BIOFEEDBACK INSTRUMENTATION

SECTION 1

REVIEWS, METHODS, & DESIGNS

Feedback modalities as a consideration in biofeedback applications

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Effects associated with specific feedback modalities are neither clear nor well explored. The present paper provides an overview of feedback modalities typically used for the presentation of information from major physiological systems. Some consideration of feedback modality in relation to theory is provided with a discussion of trends in past applications.

The central goal of this paper is to examine current practice concerning types of feedback being employed and, in particular, the sensory modes used in relation to different physiological systems. Early experimentation on motor-skills learning contributed principles basic to the development of the feedback concept and implementation of modalities. In the classic study by Trowbridge and Cason (1932), two clear distinctions among types of feedback were made and confirmed as important. One is the distinction between qualitative and quantitative feedback. In the former, the learner is informed merely that he is right or wrong; in the latter case, he is informed that he is over or under his goal by a certain amount. The second distinction is between relevant and irrelevant (or false) feedback. The Trowbridge and Cason study showed learning with quantitative feedback to be superior, whereas irrelevant feedback resulted in worse performance than the no-feedback condition.

Those principles from skill learning have been updated (e.g., Adams, 1968) and used as a conceptual background for work in biofeedback (e.g., analog vs. binary feedback; see Lang & Twentyman, 1974). The general issue of concern is when and under what circumstances the amount of feedback (in informational terms) influences the amount of behavior change. Another distinction discussed by Lang and Twentyman was that between organ feedback and performance feedback. This

differentiation is of particular relevance to theory, since it highlights the issue of whether effectiveness of feedback lies in providing augmented sensory return about organ change (to compensate for lack of afferent signals), or whether it lies in providing a motivational stimulus in the form of a reinforcer or goal stimulus.

Various theorists see issues quite differently. Black, Cott, and Pavloski (1977) discuss an awareness theory, in which the essential process in biofeedback learning is proposed as learning to discriminate internal behavior. Feedback appears to be a sensory aid or adjunct that enables people to perceive their own organ changes. A more subtle interpretation (Brenner, 1974, 1977) is that, through the operation of reinforcement, a person achieves control by learning to detect and respond to correlates of the organ change, not necessarily to the target response itself. From this it can be concluded that the orientation of feedback would not be limited to information about the particular response being trained but should be extended to other behaviors that covary with target behaviors.

Another feature of feedback signals is that the feedback facilitates verbal labeling processes. The label becomes particularly important for elements of self-reinforcement. Brenner (1977) emphasized the point when he suggested: "Internal stimuli that are the variations in activity become the denotative referents for words. Implicit in the acquisition of these associations, words acquire the capacity to designate specific behavior goals and thereby to initiate and direct activity" (p. 61).

All of the above considerations are quite different from a point of view that requires the feedback signal

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to directly modify or produce changes in the target behavior. An example of this is provided by Mulholland (1969), who modifies alpha EEG behavior by making a light stimulus contingent upon the rate of occurrence of the alpha pattern.

The foregoing discussion is intended to be largely a reminder of some of the general principles that might guide the development of effective feedback signals. Efforts to apply such principles may be contrasted with procedures that have been developed more or less fortuitously. The material that follows is concerned less with general principles than with actual practice classified in terms of sensory and response modalities.

An examination of feedback modalities and effects necessitates review of a large body of research and applicable literature. With the exception of Blanchard and Young (1973), there has not been a systematic review of feedback methods within or across physiological systems. Tables 1, 2, 3, 4, and 5 represent an effort to provide a general summary. They are designed to be representative, rather than all inclusive, and provide a sample of recent work. Unless a unique feedback form or physiological event is involved, case studies containing only within-case controls have not been included. The primary results of each study are included to emphasize comparisons such as feedback vs. control, feedback vs. other therapy, or one feedback

mode vs. another. For each physiological system, the feedback modalities have been organized with studies employing visual feedback first, followed by auditory feedback, then combinations of auditory and visual, and, finally, other forms and comparisons.

