
Biofeedback, Self-Regulation, and the Patterning of Physiological Processes: By training subjects to control voluntarily combinations of visceral, neural, and motor responses, it is possible to assess linkages between physiological responses and their relationship to human consciousness

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Biofeedback, Self-Regulation, and the Patterning of Physiological Processes

By training subjects to control voluntarily combinations of visceral, neural, and motor responses, it is possible to assess linkages between physiological responses and their relationship to human consciousness

Although we do not usually think about it, we are constantly regulating complex patterns of neural and visceral processes in our dynamic interchange with our environment. How often do we ponder the multiplicity of biological processes we must voluntarily orchestrate in order to perform an everyday act like writing a sentence? Not very often; for we usually direct our attention to the goal of our actions rather than reflecting upon the pattern of interacting processes we generate to produce the desired behavior. But if a skill is unique or unexpected—like the feats of bodily or cognitive self-regulation long claimed by certain yogis and meditators, and more recently demonstrated with biofeedback, our fascination with the nature of the processes involved is rekindled.

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It has been found that, if humans and lower animals are provided with (1) new information in the form of biofeedback for internal responses such as heart rate, blood pressure, and electrical activity of the brain, and (2) incentives or rewards for changing or controlling the feedback, they can learn to control voluntarily the physiological responses associated with the feedback. Biofeedback research has raised the question whether responses once considered to be involuntary may be controlled consciously (Miller 1969). It has also stimulated interest in the use of self-regulation techniques in both clinical treatment and in research which seeks to determine the limits of self-control.

Despite the abundance of research in this area (see Barber et al. 1971; Kamiya et al. 1971; Stoyva et al. 1972; Shapiro et al. 1973; Miller et al. 1974), there has been little effort to explain exactly how self-regulation develops or what are the underlying psychobiological mechanisms and constraints (Miller 1974). Most research treats only single responses or response systems and fails to address the more normal but complex phenomenon of the voluntary coordination of multiple physiological processes. Drawing upon research conducted by my colleagues and students over the past six years, I will describe in this paper experiments using biofeedback procedures to teach voluntary control of combinations of responses, and then relate our findings to the broader question of the biocognitive mechanisms involved. This includes our research on the regulation of imagery and emotion and its clinical application to eluci-

dating the mechanisms underlying relaxation, meditation, and other self-regulation therapies. Biofeedback and related cognitive procedures provide a unique and powerful research tool for investigating both the interrelationships among physiological systems and their constraints in the intact human and the role of patterns of physiological responses in the generation of subjective experience (Schwartz 1974, in press).

I hope that this paper will also help to dispel some of the prevailing popular notions about biofeedback. Unfortunately, research on biofeedback and on related cognitive self-regulation procedures such as meditation is tainted by simplistic and at times wild speculation by scientists and journalists alike. It is understandable how research that challenges our basic conception of man's biological structure and psychological capabilities can stimulate novel ideas about basic research and clinical issues, but such theorizing has alienated an important segment of the scientific community. One area of controversy involves the application of visceral self-regulation to psychosomatic disorders; another is the application of brain wave biofeedback to bring about altered states of consciousness. At one extreme are those who argue that biofeedback can enable us to control literally any aspect of our biology at will; at the other extreme are a growing number who dismiss biofeedback as a useless gimmick. I suggest that neither of these extremes is appropriate and that current research on biofeedback from a pattern perspective not only expands our understanding of human self-regula-

tion but helps us to recognize its limitations.

Specificity and the brain

The capacity of the human brain to regulate various dynamic patterns of neural, skeletal, and visceral responses grows out of its extraordinary capacity for response specificity. In this respect the brain is a highly efficient organ, for under most circumstances it is capable of recruiting and coordinating only those sensory, visceral, and motor processes needed to perform a given task. Biofeedback procedures have been applied to the voluntary control of individual skeletal muscles, and Basmajian (1972) has shown that subjects can learn to control individual motor units within a specific muscle when given feedback and reward for activity of the designated unit. He finds that, early in training, adjacent motor units in the muscle are also activated, but as the subject practices controlling the feedback, the irrelevant units drop out. At a more general level, Germana (1968) illustrates how, as subjects learn a variety of cognitive and motor tasks, initial learning is accompanied by increases in multiple responses including heart rate, sweat gland activity, and muscle tension over much of the body. However, as the subject masters the specific task, activation peaking occurs, and the various physiological responses return to levels adjusted to maintaining effective performance. In both of these examples, learned specificity grows out of more general physiological arousal.

The motor system is a good model for conceptualizing the self-regulation of autonomic and electrocortical responses, because it highlights the principle that learning typically progresses from more general arousal to greater response specificity with training. Cardiovascular biofeedback researchers such as Lang (1974) and Brener (1974) have recently begun to emphasize specificity of motor skill learning and its interaction with biofeedback. In my laboratory we have applied to heart rate control Fleishman's (1966) model for understanding the acquisition of autonomic skills. Fleishman describes five basic components of complex motor skills:

strength, endurance, steadiness, control precision, and reaction time. With few exceptions, biofeedback research has used a combination of the strength and endurance paradigms—the subject's task being to increase or decrease the frequency or amplitude of the response as much as possible and sustain the effect for some period of time (e.g. a minute). Schwartz, Vogler, and Young (in press) have developed a different autonomic skill—a cardiac reaction-time paradigm—in which the subject's primary task is to raise (or lower) his heart rate as quickly as possible at the onset of the trial, briefly holding control for 3 consecutive seconds. On the basis of the motor skills literature, we predicted that specificity of cardiac skill learning would show little transfer of training between the strength-endurance and the reaction-time skills. Our experiment bore out the prediction.

This finding of specificity of skill learning *within a single autonomic response* underscores the power of biofeedback procedures to tap specific capabilities for learned self-regulation normally not exercised by human beings. The study may be taken as one model for studying the similarities and differences between specific motor and visceral self-regulatory processes. However, the specific-skills approach to biofeedback leads us away from rather than toward the major concern of this paper—the nature of self-regulation of combinations of responses. We did not recognize the full importance of learned specificity with biofeedback until we were confronted with selective voluntary control of systolic blood pressure versus heart rate; this discovery prompted the development of pattern biofeedback procedures.

