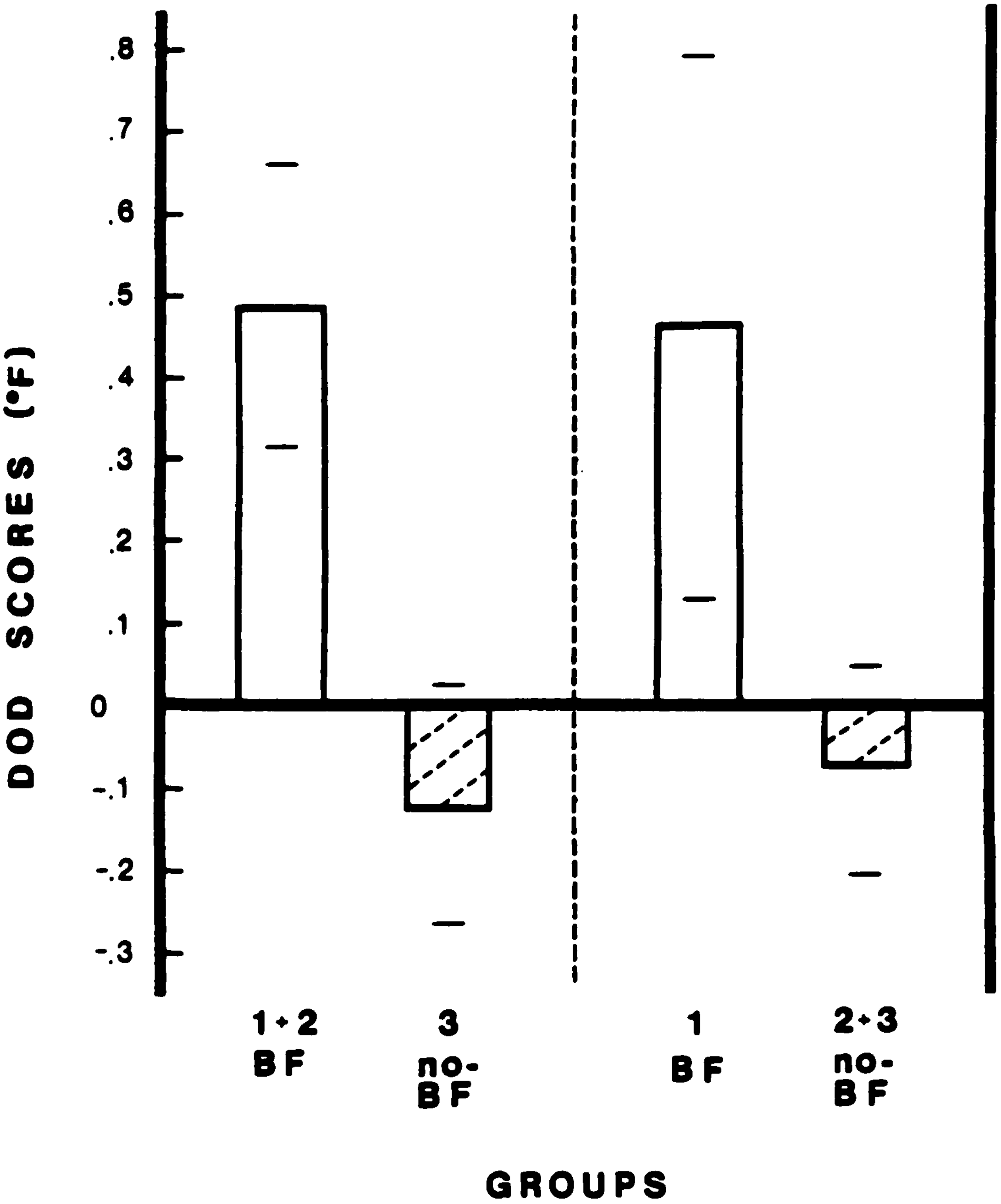

DOD SCORES (°F)
.8
.7
.6
.5
.4
.3
.2
.1
0
-.1
-.2
-.3
1+2 BF
3 no-BF
1 BF
2+3 no-BF
GROUPS

Figure Caption

Figure 2. Mean changes from baseline (i.e., Minute 5 - Baseline Minute) during increase and decrease temperature-control trials for biofeedback (BF) and no-biofeedback (No BF) conditions in both types of subject comparisons.