ELECTROMYOGRAPHIC FEEDBACK

Electromyographic feedback studies are summarized in Table 1. Skeletal muscle activity has generally been used more often than any other physiological system for supplying feedback information in clinical and experimental situations. Consequently, this system has been well studied using a variety of modalities.

Certain trends are apparent. Auditory feedback appears as the most common mode, employing a continuous tone directly related to muscle activity. While frontalis electrode placement may necessitate an auditory (or nonvisual) mode due to eye movement factors, auditory feedback has also been used with other muscle groups where eye movements are not involved. Further, while a continuous auditory or visual analog has been most widely applied, some studies suggest that discrete threshold feedback can be effective for this physiological system.

EMG feedback has been reported to be particularly effective in neuromuscular rehabilitation where muscular

Table 1
Electromyographic Feedback

Authors	Mode and System	Results
Green, Walters, Green, & Murphy (1969)	Visual. Meter display of rectified extensor EMG.	Low levels in short period of time.
Budzynski, Stoyva, & Adler (1970)	Auditory. Continuous analogue tone with changes in pitch directly related to frontalis EMG.	Effectively reduced frontalis EMG and tension headache frequency.
Leibrecht, Lloyd, & Pounder (1973)	Auditory. Of single motor unit.	Increase in speed of learning but not amount over surface EMG.
Budzynski, Stoyva, Adler, & Mullaney (1973)	Auditory. Clicks presented at a frequency directly proportional to frontalis EMG level.	Effectively reduces frontalis EMG and tension headache intensity and frequency.
Wickramasekera (1972)	Auditory. Tone pitch directly related to frontalis EMG level.	Headache intensity reduced.
Raskin, Johnson, & Rondestvedt (1973)	Auditory. Tone pitch directly related to frontalis EMG level.	Reduced EMG and short-term reduction in chronic anxiety.
Cleeland (1973)	Auditory. Tone pitch directly related to EMG level. Increase in tone coupled with cutaneous shock.	Reduction of spasmodic torticollis symptomatology.
Swaan, van Wieringen, & Fokkema (1974)	Auditory. Tone directly related to EMG levels of peroneus longus	More effective than traditional PT in reducing unwanted activity.
Hanna, Wilfling, & McNeill (1975)	Auditory. Tone directly related to EMG levels in laryngeal muscles.	Dramatic decrease in stuttering frequency after two sessions with one patient.
Basmajian (1974)	Visual and Auditory. CRT and click presentation of spinal motoneuron activity.	Control of motor units and neurons.
Smith, Basmajian, & Vanderstoep (1974)	Visual and Auditory. CRT and click presentation of spinal motoneuron.	Selective inhibition and activation of spinal motoneurons.
Brudney, Korein, Levidow, Grynbaum, Lieberman, & Friedman (1974)	Visual and/or Auditory. Meter and tone presentation of EMG in various muscle groups suffering from CNS disorders.	Thirty-two of 36 patients showed relief ranging from functional recovery to symptomatic relief within 8-12 weeks of training.