Systolic pressure and heart rate control

One of the most convincing, but initially surprising, illustrations of the specificity of human self-regulation in the autonomic nervous system emerged in our early studies on the self-regulation of systolic blood pressure and heart rate (Shapiro et al. 1969; Shapiro, Tursky, and Schwartz 1970a, 1970b). In the first two experiments, subjects were given binary (on/off) feedback (a

light and tone) at each heart beat when systolic blood pressure was either higher or lower than the median blood pressure for a 50-beat trial (Tursky, Shapiro, and Schwartz 1972). Subjects were instructed to make the feedback light and tone occur as often as possible; however, they were not told the nature of the response or the direction in which it was to change. As an added incentive, subjects were shown bonus slides after every 20 feedback stimuli (in the early studies, the all-male subjects were shown pictures of nude females; later, a variety of rewards including travel slides and monetary bonuses were added). The results of both experiments showed that, in a single experimental session, subjects could exert relative self-control over their blood pressure and that these changes were independent of heart rate.

In the third experiment, the procedure was reversed; subjects were given feedback and reward for raising and lowering heart rate while systolic blood pressure was monitored; here subjects showed relative self-control of heart rate independent of blood pressure. As we discovered from postexperimental questionnaires, the essentially *uninstructed* subjects did not report using consistent cognitive or somatic strategies; for example, those who decreased their blood pressure or heart rate did not use relaxing imagery more frequently than those who increased these responses.

Given the complex physiological constraints between these two responses (heart rate, in addition to stroke volume and peripheral resistance, can act as a physical determinant of blood pressure), the ease and speed with which specificity was learned was surprising. The biofeedback results seemed to be pointing to something specific about the behavioral relationship (presumed but not explicitly measured) between the two responses (Schwartz 1972).

If systolic blood pressure and heart rate were so related over time that increases in one were always associated with increases in the other, then when an experimenter gave feedback and reward for one, he would unwittingly provide it for the other as well. Therefore, we would

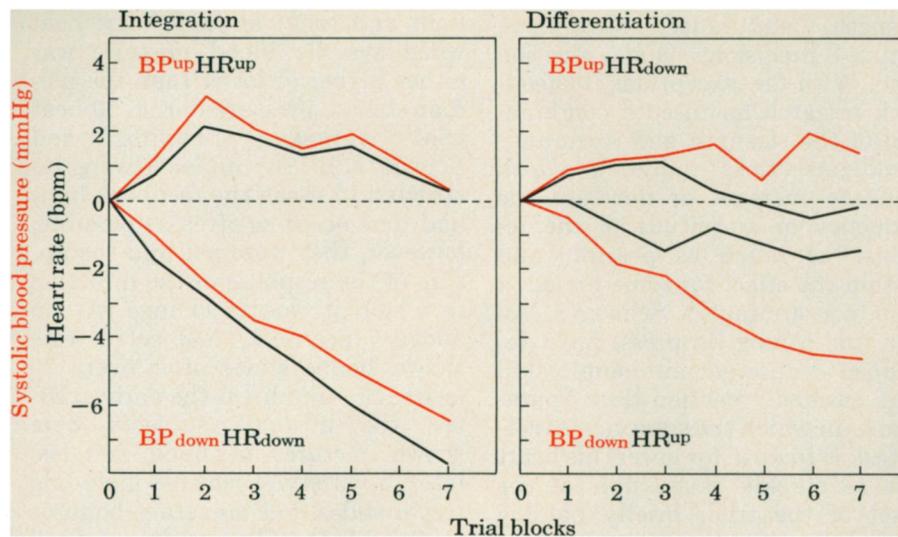


Figure 1. A strong blood pressure–heart rate (BP–HR) integration constraint emerges with pattern biofeedback. In one experiment, each of 4 groups of subjects received biofeedback for one of the 4 possible BP or HR patterns. Simultaneous control of systolic blood pressure (color) and heart rate (black) was achieved rapidly when subjects were required to integrate these functions (raising or lowering them together) (left).

When subjects were required to differentiate the two—to make blood pressure change in the opposite direction from heart rate—only moderate control was attained (right). Curves represent the mean of 10 subjects, 5 trials each, set to zero by the pre-experimental baseline values; beats per minute and millimeters of mercury are therefore on the same axis. (From Schwartz 1972.)

expect that both functions should be learned simultaneously and in the same direction. But if these two functions were so related that when one increased, the other simultaneously decreased, then if feedback and reward were given for one, the other would simultaneously receive the opposite inducement. Both functions should again be learned, only now in opposite directions. However, since neither of these findings was empirically obtained in our prior research, it would follow that systolic blood pressure and heart rate must be so related that binary feedback for one causes simultaneous *random* feedback for the other.

If this were so, how could a subject be taught to control both processes? One approach might be to give the feedback and reward only when the desired *pattern* of responses occurs. In theory, it should be possible to teach a person to integrate his systolic blood pressure and heart rate voluntarily (make both functions increase or decrease together) or differentiate them (make them go in opposite directions) by providing feedback and reward for the desired pattern. The required procedure for tracking, in

real time, patterns of phasic and tonic changes in both systems was developed based on the binary feedback model that detected at each heart beat whether blood pressure and heart rate were in one of the 4 possible states: $BP^{up}HR^{up}$, $BP^{up}HR^{down}$, $BP^{down}HR^{up}$, or $BP^{down}HR^{down}$ (Schwartz, Shapiro, and Tursky 1971).

If behavior operated without physiological constraints, a straight behavioral analysis of the feedback–response relationship could alone predict learned patterning. But these predictions would fail to the extent that biological constraints are operative. This realization led to the hypothesis that, by determining the ease with which subjects could learn both to integrate and to differentiate various combinations of physiological responses, it would be possible to uncover and assess natural biological relationships in the intact human (Schwartz 1972). Quite unexpectedly, the pattern biofeedback procedure was found to be a far more sensitive indicator of underlying constraints than the single-system biofeedback procedure.

We next performed an experiment

using binary feedback and instructions like those of the initial studies, but with four groups of subjects, each of which received biofeedback for one of the four possible BP–HR patterns (Schwartz 1972). Analysis of the resting frequency of the BP–HR patterns indicated that each occurred spontaneously about 25% of the time; this supported the initial prediction that systolic BP and HR are phasically unrelated, at least from the point of view of a simple binary feedback system. However, as can be seen in Figure 1, pattern feedback uncovers strong constraints between the systems that were not exposed with single-system training.

When subjects were required to produce an integration pattern ($BP^{up}HR^{up}$ or $BP^{down}HR^{down}$) they showed simultaneous control of both blood pressure and heart rate in the same direction. This is in contrast to the previous findings, which showed specific control of one response without simultaneous changes in the other. More important, however, is that feedback for the integration patterns produces more rapid learning and somewhat larger changes than biofeedback for the single systems alone! The findings for the differentiation conditions bore out this conclusion. Although the curves suggest that some $BP^{down}HR^{up}$ and $BP^{up}HR^{down}$ control was achieved, the magnitude of control was substantially less than that obtained for integration control.