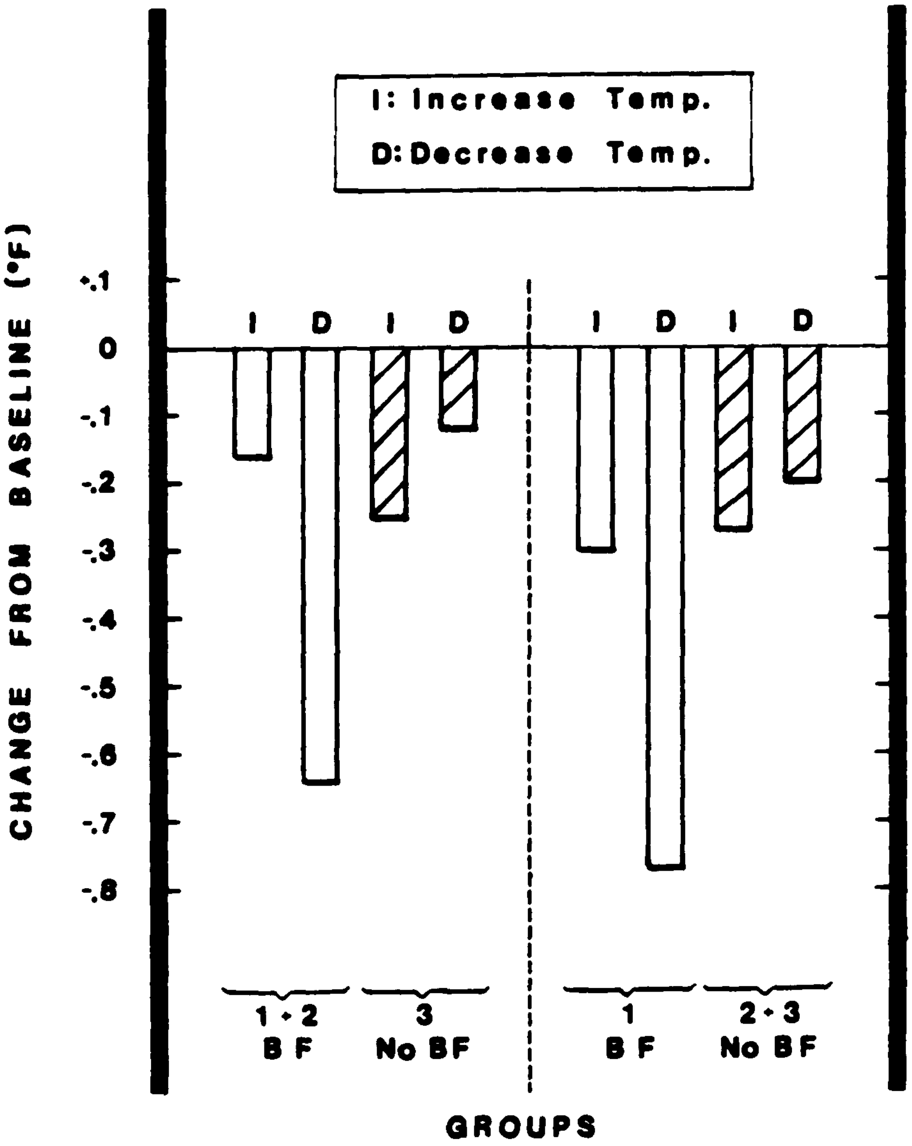

I: Increase Temp.
D: Decrease Temp.
CHANGE FROM BASELINE (°F)
+.1
0
-.1
-.2
-.3
-.4
-.5
-.6
-.7
-.8
I
D
I
D
I
D
I
D
1 + 2
B F
3
No BF
1
B F
2 + 3
No BF
GROUPS

Figure Caption

Figure 3. Mean difference of the differences (DOD) scores (i.e., Minute 5 - Baseline Minute) for all trials of the three groups receiving different probabilities of biofeedback (i.e., Group 1 with 100%, Group 2 with 50%, and Group 3 with 0% of the temperature-control trials containing biofeedback). Horizontal markings indicate ±1 standard error of the mean.