Table 1 Continued

Authors	Mode and System	Results
Kukulka & Basmajian (1975)	Visual and Auditory. Threshold lights and tone presentation of EMG from various normal muscle groups.	Increase or discovery of new EMG control with normal subjects.
Schandler & Grings (1976)	Comparison of meter, auditory pulse, and tactile pulse presentations of extensor EMG and progressive relaxation.	Tactile and progressive relaxation superior to other modes in reducing EMG in normal subjects.
Cox, Freundlich, & Meyer (1975)	Comparison of continuous auditory presentation of frontalis EMG, progressive relaxation, and medicine placebo.	Feedback and progressive relaxation superior to medicine placebo in reducing EMG with normal subjects.
Haynes, Griffin, Mooney, & Parise (1975)	Comparison of continuous auditory presentation of frontalis EMG and progressive relaxation with muscle tension headache patients.	Feedback and progressive relaxation produced reduction in muscle tension headache frequency over six .5-h sessions.
Haynes, Moseley, & McGowan (1975)	Comparison of continuous auditory presentation of frontalis EMG, progressive relaxation, passive relaxation instructions, and false feedback.	True feedback and passive relaxation superior to other methods in normal subjects.
Alexander, French, & Goodman (1975)	Comparison of continuous auditory and meter display of frontalis EMG.	Auditory superior to visual in normal subjects.
Kinsman, O'Banion, Robinson, & Staudenmeyer (1975)	Comparison of auditory click presentation of frontalis EMG, verbal feedback, and no feedback with normal subjects.	Auditory feedback superior to verbal feedback; both superior to no feedback.
Coursey (1975)	Comparison of continuous auditory presentation of frontalis EMG, relaxation instructions, and a constant tone.	Auditory superior to other methods in reducing EMG. No difference among methods in reducing state or trait anxiety with normal subjects.
Reinking & Kohl (1975)	Comparison of continuous auditory or visual motor presentation of frontalis EMG and progressive relaxation combined and separate.	Instructions and feedback and feedback alone superior to instructions alone with normal subjects.
Chesney & Shelton (1976)	Comparison of continuous auditory and visual meter presentation of frontalis EMG and progressive relaxation in treating muscle tension headaches.	Instructions and feedback superior to feedback alone in reducing severity and frequency of muscle tension headaches.
Hefferline, Keenan, & Harford (1959)	Use of switch movement contingent on EMG reduction to terminate aversive stimulus.	Learn escape and avoidance by lower EMG levels.

control is required. In those applications, there is a trend toward the use of combined auditory and visual feedback modalities to supply continuous information.

Unlike feedback studies with other physiological systems, there have been numerous comparisons among muscle feedback modalities and between feedback and traditional (nonfeedback) procedures. However, no clear-cut differences have been found. Apparently, any form of feedback is more effective than no feedback, and feedback effectiveness is enhanced by combination with nonfeedback treatments. However, neither visual nor auditory modalities produce effects that are superior to traditional (nonfeedback) treatments. While an exception might be made concerning comparative effectiveness of feedback and physical therapy in neuromuscular reeducation studies, there has been no systematic comparison with controls. Comparisons of visual and auditory modes have been confounded by possible interactions between muscle pick-up site and

feedback modality. Studies using different modalities and those making modality comparisons suggest the importance of modality as a variable.

CARDIOVASCULAR FEEDBACK

A summary of cardiovascular feedback, including heart rate, blood pressure, and pulse flow, is provided in Table 2. The studies covered have, for the most part, occurred subsequent to Blanchard and Young's (1973) review. With very few exceptions, visual feedback has been the most common method for presenting heart rate information. Both binary threshold and continuous information forms are used to supply rate, beat-by-beat information, and time data (interbeat interval length). Several mode comparisons suggest interactions among modality type, direction of change, rate or time changes, and task instructions.