An additional finding of particular importance to the pattern concept was that when subjects were taught to lower *both* functions simultaneously (as opposed to lowering either function alone), they began spontaneously and consistently to report feelings of relaxation and calmness, a subjective state we would expect to be associated with more diffuse physiological relaxation. If we recall that these subjects were told nothing about the precise meaning of the feedback, this finding becomes even more significant. In the attempt to understand and extend biofeedback techniques to patterns of responses, the research uncovers new information about the nature of the physiological systems and constraints and their relation to subjective experience.

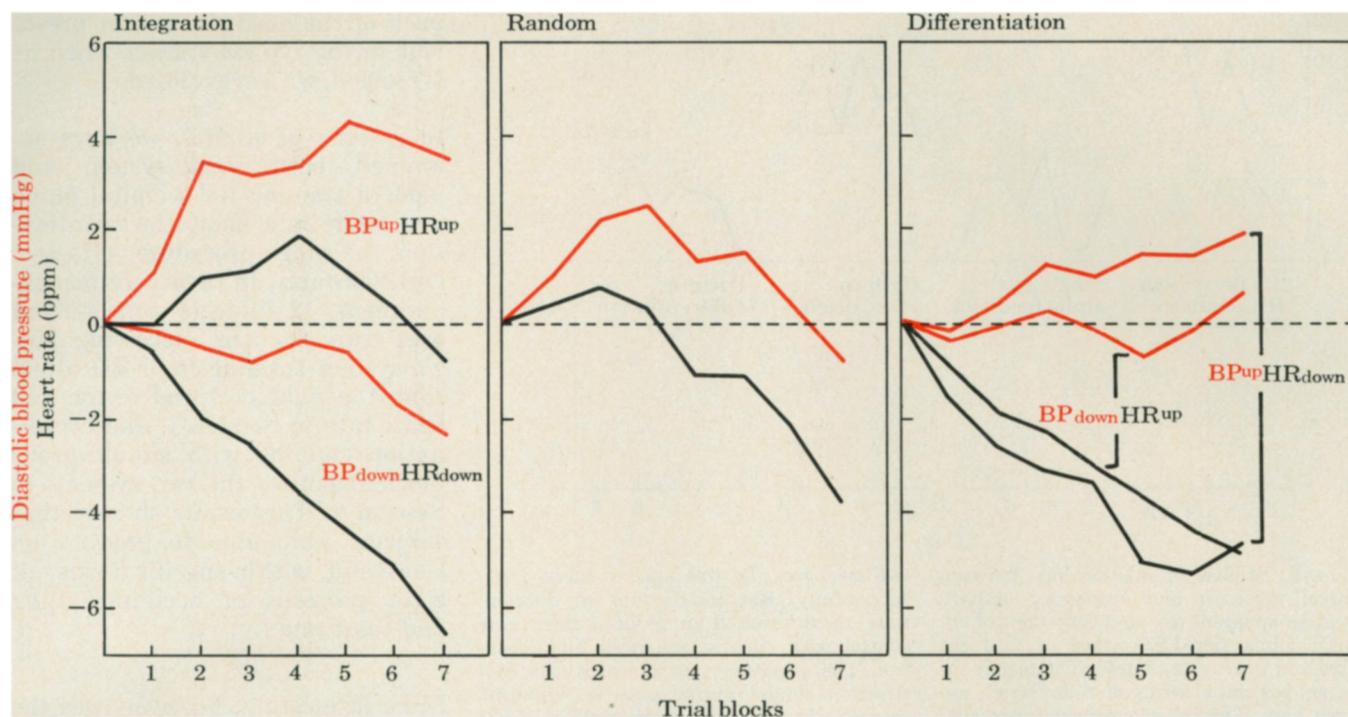


Figure 2. In order to assess accurately a subject's ability to regulate patterns of internal responses, the results for feedback groups must often be compared with results obtained for groups given random biofeedback. In this experiment, in the random condition (center), diastolic blood pressure

(color) and heart rate (black) not only do not remain constant over a session but change at different rates. Subjects required to integrate BP and HR (left) were able to do so rapidly; but subjects required to differentiate the two responses (right) showed no ability to separate them beyond their

normal divergence in the random condition. Curves represent the mean of 10 subjects, 5 trials each, set to zero by the pre-experimental baseline values; beats per minute and millimeters of mercury are therefore on the same axis. (From Schwartz 1974.)

Diastolic pressure and heart rate control

Shapiro, Schwartz, and Tursky (1972) observed that, when uninstructed subjects were given direct binary feedback and reward for *diastolic* as opposed to systolic blood pressure, some covariance of heart rate control also occurred. An important finding was that the learned changes in diastolic blood pressure emerged earlier in the session than those for heart rate, and the magnitude of the heart rate change was smaller than that previously observed for direct heart rate biofeedback.

On the basis of these observations, we predicted that diastolic blood pressure and heart rate must be partially (but not completely) phasically integrated. Consequently, biofeedback for the pressure would result in partial (but not complete) feedback for comparable heart rate changes as well; this would explain why some learning of heart rate control occurred with diastolic pressure biofeedback. Analysis of the resting BP-HR patterns

confirmed that the two responses changed spontaneously in the same direction about two-thirds of the time. In light of this apparent phasic constraint, we predicted that subjects should be readily able to integrate their diastolic blood pressure and heart rate at will, but they would find it extremely difficult to differentiate them. We performed an experiment modeled after the previously described (Schwartz 1972) pattern experiment but added a fifth group as a control, to be given random feedback and reward (Schwartz, Shapiro, and Tursky 1972). The results are shown in Figure 2.

The curves for random feedback reveal that the baselines for diastolic blood pressure and heart rate not only do not remain constant over the session but change at relatively different rates (HR lower than BP). Thus, to assess learning over time accurately, self-regulation must be measured vis-à-vis the changing baselines that are exposed, for example, by comparison with a random feedback control group (Cridder, Schwartz, and Shnidman

1969). Note that for integration feedback, rapid learning of both diastolic pressure and heart rate occurs; again, the rate of growth in learning is greater than that obtained for single-system biofeedback. This finding is contrasted with the results for the two differentiation conditions, which show essentially no evidence of separation beyond that occurring with random feedback.