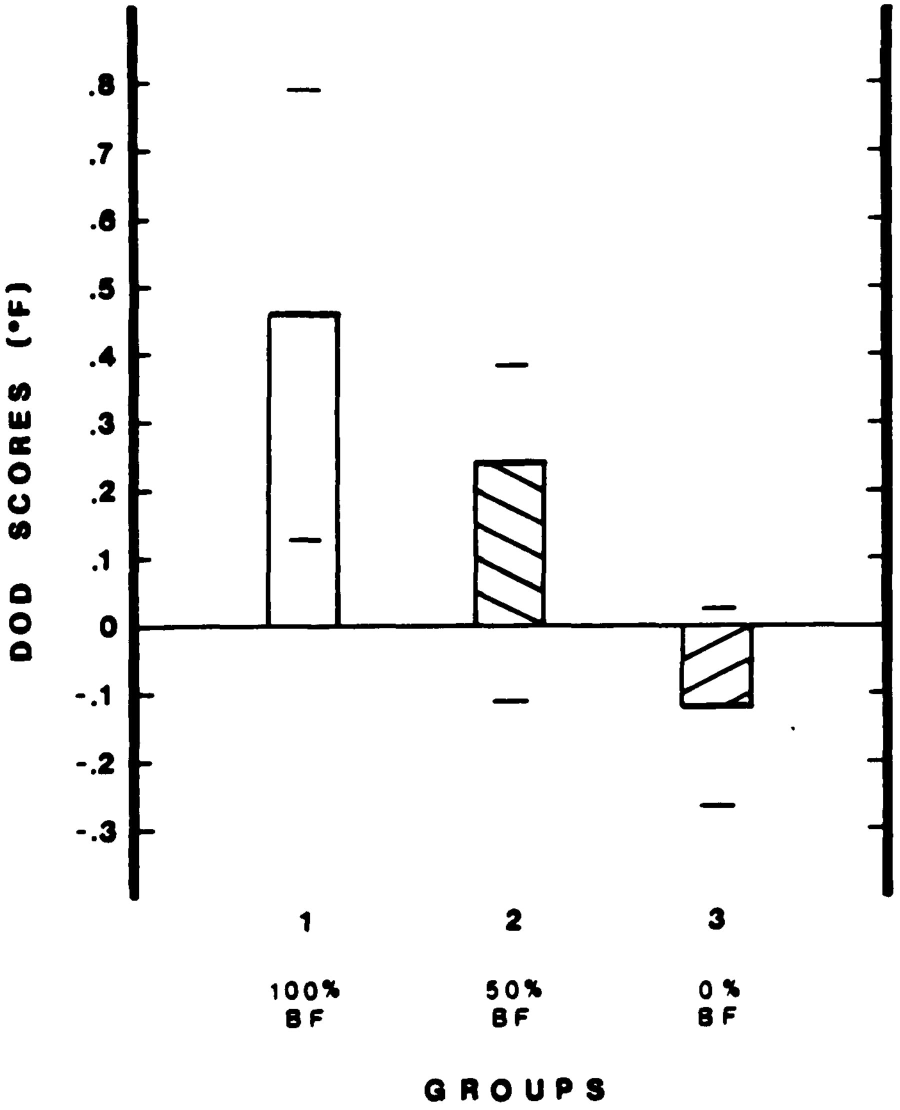

DOD SCORES (°F)
.8
.7
.6
.5
.4
.3
.2
.1
0
-.1
-.2
-.3
1
2
3
100%
BF
50%
BF
0 %
BF
GROUPS

Figure Caption

Figure 4. Mean changes from baseline (i.e., Minute 5 - Baseline Minute) during all increase and decrease temperature-control trials for the three groups receiving different probabilities of biofeedback (i.e., Group 1 with 100%, Group 2 with 50%, and Group 3 with 0% of the temperature-control trials containing biofeedback). Horizontal markings indicate ±1 standard error of the mean.