Both visual and auditory modalities have been used to

Table 2
Cardiovascular Feedback

Authors	Mode and System	Results
	Heart Rate	
Hnatiow & Lang (1965)	Visual. Meter, red target zone surrounded by blue margins.	Learned stabilization.
Bleecker & Engel (1973)	Visual. Lights indicating shortening or increase in R-R interval.	Learned increase and decrease in R-R interval.
Bouchard & Corson (1976)	Visual. Lights indicating successful increase threshold and failure.	Increase to success signal; decrease to failure signal.
Lang, Troyer, Twentyman, & Gatchel (1975)	Visual. Computer CRT display for speed and slow.	Best control in college students, worse with cardiac patients.
Gatchel (1974)	Visual. Computer CRT display for speed and slow.	Continuous feedback superior to 5- or 10-beat delay for increase, no change in decrease.
Sirota, Schwartz, & Shapiro (1976)	Visual. Meter for increases and decreases plus money.	Learned increases and decreases a function of feedback, reward, perceived punishment, and individual differences.
Pickering & Gorham (1975)	Visual. Meter for increases and decreases.	25-beat/min increase and 1- to 2-beat/min decrease.
Blanchard, Scott, Young, & Edmundson (1974)	Visual. Meter display of heart rate information, correct or incorrect information concerning feedback information.	Visual correct produced greater increases and decreases over visual or no-feedback correct and visual only.
Lang & Twentyman (1974)	Visual. Computer display binary or analog increase and decrease information.	Analog produced greater increases; no difference for decrease; feedback better than no feedback.
Young & Blanchard (1974)	Auditory. Continuous proportional discontinuous proportional binary feedback heart sounds.	Feedback produced increase but not decrease relative to no feedback; no clear feedback differences.
Brener & Hothersall (1966)	Auditory. High and low tone to heart rate increases and decreases.	Decrease percentage of short interbeat intervals to high tone; increase percentage to low tone.
Headrick, Feather, & Wells (1971)	Visual and Auditory. Meter and tone directly related to heart rate increase and decrease.	Visual produces increase and decrease; auditory resulted in decrease only.
Manuck, Levinson, Hinrickson, & Gryll (1975)	Visual. Light display of interbeat interval: Binary interbeat interval, real-time interbeat interval, numerical proportional interbeat interval. No feedback.	No clear differences.
McCanne & Sandman (1976)	General review of relevant heart rate feedback variables.	Individual differences in response and control are the major factors.
	Blood Pressure	
Blanchard & Young (1973)	Review of operant and feedback cardiac control techniques to 1973.	Changes generally small; processes unclear; comparisons with other feedback and clinical modes are necessary.
Kristt & Engel (1975)	Visual. Continuous light display of systolic.	Over 5 months, high blood pressure patients learned to increase and decrease pressures.
Goldman, Kleinman, Snow, Bidus, & Korol (1975)	Visual and Auditory. Discrete lights and continuous tone for increases and decreases in systolic and diastolic.	Systolic decreases within sessions and diastolic decreases between nine 2-h sessions.
Elder & Eustis (1975)	Visual and Verbal. Green light and red light coupled with verbal reinforcement for reductions in systolic.	Reductions demonstrated for hypertensive patients but below the "20%" criterion recommended by Blanchard & Young (1973).
Blanchard, Young, & Haynes (1975)	Visual. Closed-circuit television picture of polygraph recording for entire session with points marked indicating minute-by-minute updates.	Positive reductions in systolic and diastolic in four to nine sessions.
Friar & Beatty (1976)	Visual.	Extracranial vasoconstriction and improvement in headache symptomatology across eight sessions.

present blood pressure and pulse flow information. No systematic comparisons have been made. Pulse flow represents a relatively new feedback form that has yet to be extensively explored.

It is interesting to note Blanchard and Young's (1973) statement concerning feedback modality type. After noting the use of visual or auditory modalities without apparent rationale or statistical differences (e.g., Blanchard & Young, 1972), they concluded that "the decision as to which sensory modality one should use . . . must rest on factors other than efficacy" (1973, p. 151).

ELECTROENCEPHALOGRAPHIC FEEDBACK

Table 3 contains the summarized information from EEG feedback studies. A general distinction can be made

between the use of alpha or theta information feedback and the feedback of epileptic seizure patterns. A discrete, binary, on-off auditory modality has been the most prevalent form of alpha feedback. There appears to be no uniformity of relation between feedback event and physiological function change. For example, in some instances, auditory onset has been associated with alpha onset; in other situations, the reverse has been applied (with different effects). While alpha-blocking factors associated with eyes-open behavior suggest use of an auditory modality, there is at least one comparison study (Lynch, Paskewitz, & Orne, 1974) that suggests that visual feedback increases alpha density and auditory feedback enhances alpha amplitude. Regardless of modality, there appears to be an interaction between instructional set and feedback process.