These data support the notion that the resting phasic relationship observed between diastolic blood pressure and heart rate reflects a biological constraint. However, it should be emphasized that a simple correlation of two responses over time does not necessarily indicate a causal relationship between them. A causal relationship can be proved only by determining the ease with which the two responses can be separated—for example, using the self-regulation pattern strategy described here. Further, an accurate assessment of the degree to which such relationships are fixed requires additional sessions of training. Unfortunately, with the exception of

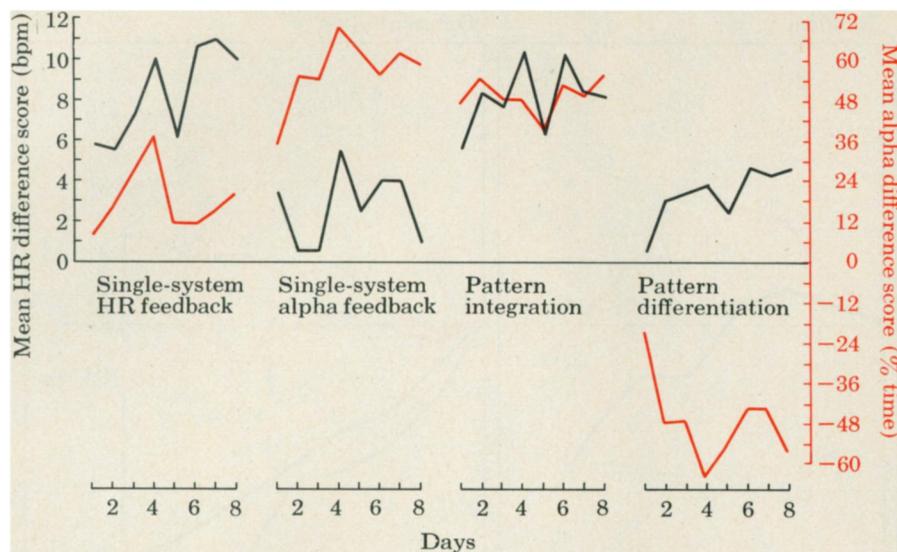


Figure 3. Studies of relationships between cortical processes and autonomic activity reveal an apparent one-way constraint of occipital alpha (an EEG wave of 8-13 hz; color) and heart rate (black). The results for one subject in a series of 8-day tests are shown here. The subject achieved very specific control in the single-system response tests, and when instructed to integrate the

two responses, he was able to do so fairly successfully. But instructions to differentiate them resulted in reduced heart rate control with slightly enhanced alpha control. The consistency with which this constraint is found during pattern regulation suggests that occipital alpha may influence heart rate, but not vice versa. (From Hassett and Schwartz, in press.)

the experiment to be described below, multisession pattern studies have not yet been reported.

EEG and heart rate control

If pattern biofeedback training can be used effectively to study relationships *within* the autonomic nervous system, then perhaps the pattern approach may have more general use in investigating integrations and constraints across sensory, visceral, and motor systems (Schwartz 1974; Black 1974). My laboratory has recently been using the pattern biofeedback approach to examine the role of cortical processes in the self-regulation of autonomic activity. At the outset, it became clear that it would be desirable to teach an individual rapidly to regulate, on command, a host of different patterns of EEG and autonomic activity, so as to reduce problems of intersubject variability and to enable us to assess the stability of constraints over time.

Learning to perform a dual task—for example, rubbing the stomach with one hand and patting the head with the other—can be difficult. One way to achieve a patterned skill is to practice each response

alone and then coordinate the two. This training strategy is valuable for a number of reasons. Unlike the direct pattern feedback approach, which requires digital logic or computer facilities to quantify complex patterns on-line to provide feedback (we currently use a PDP11 system for measuring multiple responses on-line), the coordination approach requires simple biofeedback equipment. Separate portable devices for different responses can be used to train combinations of responses outside the laboratory. In addition, this procedure stimulates the subject to develop self-control naturally. He is allowed to experiment at his own pace in learning what strategies are effective for increasing and decreasing the feedback (Engel 1972), and the “free play” periods interspersed with test trials make the task both more challenging and more rewarding.

Previous single-system studies have suggested that, while heart rate control has no appreciable effect on EEG from the occipital region (Schwartz, Shaw, and Shapiro 1972), self-regulation of occipital alpha may have a small effect on heart rate (Beatty and Kornfeld 1973). Occipital alpha is an EEG wave of 8–13 hz recorded from the

back of the head. It is most prevalent in the typical subject when he is relaxed, with eyes closed.

In a series of studies, we have examined both single-system and pattern training for occipital alpha and heart rate using the coordination training procedure (Hassett and Schwartz, in press). In one experiment, 12 subjects were studied over two sessions, receiving single-system training for EEG alpha from the right occipital region and heart rate in Session 1, and coordination training with simultaneous biofeedback for the two systems in Session 2. The results showed that subjects were able to produce on command, within specific limits, all eight patterns of occipital alpha and heart rate.

More interesting, however, was the consistency of the alpha-heart rate constraints. The results showed that occipital alpha regulation influenced heart rate, while the opposite was not the case. This effect was especially evident in the pattern conditions, where heart rate control was actually enhanced when alpha was simultaneously self-regulated in an arousal pattern (e.g. $HR^{up\alpha^{off}}$). Conversely, differentiation of heart rate and alpha led to an impairment of heart rate regulation, compared to single-system heart rate control. These results were maintained even when subjects were tested after training without feedback.

Three subjects have been run for 8 training sessions, and the results, especially for the pattern conditions, are quite consistent from day to day. A particularly good self-regulation subject, showing exceptional specificity during single-system control in both responses over the 8 days, is shown in Figure 3. Whereas during integration he produced substantial regulation of both responses, during differentiation he showed reduced heart rate control and slightly enhanced alpha control (but in the opposite direction, as expected). The consistency of this pattern effect with repeated training and testing makes the concept of a one-way occipital alpha-heart rate constraint more compelling. When two of the subjects were posttested, in a ninth session 7 months after the training sessions,

self-regulation of the patterns was retained, as was the alpha-heart rate constraint.

Cognitive mechanisms in pattern control

Given that subjects can learn with the aid of pattern biofeedback training to regulate combinations of autonomic and brain wave activity, the next question is, How do they do it? We might begin by asking them—and this leads us to the question of the relationship between cognitive strategies and the control of particular patterns of physiological activity. Can cognitive processes elicit or “mediate” patterned physiological changes?