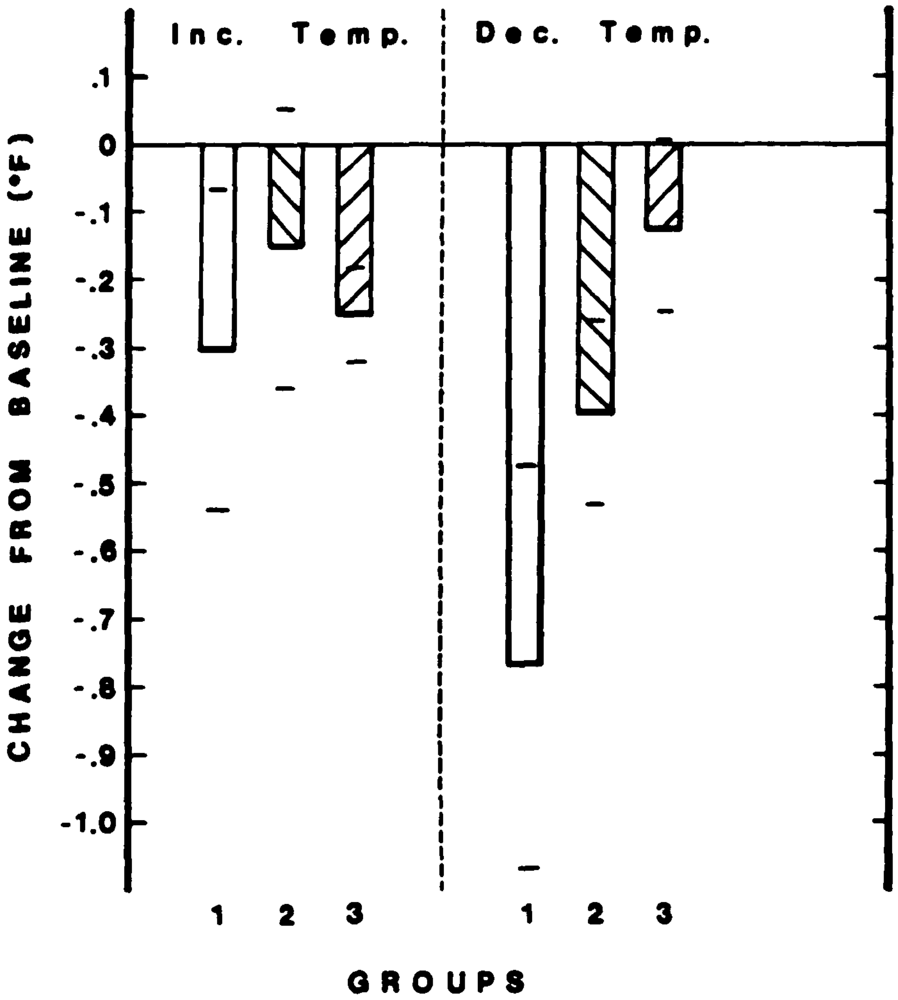

Inc. Temp.
Dec. Temp.
CHANGE FROM BASELINE (°F)
.1
0
-.1
-.2
-.3
-.4
-.5
-.6
-.7
-.8
-.9
-1.0
1
2
3
1
2
3
GROUPS

Figure Caption

Figure 5. Mean difference of the differences (DOD) scores (i.e., Minute 5 - Baseline Minute) for each of the four successive quarters of training for biofeedback (BF) and no-biofeedback (No BF) conditions in both types of subject comparisons.