Seizure feedback studies use both visual and auditory

Table 3
Electroencephalographic Feedback

Authors	Mode and System	Results
Sterman (1973)	Visual. Light on/off indicating sensorimotor epileptic EEG frequency of 13 Hz.	General reduction in frequency of seizure occurrence.
Travis, Condo, & Knott (1974)	Visual. Light on/off indicating on/off of alpha activity with eyes open.	Contingent feedback produced more alpha than yoked or nonreinforced controls.
Nowlis & Kamiya (1970)	Auditory. Tone on/off indicating alpha on/off.	Learned control of on/off and duration of alpha occurrence.
Peper & Mulholland (1970)	Auditory. Tone on/off indicating alpha on/off.	Most subjects learned to decrease, few learned to increase.
Beatty (1972)	Auditory. Tone on/off indicating alpha on/off and instructions for increase and decrease.	Instruction between alpha occurrence and instructional set.
Peper (1972)	Auditory. Tone on/off indicating alpha on/off from several sites.	Learned partially localized control of alpha occurrence.
Regestein, Pegram, Cook, & Bradley (1973)	Auditory. Tone on/off indicating alpha on/off.	Long-term production of alpha.
Beatty, Greenberg, Deibler, & O'Hanlon (1974)	Auditory. Tone on/off indicating theta on/off.	Theta enhancement suppression resulted in facilitation and inhibition of vigilance task performance.
Dewan (1967)	Visual and Auditory. CRT displaying EEG, Schmitt alpha threshold clicks, and alpha-contingent Morse code.	Increase in alpha activity.
Rosenfeld, Rudell, & Fox (1969)	Visual and Auditory. CRT display of auditory evoked potential activity with reinforcement for increase in auditory evoked potential amplitude.	Increase in auditory evoked potential and amplitude.
Sterman, MacDonald, & Stone (1974)	Visual and Auditory. Light and tone indicating onset of sensorimotor EEG rhythm.	Enhanced sensorimotor rhythm in subjects, reduced seizure activity in epileptic patients.
Finley, Smith, & Etherton (1975)	Visual and Auditory. Light and tone indicating onset of sensorimotor EEG rhythm.	10X reduction in sensorimotor rhythm seizures after 6 months' training with one subject.
Valle & Levine (1975)	Auditory and Instructions. Tone on/off indicating alpha on/off and expectations of enhancement.	Increased alpha duration.
Peper (1970)	Comparison of visual light display of alpha onset and instructions to use internal state to produce alpha.	Both feedback forms affect EEG occurrence as well as oculomotor functions.
Lynch, Paskewitz, & Orne (1974)	Comparison of light and tone on/off to increase alpha.	Visual feedback resulted in greater alpha density than auditory.
Walsh (1974)	Auditory. On/off tone for on/off alpha and instruction set.	Feedback plus instruction set required for enhancement of alpha.

Table 4
Temperature Feedback

Authors	Mode and System	Results
Sargent, Green, & Walters (1973)	Visual. Meter display of hand temperature.	Reduction in number and severity of migraine headaches.
Turin & Johnson (1976)	Visual. Meter display of finger temperature.	Finger warming reduced headaches in seven subjects; finger cooling and autogenic training resulted in stable or increased headaches.
Wickramasekera (1973)	Visual. Meter display of temperature and meter display of EMG.	EMG ineffective in controlling migraine headaches; temperature training effective.
Lynch, Hama, Kohn, & Miller (1976)	Visual. Meter display of difference between hands or fingers.	Temperature control between the two hands in children; one child demonstrated control between two fingers of the same hand.
Taub & Emurian (1976)	Visual. Meter display of hand temperature.	9°-14°F increase or decrease after training.
Keefe (1975)	Visual and Auditory. Meter and tone of hand and finger temperature.	Increase and decrease differential control of hand and finger temperature.
Step toe, Mathews, & Johnston (1974)	Visual and Auditory. Meter and tone of right and left earlobe temperature.	Voluntary .3°F differential changes.

signals to provide simultaneous discrete and continuous information. The effects have been particularly clear in reducing or modifying the specific physiological events.