The idea that cognition was an epiphenomenon, either unimportant or downright interfering, was long held by strict behaviorists and is still in vogue in some quarters. Katkin and Murray (1968) went so far as to conclude that, in order to demonstrate true instrumental conditioning of an autonomic response in humans, it would be necessary for the subjects to be paralyzed by curare (to remove overt skeletal mediators) and to be rendered unconscious (to eliminate cognitive mediators)! In reply to this article, Crider, Schwartz, and Shnidman (1969) pointed out that there was surprisingly little experimental data from which to argue that cognitive events could influence discrete physiological responses in the first place. More recently, Kimmel (1974) in an evaluation of the blood pressure-heart rate pattern findings, stated that “mediationists may also have to become cognitive contortionists to deal with data such as these.” However, data and theory have made substantial progress over the past six years, and Kimmel’s conclusion needs to be qualified.

Carefully controlled studies have demonstrated that cognitive activity can elicit physiological responses (McGuigan and Schoonover 1973). Self-induced affective thoughts can themselves elicit increases in heart rate (Schwartz 1971). In another experiment (Schwartz and Higgins 1971), generating a verbal image (silently thinking the word “stop”) at the end of a 5-second light elicited anticipatory time-locked

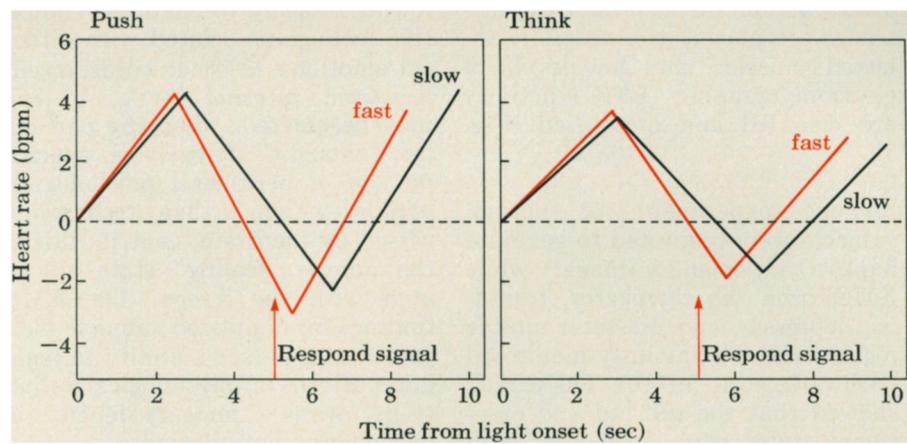


Figure 4. Studies have shown that cognitive activity can elicit physiological responses. In one study, silently thinking the word “stop” at the end of a 5-second warning light produced (right) changes in heart rate comparable to those elicited when subjects responded overtly to the signal by pushing a button (left). In both cases, fast responses to

the signal (colored curves) are preceded by a slowing down of heart beat that reaches its trough sooner than if the same task is performed slowly (black curves). Curves represent mean heart rate values at critical points in the trial for 20 subjects. (From Schwartz and Higgins 1971.)

changes in heart rate comparable to those observed when subjects performed a simple task (pushing a button). As shown in Figure 4, fast button-presses are preceded by a cardiac deceleration that reaches its trough sooner than if button-presses are made deliberately slow; the identical, although slightly attenuated, anticipatory heart rate curves are generated when the same paced task is performed cognitively with no obvious overt response. In other words, thoughts can act as both “stimuli” and “responses” with predictable physiological consequences.

The question remains whether there is any evidence that classes of cognitive events can elicit specific patterns of physiological responses corresponding to those regulated through biofeedback. And if so, are we therefore justified in concluding that the strategies reflect underlying neural mechanisms involved in regulating the physiological changes? In the clinical area, in a series of classic studies in the 1950s (reviewed by Graham 1972), Graham and his associates demonstrated that various psychosomatic disorders were associated with definable attitudes in patients. For example, hypertensive patients reported feeling threatened with harm and having to be ready for anything. Further, when such attitudes were suggested to normal subjects under hypnosis, the

suggestion elicited measurable changes that mimicked the patterns originally observed in the patients. It is unfortunate that these early studies have not been followed up, for current advances in psychophysiology and neuropsychology provide a framework in which such findings can be understood.

Patterns of facial muscle activity

Drawing on Darwin’s early observations of emotion in lower animals and man (1872), Ekman, Friesen, and Ellsworth (1972) and Izard (1971) have provided experimental data indicating that specific facial expressions reflect distinct emotions which are innate and universal, although their overt manifestation can be regulated to some extent. Of particular importance for the self-regulation pattern concept is Izard’s neurophysiological theory of emotion, which postulates that discrete patterns of facial and postural muscle activity are processed in parallel and integrated by the brain and, in fact, make up a significant component of the conscious experience of emotion.

We have recently extended this concept to self-regulated imagery, demonstrating that small but discrete patterns of facial muscle activity are reliably generated when a person simply thinks about prior emotional experiences (Schwartz et

al. 1974a, b; in press a, b). Electrodes are placed over carefully selected muscles, and low levels of electromyographic (EMG) activity are recorded and quantified (Fig. 5).

In one experiment 12 normal subjects were requested to generate happy, sad, or angry imagery while EMG from the corrugator, frontalis, depressor, and masseter muscle regions was continuously monitored (Schwartz et al. 1974b). The results showed that the self-induced emotional states were associated with identifiable "covert" facial expressions not typically noticeable by either the casual observer or the subject himself. As seen in Figure 6, "happy" imagery in normal subjects is associated with decreases in corrugator EMG below resting levels, while "sad" imagery produces increases in corrugator EMG. On the other hand, "angry" (more than "sad") imagery elicits reliable activity over the depressor region of the mouth.

It is interesting to note the similarity in the normal subjects' "happy" and "typical day" graphs in Figure 6. Asked to think about a "typical day," normal subjects generated an EMG pattern very like the happiness pattern. Another comparison of interest is between the normal results and those obtained from 12 subjects who were clinically depressed. In the depressed state people characteristically feel sad, blue, and often angry. At the same time, they feel incapable of making themselves feel happy—that is, of regulating a happy state. The EMG patterns for the four imagery conditions provide objective support for this generalization. While depressed subjects produce EMG patterns comparable to those of normal subjects for sadness and anger, they show attenuated EMG patterns for the self-induced happy condition. And when depressed subjects are asked to think about a typical day, the resulting EMG pattern is one of sadness.