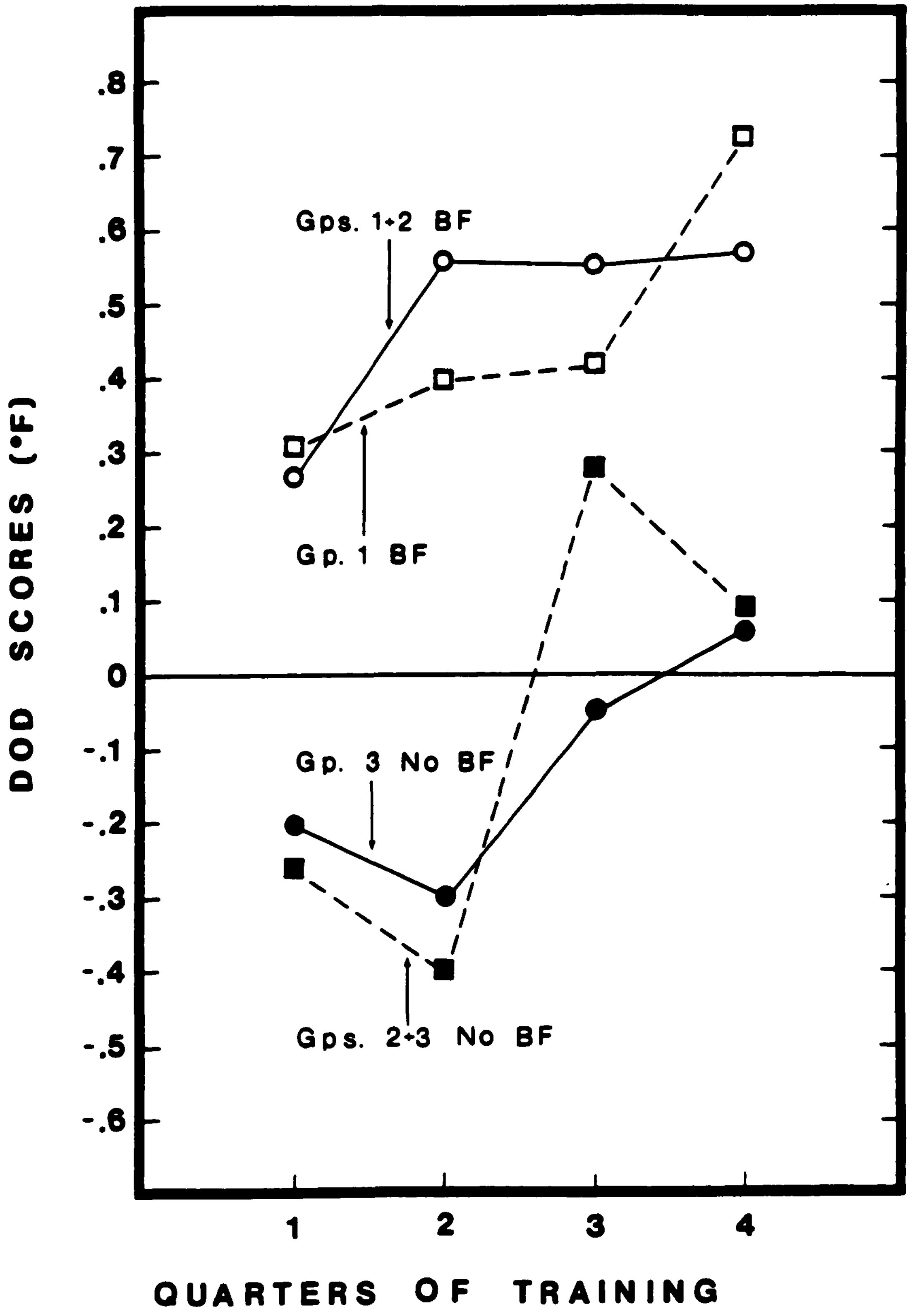

DOD SCORES (°F)
.8
.7
.6
.5
.4
.3
.2
.1
0
-.1
-.2
-.3
-.4
-.5
-.6
Gps. 1+2 BF
Gp. 1 BF
Gp. 3 No BF
Gps. 2+3 No BF
1
2
3
4
QUARTERS OF TRAINING

Figure Caption

Figure 6. Mean changes from baseline (i.e., Minute 5 - Baseline Minute) during increase and decrease temperature-control trials for the four successive quarters of training and for the mean of all four quarters (All) contrasting Group 1 (100% biofeedback), Group 2 (50% biofeedback -- plotting separately biofeedback and no-biofeedback trials), and Group 3 (0% biofeedback).