TEMPERATURE FEEDBACK

A review of temperature feedback is provided in Table 4. Visual or combined visual and auditory modalities have been used most often. There have been no comparisons of feedback modalities and their effects.

OTHER FEEDBACK FORMS

Table 5 contains summaries of gastrointestinal, salivary, and electrodermal studies using visual and

auditory feedback. The results appear to be positive for all feedback modalities utilized.

DISCUSSION

In some systems, the use of a particular sensory modality for feeding back information on physiological change may inhibit or facilitate the effectiveness of the procedure. The relationship between EEG alpha blocking and visual system activity has resulted in the most frequent use of auditory feedback modalities for training alpha enhancement. Similarly, auditory feedback appears to be more widely used than visual feedback in frontalis EMG relaxation training, possibly because of the relationship of frontalis activity to eyelid

Table 5
Other Feedback Forms

Authors	Mode and System	Results
Gastrointestinal Feedback		
Nikoomanesh, Wells, & Schuster (1973)	Visual. Esophageal pressure meter.	Reduced pressure.
Engel, Nikoomanesh, & Schuster (1974)	Visual. Polygraph record of external and internal sphincter activity.	External sphincter contraction in synchrony with internal sphincter relaxation.
Welgan (1974)	Visual. Meter display of pH meter displaying gastric acidity.	Increases and decreases in acid volume and concentration.
Whitehead, Renault, & Goldiamond (1975)	Visual. pH meter displaying gastric acidity and B reinforcement for achieving required effect.	Increases secretion and subsequent reduction to initial baseline.
Furman (1973)	Auditory. Stethoscope presenting stomach activity.	Presentation during stress and non-stress resulted in positive control of functional diarrhea.
Dickner, Hill, & Bourne (1972)	Auditory. Stethoscope presenting stomach activity.	Learned control of gastric slow-wave frequency.
Electrodermal Feedback		
Klinge (1972)	Visual. Meter display of spontaneous GSR meter, accurate meter, positive-only meter, negative only, instructions only.	Continuous accurate most effective in increasing and decreasing.

Table 5 Continued

Authors	Mode and System	Results
	Salivation Feedback	
Frezza & Holland (1971)	Visual. Counter display of instances when salivary output exceeded threshold.	Positive control of increases.
Wells, Feather, & Headrick (1973)	Auditory. Continuous tone indicating salivary output.	Increases and decreases.

movement. In a comparison of auditory and visual frontalis EMG biofeedback, Alexander (1975) noted the importance of the obvious inhibitory modality interaction, using the visual mode to provide frontalis information.

Certain feedback forms involve physiological systems that necessitate a particular mode. Neuromuscular reeducation represents such an application. In Booker, Rubow, and Coleman's (1969) report of feedback to train the use of restructured muscle, visual feedback via mirror was essential to the subject's eventual coordination of muscle movements. At a very general level, such straightforward considerations suggest advantages and disadvantages for selecting and applying particular feedback modalities.

Conversely, some investigators appear to have purposefully employed a feedback mode that is naturally inhibitory to the production of the desired physiological effect. This may allow for exploration of the degree and direction of physiological change possible through feedback. There are instances in which the facilitative effect produced with a naturally inhibitory modality is viewed as representing a particularly strong effect. Travis et al. (1974) used visual feedback to train "eyes-open" alpha enhancement. This process is seen as representing the learned control and reduction of an inhibitory mechanism, rather than a more simple response to a facilitative mode.