The ability of affective imagery to produce discrete muscular patterns supports the view that specific self-induced cognitive states can generate discrete bodily patterns, and that these heretofore unnoticed somatic patterns may serve as a major physiological mechanism al-

lowing imagery to elicit the subjective feelings associated with different emotions. In other words, a self-regulated internal feedback loop may be created, when the particular "thought" triggers a specific pattern of peripheral physiological activity which is then itself reprocessed by the brain, contributing to the unique "feeling" state associated with the image. The EMG findings for depressed subjects indicate that a person's ability to regulate patterns of physiological activity by means of imagery depends in part on his emotional state.

Patterns of hemispheric asymmetry

Another important illustration of how self-regulated cognitive processes can be associated with discrete patterns of physiological activity has emerged recently from studies of hemispheric asymmetry and human behavior. By means of a variety of EEG and behavioral indices, it has been found that cognitive tasks requiring verbal or sequential processes are associated with activity in the left hemisphere of the brain (in the normal right-handed subject), while tasks requiring spatial, musical, or simultaneous processes tend to be associated with activation of the right hemisphere (Galín and Ornstein

1972; Kinsbourne 1972; Kimura 1973).

If the pattern perspective on self-regulated physiological activity can be generalized, then, on the basis of the analogy with tasks requiring dual motor skills, self-regulated patterns of cognitive and affective processes may be considered complex neuropsychological skills with associated physiological response patterns. For example, Schwartz, Davidson, Maer, and Bromfeld (1974) have observed that speaking the lyrics to a familiar song in a monotone produces relative activation of the EEG (alpha^{off}) over the left hemisphere, while whistling the song produces relative activation of the EEG over the right hemisphere. We would hypothesize that singing, a dual skill pattern, is a complex task involving, at least initially, activation and coordination of both hemispheres. The EEG data bear this out.

Similarly, we have found that the nonverbal component of emotion (like music, which long has been used as a stimulus for influencing mood) involves the right hemisphere. Questions involving both verbal (left hemisphere) and emotional (right hemisphere) processes (e.g. What is the primary difference in the meaning of the words "anger" and "hate?") accordingly elicit evidence of dual hemispheric activation. Questions that involve both spatial (right hemisphere) and emotional (right hemisphere) processes (e.g. Picture your father's face—what emotion first strikes you?) elicit evidence of accentuated right hemispheric activation.

The hemispheric asymmetry data are important because they lead us to dissect complex self-regulated cognitive tasks or "states" into components that make neuropsychological sense. Once the basic processes have been isolated, we can investigate how the components can be voluntarily combined into more complex gestalts with their associated physiological pattern correlates. Subjects may then be trained with biofeedback to regulate specific patterns of EEG activity across the hemispheres and to relate these physiological states to specific underlying cognitive and affective experiences.

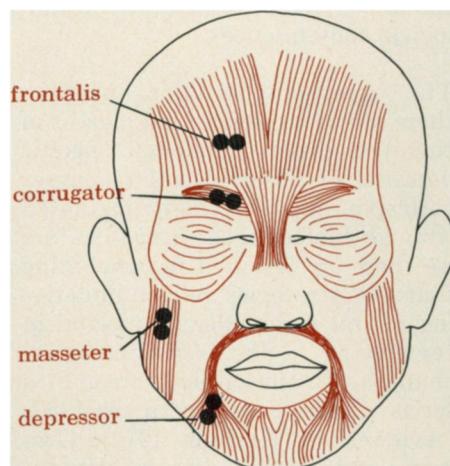


Figure 5. Emotional states are associated with identifiable covert facial expressions that may not be readily discernible to either the casual observer or the subject himself. The expressions may be monitored by recording and quantifying electromyographic (EMG) activity by means of electrodes placed over specific muscles. The muscles involved and the positioning of the electrodes are shown here. (From Schwartz et al. 1974b.)

Cognitive and somatic patterning

As compelling as these data are, are we justified in concluding that *all* physiological self-regulation has a discrete or identifiable cognitive referent? Clearly, regulation of specific muscles or patterns of motor behavior is not necessarily associated with specific cognitive referents (if asked How do you move your arm? most people cannot tell you). Similarly, control of individual physiological responses may not typically have identifiable subjective states. But we can hypothesize that certain self-regulated *patterns* of sensory-autonomic-motor activity do have strong subjective referents, and when a person generates those subjective experiences, he is also regulating their associated physiological patterns.

Humans, unfortunately, are not very good at observing and categorizing internal sensations. Therefore we must avoid taking subjects' reports at face value and must place such reports in a neuropsychological framework if we are to understand them. When subjects are simply *instructed*, without feedback, to "control and raise your heart rate" when one light comes on and to "control and lower your heart rate" when another light comes on, the typical subject almost immediately produces up-minus-down differences in heart rate on the order of 8 beats per minute (Bell and Schwartz, in press).

When these instructed subjects are asked later to list what kinds of thoughts they used, they report generating angry, aggressive, tense, or sexual fantasies while raising heart rate, and quiet, relaxing fantasies while lowering it. This consistency in subjective strategy is very different from that observed in the previous single-system studies, where subjects were not so instructed. Instructions lead subjects to draw immediately on previously learned cognitive strategies; the few data on this suggest that such instructions actually elicit patterns of autonomic arousal out of which specificity can grow with biofeedback training (Klinge 1972; Brener 1974).