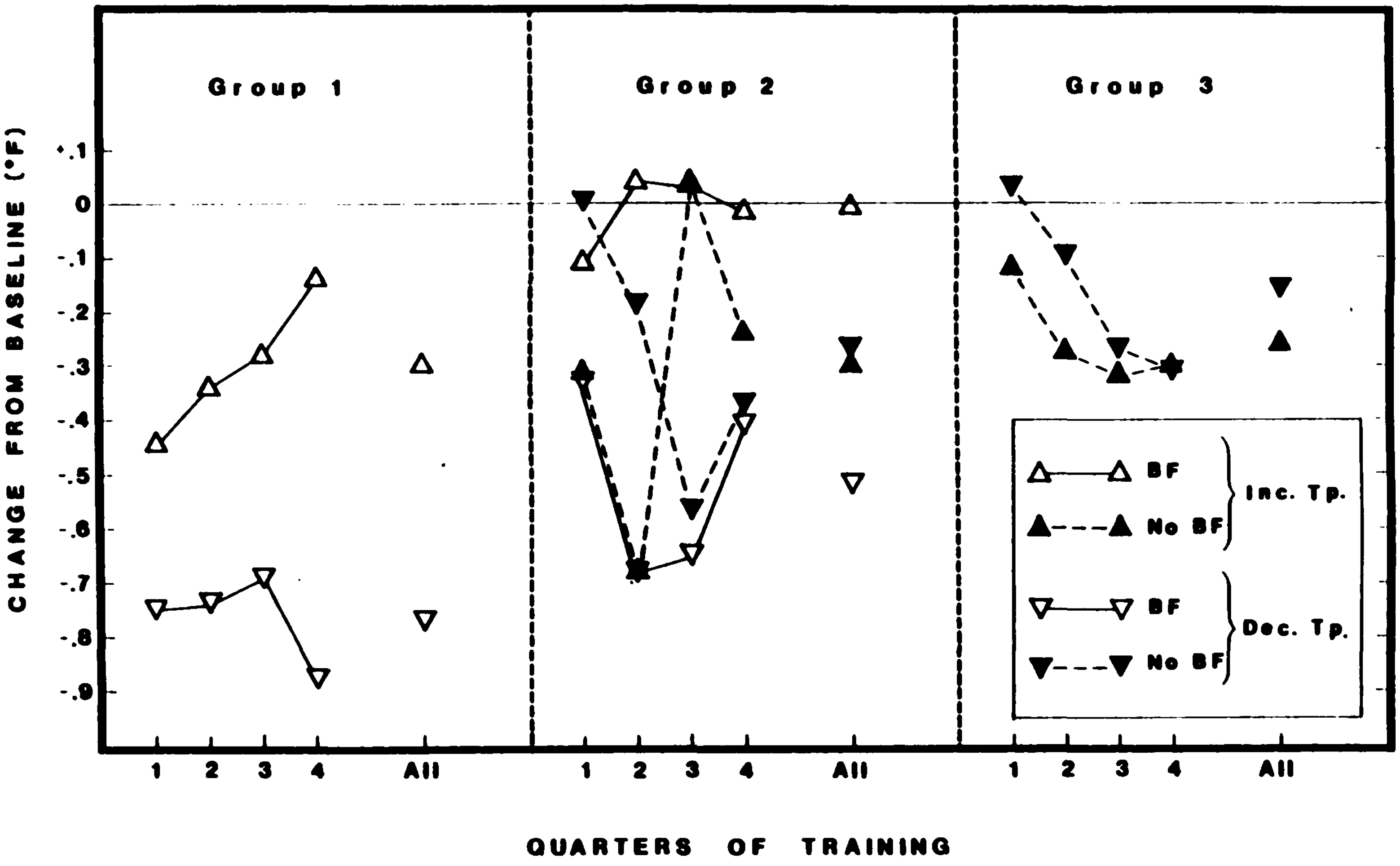

Group 1
Group 2
Group 3
CHANGE FROM BASELINE (°F)
+.1
0
-.1
-.2
-.3
-.4
-.5
-.6
-.7
-.8
-.9
1
2
3
4
All
QUARTERS OF TRAINING
△—△ BF
▲---▲ No BF
Inc. Tp.
▽—▽ BF
▼---▼ No BF
Dec. Tp.