While the preceding considerations are fairly straightforward, there are more subtle interactions between feedback modality and physiological system. Some of these represent matters of instrumentation. For example, the presentation of heart rate or EEG alpha is highly dependent on frequency of activity rather than amount of physiological output. Thus the discriminative ability of the instrumentation and its general configuration are major factors. Consider an alpha feedback example. Assuming "ideal" filters with "ideal" frequency-discrimination characteristics, the general physiological event consists of a synchronous signal changing polarity over an average period of .1 sec. An instrument sensitive only to positive and negative cycles per second (hertz) requires a minimum of .1 sec to sense and report the event of alpha. An instrument sensitive to zero crossings of the signal requires a minimum sensing time of .05 sec (half-cycle duration). More refined instruments may be capable of sensing quarter-cycle periods (.025 sec) or rise-time characteristics. In all

instances, a certain number of events must be sampled to measure the period of an alpha bundle as contrasted to momentary artifacts. The feedback signal will be delayed from the physiological event by an amount equal to the period of single-event discrimination, the number of single events required for labeling as an event vs. an artifact, and the time required for the instrument to provide the feedback signal. The feedback also continues after offset of the event by the amount of delay. The fact that most instruments do not offer anything approaching ideal discrimination filters may produce a compounding effect in which the feedback may be so delayed as to not closely reflect the physiological event.

A more dramatic example involves the use of a reflectance plethysmograph to provide pulse flow or heart rate feedback. Typically, the plethysmograph transducer is mounted on the limbs or cranial arteries some distance from the heart. Because of physical distance and relatively slow period of detection, this type of signal lags heart activity by several hundred milliseconds. For feedback purposes, the pulsed physiological signal is further smoothed by averaging or rectification, resulting in an auditory or visual analog lagging the physiological event by seconds. The subject may therefore be attempting the control of a fairly distant past event. In some cases, such delay is beneficial. Since muscle-group activity represents a relatively spontaneous, asynchronous event, attempts to control all components of the signal supplied by surface electrodes would be futile for the subject. In such instances, the delay associated with signal averaging is advantageous.

The relationship between physiological event and feedback is not only a matter of instrumentation. There are perceptual factors, such as meaningfulness of the signal, that are of major importance. The degree of "artificiality" of the feedback information is a case in point. Artificiality can be defined in terms of the qualitative and quantitative differences between the feedback signal and the physiological event. Differences between sensitivity perceived within the feedback representation and the normal sensory sensitivity need to be considered.

Another factor is the relative direction of change in the feedback and the physiological event. There are instances, such as pulse flow feedback, in which vasodilation or increase in flow is presented by a decrease in tone pitch. In this application, it might be assumed that

pitch reduction is facilitative of relaxation and further dilation.

Few investigators employ a feedback signal of actual physiological activity such as raw EMG or alpha. The assumption seems to be that a signal of this type contains excessive information and does not provide understandable and operable information. Lights, meters, and computer displays are only representations of the ongoing physiological event; more easily presented information of this type can have reduced meaningfulness and clarity for the subject. Yet information supplied in the form of precise meter displays or numbers with a numerical but no physiological reference may be too full of meaning. This results in the subject attempting to achieve a number rather than controlling a particular physiological system. Thus, the display type can in itself produce goals with associated frustrative and reinforcement properties.

Discrete (binary) feedback presentation modes can contain physiological and psychological interactions in addition to artificiality. Certain studies of alpha feedback, heart rate, and electrodermal feedback used a feedback modality consisting of on-off or yes-no threshold attainment. With alpha training, a sudden tone onset can result in attenuation or blocking of the desired response, and a similar signal may provide an orienting reaction consisting of increased activity in electrodermal and heart rate responding. Short-term changes of this type are not necessarily inhibitory to the long-term learning of control. However, in operant conditioning paradigms employing feedback, an inhibitory interaction can occur if the desired (reinforced) response is opposite to the physiological effect produced by feedback of threshold attainment. In effect, the subject may receive both positive reinforcement of threshold attainment and negative reinforcement of reduced control.

Reviews like the present one serve primarily to raise questions, not to answer them. Some features of the "state of the method" do become evident, however. At the present stage of investigations on learned physiological change with biofeedback, research on issues of methodology associated with feedback modality is needed and can be undertaken with an expectation of payoff to both behavior theory and practical application.

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