But to what extent are these cognitive images the sole mechanism

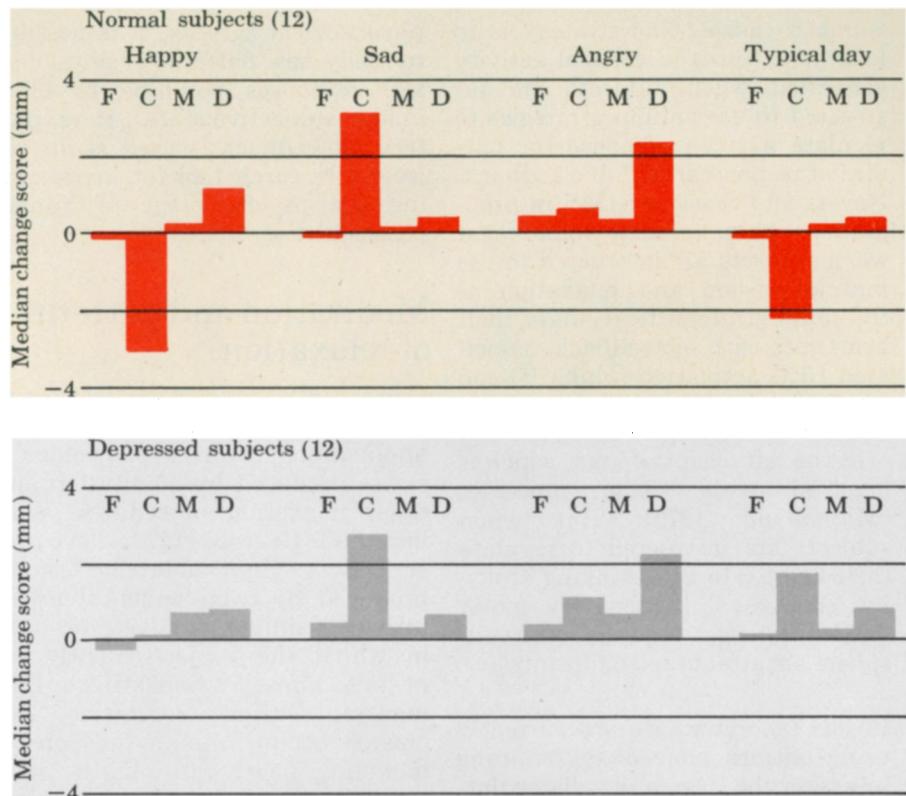


Figure 6. Changes in facial muscle tension (EMG) were monitored for 12 normal subjects (colored bars) and 12 depressed subjects (black bars), who were instructed to generate imagery for happiness, sadness, anger, and a "typical day." The muscle regions monitored, the frontalis (F), corrugator (C), masseter (M), and depressor (D), are shown in Figure 5. For the normal subjects, the 3 classes of affective imagery

elicit different EMG patterns, while the "typical day" imagery produces a miniature "happy" pattern. The depressed subjects show strong EMG patterns for sad and angry imagery, but they are less able to generate a "happy" image pattern; for them the "typical day" EMG pattern is one of sadness. The data represent integrated EMG, with 1 mm = 45 microvolts/30 sec. (From Schwartz et al. 1974b.)

eliciting the observed heart rate changes? If subjects were directly instructed to "make yourselves aroused by thinking arousing thoughts," this should presumably elicit large heart rate changes, comparable to those observed with "control and raise" instructions. But this hypothesis does not take into account that one of the major physiological determinants of heart rate is somatic activity and associated metabolic demands (Obrist et al. 1974). Obrist and his colleagues have shown that, as subjects are given, via instructions, more and more freedom to move around and use their muscles in the heart rate biofeedback situation, larger and larger heart rate increases are observed.

In light of these findings, Bell and Schwartz (1973) predicted that simple instructions to "think arousing thoughts," without mentioning control of heart rate, would not generate large heart rate increases

in comparison to "control and raise" instructions. We hypothesized that the "think" instructions would lead subjects to direct so much of their attention to the generation of imagery per se that this would produce a relative inhibition of general body movement; on the other hand, the "control" instructions would lead the subjects actively to generate subtle movement commands in concert with the imagery, even though they might not be aware of it. When this experiment was performed, our prediction was confirmed. Apparently there is a major difference between *having* a fantasy and *acting* upon it.

We are only beginning to accumulate data on combinations of cognitive and somatic mechanisms in biofeedback, and many questions remain. Recording discrete patterns of physiological activity selected because of their neuropsychological association with the processes under study is a fruitful direction in

which to move. One strategy is to look at patterns of cortical activity generated when subjects are instructed to use various strategies to regulate a given response (or pattern of responses) with biofeedback. Neyers and Schwartz (MS in preparation) have recently found that when subjects are instructed to use muscle tension and relaxation as the main strategy to regulate their heart rate with biofeedback, associated EEG activation (α^{off}) can be found over the left sensory motor area (Stermann 1973) but not over the left occipital area, which is involved with visual processes (Mulholland 1973). But when subjects are instructed to regulate their heart rate by "thinking arousing thoughts," the sensory motor EEG differences over the left hemisphere are attenuated or disappear.

In our laboratory we are currently using pattern biofeedback training to assess the degree of self-regulated integration and differentiation that can be achieved between heart rate and these two different cortical EEG sites. If heart rate-sensory motor EEG pattern regulation shows enhanced integration and restricted differentiation compared to heart rate-occipital alpha EEG, this finding will provide further evidence of a cardiosomatic constraint at the level of the brain (Obrist et al. 1974). We are also investigating the possibility that the "thinking arousing thoughts" strategy, in light of our previous hemispheric asymmetry data, may involve right rather than left hemispheric sensory-motor sites.

Researchers interested in the mechanisms by which people learn to control specific functions or patterns of functions have an obvious interest in assessing cognitive correlates. However, this requires the use of sophisticated cognitive paradigms and neuropsychological strategies on a par with the methodology already developed for physiological recording and feedback displays. Such cognitive approaches are available (e.g. Luria 1973) and may be combined with the biofeedback paradigm. In addition, biofeedback may be used as the independent variable in investigating the physiology of subjective experience. By training uninstructed subjects to control patterns of

physiological activity, it is possible to study how patterns of physiological responses combine to elicit unique subjective states. Here, pattern biofeedback is used as an objective research tool for investigating the psychobiology of human consciousness.

Meditation and patterns of relaxation

One aspect of our self-regulation pattern approach with direct clinical applications involves physiological states produced by meditation and other relaxation procedures. Wallace and Benson (1972) have described a "hypometabolic" state produced by transcendental meditation—a simple, passive procedure in which the subject silently repeats to himself a Sanskrit word, or mantra. During meditation, decreases occur in many responses, including heart rate, blood pressure, sweat gland activity, respiration rate, EEG frequencies (to alpha/theta ranges), level of lactate acid in the blood, and measures of body metabolism. Although the EEG patterns superficially represent a drowsy or Stage 1 sleep pattern, and the decreases in metabolism appear equal to, if not greater than, those occurring during sleep, the meditator claims to feel awake and alert.

Recently, Benson and his colleagues have described this pattern as reflecting a more centrally integrated "relaxation response" (Benson, Beary, and Carol 1974), opposite to the fight-or-flight response originally described by Cannon (1936). Claiming that it is an innate, integrated neurophysiological pattern, they show that when subjects regulate a simple pattern of attention and cognition, attending passively to their breathing and saying the word "one" after each breath—an American analogue of certain Zen procedures—marked decreases in metabolism are obtained (Beary and Benson 1974).