Figure Caption

Figure 7. Mean difference of the differences (DOD) scores for each of the five minutes making up a trial (i.e., Minutes 5, 4, 3, 2, and 1 - Baseline Minute) for biofeedback (BF) and no-biofeedback (No BF) conditions in both types of subject comparisons.

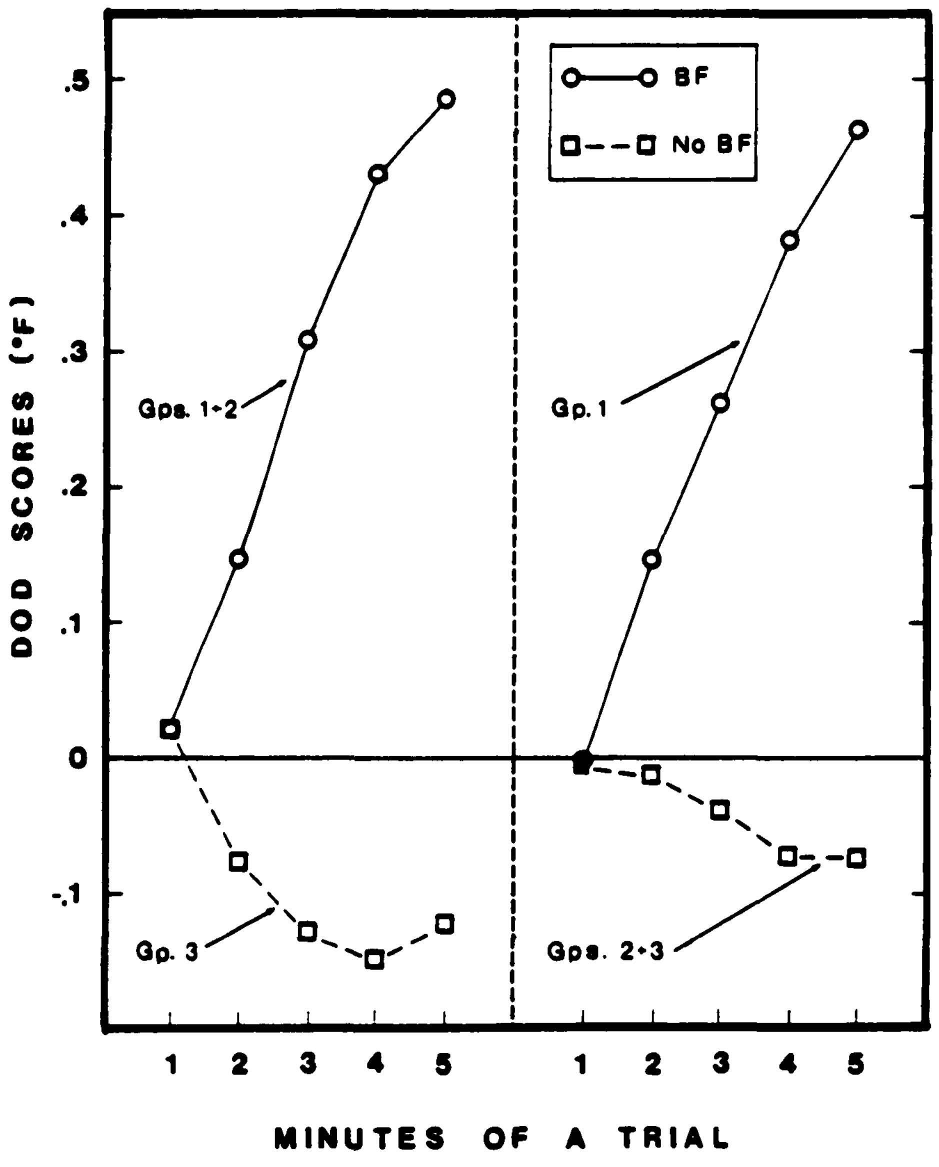
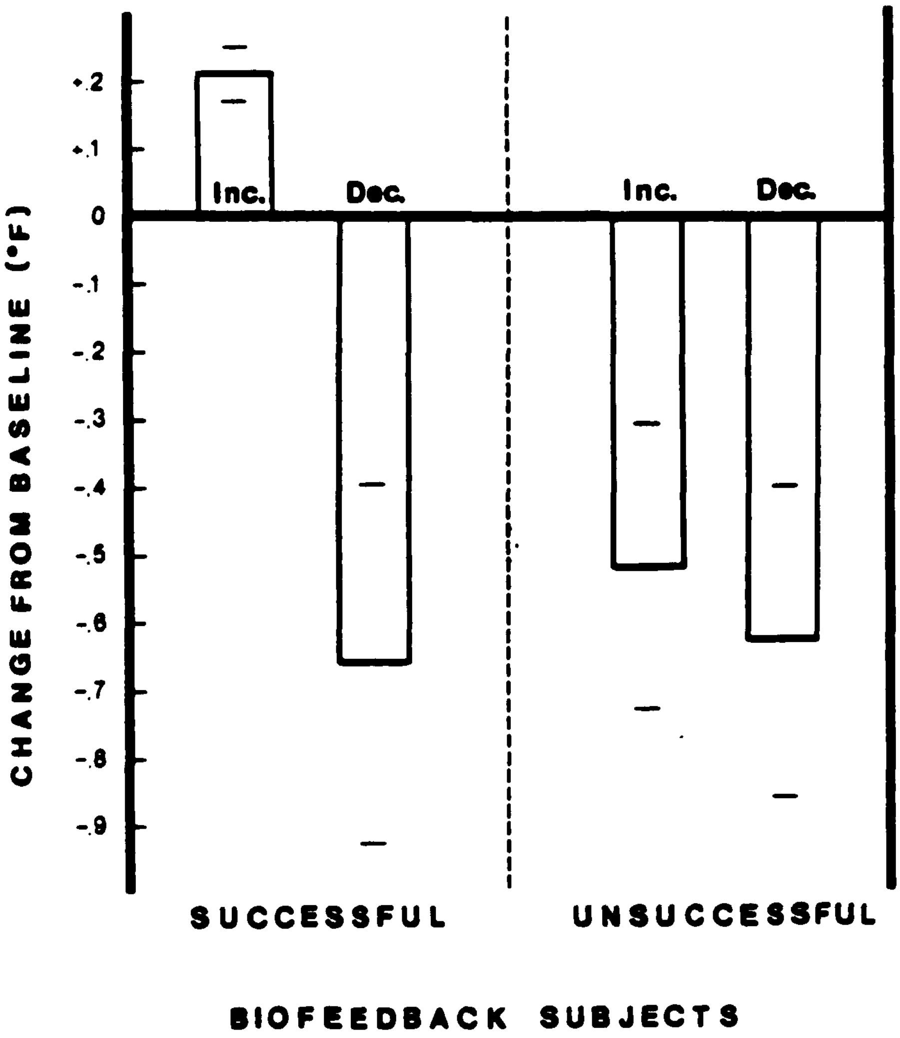

BF
No BF
DOD SCORES (°F)
.5
.4
.3
.2
.1
0
-.1
Gps. 1+2
Gp. 3
Gp. 1
Gps. 2+3
1
2
3
4
5
1
2
3
4
5
MINUTES OF A TRIAL

Figure Caption

Figure 8. Mean changes from baseline (i.e., Minute 5 - Baseline Minute) during increase (Inc.) and decrease (Dec.) temperature-control trials for relatively successful and relatively unsuccessful biofeedback subjects. Horizontal markings indicate ±1 standard error of the mean.


CHANGE FROM BASELINE (°F)
+.2
+.1
0
-.1
-.2
-.3
-.4
-.5
-.6
-.7
-.8
-.9
Inc.
Dec.
Inc.
Dec.
SUCCESSFUL
UNSUCCESSFUL
BIOFEEDBACK SUBJECTS

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