Stimulated by such findings, many biofeedback researchers formulated the following hypothesis: since low-frequency EEG occurs in passive meditation, and subjects can learn with biofeedback to regulate such EEG patterns, then biofeedback for these changes will lead to deep re-

laxation—an "instant, electronic yoga." The major fallacy in this logic is that single-system biofeedback training is prone to emphasize specificity, not patterns. As mentioned earlier, consistent reports of subjective relaxation emerged when uninstructed subjects were lowering a *pattern* of low blood pressure and low heart rate ($BP_{\text{down}}HR_{\text{down}}$); decreases in either one alone did not produce this result (Schwartz 1972). Similarly, when subjects regulate patterns of occipital alpha and heart rate (Hassett and Schwartz, in press), they report that $HR_{\text{down}}\alpha_{\text{on}}$ is quite relaxing. In fact, one of the subjects run for 8 sessions found this particular pattern so rewarding that she continued to practice it outside the laboratory as a means of producing relaxation. Deep physiological relaxation is not simply low frontalis muscle activity, or low heart rate, or occipital alpha, or slow breathing, but rather the combination of such changes.

Individuals differ in their patterns of response to stress (Lacey 1967), and the systems or combinations of systems associated with deep relaxation also depend on the individual. If subjects are trained with biofeedback to decrease their heart rate voluntarily in anticipation of receiving a noxious stimulus, the pain is experienced as less intense. However, this effect occurs primarily in subjects who report experiencing cardiac symptoms in normal stress situations (Sirota, Schwartz, and Shapiro 1974).

Patterns in meditation are likely to be even more complex than currently acknowledged. In *Psychophysiology of Zen*, Hirai (1974) provides physiological data from Japanese subjects and argues for the concept of a state of "relaxed awareness." Similarly, in the U.S., Goleman and Schwartz (MS) have found evidence that a major effect of transcendental meditation is the generation of a unique and somewhat paradoxical pattern of cortical and limbic arousal, roughly equivalent to the differential subjective experiences of perception versus emotion. We hypothesize that passive meditation practices can lead to *heightened cortical arousability plus decreased limbic arousability at the same time*, experienced as

heightened perceptual awareness and simultaneously reduced emotional arousal and stress.

If this conclusion is generally correct, several important issues arise: Is it possible, using biofeedback techniques, to mimic this psychophysiological state? What combination of responses and biofeedback training procedures would be necessary to match the pattern of physiological changes that occur naturally during meditation? And if it is possible, is it worth the effort?

My own response is divided according to the needs of basic research versus clinical applications. The pattern biofeedback approach provides a new research procedure for investigating how patterns of physiological systems combine to produce unique subjective gestalts and behavioral correlates; at this level, the approach promises to be quite fruitful. However, if the physiological patterns produced by meditation or other relaxation techniques are of therapeutic value (e.g. for reducing overall limbic stress and its many expressions in diseases; Selye 1973), then they should be induced and practiced using the nonelectronic, easily portable, and generalizable machinery of our own biocognitive system.

When we consider the phenomenon of relaxation still more broadly, it becomes clear that various patterns of cognitive, attentional, and somatic strategies can be brought into play, and that different relaxation procedures emphasize the regulation of *different combinations* of processes. Davidson and Schwartz (in press) have outlined how relaxation paradigms utilize different combinations of strategies, which will be reflected in different patterns of physiological responses. Similarly, it is possible to classify various kinds of anxiety, involving combinations of cognitive, visceral, and somatic components. The most effective relaxation procedure may depend on the type of anxiety the person is experiencing at the time.

Take for example a case of high cognitive-low somatic anxiety, in which a person, although physically exhausted, is unable to fall asleep because his mind is racing with disturbing images and thoughts. The

age-old treatment for this pattern of anxiety is to visualize sheep and count them—a cognitive self-regulation procedure that may be effective because it blocks both unwanted visual (right hemisphere) and verbal (left hemisphere) images at the same time.

Another pattern is exemplified by the person who feels somatically tense and jittery, but can point to no particular cause for his anxiety (no specific images come to mind). For such cases of low cognitive-high somatic anxiety, effective “relaxation” strategies include jogging, gardening, or other self-generated somatic activities that serve to block the undesirable somatic state and use up some of the unwanted metabolism at the same time, thereby producing fatigue.

The pattern orientation to anxiety assessment and relaxation treatment is not unlike Lazarus’s (1973) concept of multimodality therapy, which seeks to classify for the individual the patterns of responses that need to be modified and treat them either singly or in combination, recognizing that the selected treatment for one component will not necessarily lead to reductions in others. Similar applications of the pattern approach to biofeedback therapy are described elsewhere (Schwartz, in press).

Pattern biofeedback and emergent property

One major thesis that has slowly emerged from biofeedback research is that patterns of physiological processes can be both generated and processed by the brain, producing unique cross-system interactions and perceptual gestalts that make up a significant component of human behavior and subjective experience. The concept of pattern refers not simply to viewing, in isolation, combinations of physiological responses, but rather goes beyond the individual responses making up the pattern to recognize the novel, interactive, or emergent property that patterns can acquire. Simply stated, the whole can be qualitatively different from the sum of its parts, and yet be dependent upon the organization of its parts for its unique properties. This phenomenon is seen at all levels of

physics and chemistry and extends through biology and neuropsychology (Weiss 1969).

The concept of emergent property is what I wish to emphasize in patterning. Although it is not new, with few exceptions it is still ignored. Neuropsychologists concerned with the biology of consciousness employ the same idea when they speak of cell assemblies (Hebb 1974), neural engrams (John 1972), holograms (Pribram 1971), dynamic neural patterns (Sperry 1969), or functional systems (Luria 1973). Emotion was described by William James (1890) as the perception of patterns of autonomic consequences of action. More recent researchers, such as Schachter and Singer (1962), have added cognitive processes to autonomic arousal as an integral part of this pattern. Today, theorists like Izard (1971) stress the interaction of combinations of neurophysiological systems, including discrete patterns of postural and facial muscle activity, as the mechanism underlying the emergent experience of emotion.

Research on biofeedback and the regulation of combinations of responses extends this basic concept of patterning by providing a new paradigm for investigating physiological relationships in the intact human. Self-regulation as a general research strategy is useful because it enables researchers to isolate component parts of systems and then examine how they combine to produce unique physiological and associated subjective states. Our laboratory has shown that the regulation of patterns of responses can produce effects that are different from those observed when single functions are regulated. As I have illustrated, this simple principle proves to have important basic as well as clinical ramifications.

It is not inconceivable, however, that the act of regulating a pattern of responses will have consequences somewhat different from those found when a similar pattern is elicited by other means. If future research proves this to be true, it would limit the general applicability of the approach. On the other hand, such a finding could provide a further key to the nature of the self-regulation process itself.

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