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SPECIAL ISSUE

The Biofeedback Odyssey: From Neal Miller to Current and Future Models of Regulation

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Neal Miller's research on animals and humans launched the field of self-regulation, enabling individuals to take a more active role in their health and well-being. However, his inquiry into whether autonomic operant conditioning occurs remains open to debate. This article contends that present-day biofeedback therapists continue to be confronted by this dilemma. In addition, the authors suggest other models of biofeedback in which the role of the practitioner has been expanded and to which a large repertoire of self-regulation techniques have been added. They propose that, in the future, the regulatory capacity of interpersonal interactions is recognized as in the proffered model of biofeedback, dyadic biofeedback (DBF). DBF allows for real-time training of interpersonal interactions, emphasizing learning through direct observation and active involvement, thus making a return to Miller's model.

Introduction

Almost half a century has elapsed since Miller began his sojourn into the area of visceral learning, wherein he tested the hypothesis that the autonomic nervous system can be operationally conditioned (Miller, 1976). After conducting this set of experiments, Miller noted that ''visceral learning remains an open question'' (Dworkin & Miller, 1986, p. 312). Others have tried to address this question in various experimental paradigms (e.g., work on the conditioning of heart rate in monkeys [Ainslie & Engel, 1974; Gruber & Taub 1998] and the conditioning of human autonomic responses [Roberts, Kewman, & Macdonald, 1973]). The current discussion examines the relevancy of this question to current practice and suggests an innovative model that can lead to future applications.

First, we suggest that biofeedback clinicians, in their daily practice, confront the same questions raised by Miller. Second, we will explore how Miller's model of biofeedback compares with current, human-based models. Finally, we will introduce dyadic biofeedback, a model that is considered a return to the original model presented by Miller's experiments, but significantly enriched.

Miller's Odyssey

Miller's odyssey began with experiments that challenged the distinction between classical and operant conditioning. Prior to that, psychologists believed that the autonomic nervous system was subject only to classical conditioning. That is, it was generally accepted that organisms have control over bodily functions governed by the central nervous system (or voluntary nervous system). The internal physiological processes controlled by the autonomic (or involuntary) nervous system were regarded as operating beyond conscious awareness or control. Miller set out to prove categorically that instrumental (operant) conditioning of autonomically mediated responses was possible. The prerequisite was to show that no other mechanism could account for the autonomic changes. Critics had argued that an autonomic (involuntary) response can be produced by several voluntarily controlled responses. This fact made it quite challenging to prove a direct conditioning of the autonomic response itself. Rather, one could always argue that voluntary responses were being conditioned and that these voluntary changes were producing any autonomic response. The inherent problem in this research task is illustrated when looking at heart rate changes, which can be exacted via voluntary actions, including changes in breathing rate and/or depth or through the contraction of specific muscles. Therefore, if the autonomically mediated response of altered heart rate follows a modification in voluntarily controlled responses, one has not accomplished a proof that heart rate can be instrumentally conditioned.

Miller, however, accomplished a successful demonstration of this instrumental conditioning of autonomic functions in an ingeniously designed experiment. Rats were injected with curare, causing total paralysis of all muscles, and via use of artificial respiration their breathing rate was continuously regulated. Positive reinforcement was delivered via electrical stimulation of a reward center situated in the hypothalamus. These experiments showed successful operant conditioning of heart rate and also of blood pressure, urine formation, and the degree of blood vessel constriction in the ear (DiCara & Miller, 1968).

The degree of change in visceral activity prompted speculation that various psychosomatic disorders could be treated with biofeedback. Despite the failed attempts to replicate results gained in animal research, Miller continued to focus on the role of learning in psychosomatic illnesses and the uses of both biofeedback and learned behavior in preventing stress-related illness. Moss (1998) summarized this set of experiments as follows:

> Miller's research inspired the hope that biofeedback can enable a human being to take a more active role in recovering and maintaining health. Further, it encouraged the dream that human beings can aspire to previously unimagined levels of personal control over bodily states, reaching unprecedented states of wellness and self-control. (pp. 148–149)

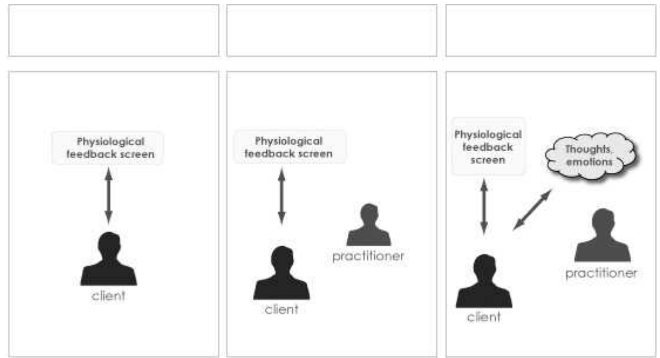

Figure 1. Plausible models for today's clinician. (A) Through a process of trial and error, the subject learns autonomic regulation. (B) A coach teaches relaxation methods while using the physiological feedback to enhance motivation and application. (C) Bringing emotions and thoughts into awareness allows subjects to observe what went on in their minds and to share this with the therapist. This process reveals the relationship between thoughts and emotional/physiological reactions.

Current Biofeedback Models

Present-day biofeedback therapists continue to be confronted by the same 50-year-old dilemma: Are the autonomic changes achieved in biofeedback sessions due to some type of change in breathing pattern and muscle tension (or any other voluntary peripheral activity), or are they related to some central change that has been reinforced by the feedback-based conditioning procedure? In practical terms, when patients in the clinic gradually learn to change their electrodermal activity and skin temperature or heart rate variability, is this achieved via some type of conditioning process, or is it more simply due to the practice of relaxation techniques they have been taught?

The case of heart rate variability (HRV) biofeedback serves as an interesting illustration of this dilemma. Consider a clinician whose aim is to train a patient to raise his or her HRV. In line with Miller's animal studies, the clinician can simply provide the patient with real-time feedback about HRV. Miller would have urged biofeedback manufacturers to ensure the interval between responses and visual or auditory feedback is sufficiently short and conforms to the laws of learning theory. That is, according to the conditioning model (see Model 1 below, Figure 1A), there is no need to teach the patient anything; as long as good feedback (or reinforcement) is provided, after a significant amount of trials, patients will learn to increase their HRV.

A modern clinician, however, might adopt a second strategy (see Model 2 below, Figure 1B), in which certain breathing patterns are taught to the patient. Gevirtz (2003) and Lehrer (2007) have found that breathing at a slow pace can enhance respiratory sinus arrhythmia, thus increasing HRV. Breathing slowly results in enhanced HRV due to mechanistic, physiological reasons, providing an example of voluntary/conscious control of cardiovascular activity. From this standpoint, HRV training is considered as a mainly voluntary, peripheral activity (breathing).

A third strategy to teach patients how to increase HRV is also plausible. This strategy requires that the clinician explores not only patient behavior but also emotions and cognitions. Appelhans and Luecken (2006) have summarized a large body of research suggesting that HRV is influenced by emotional states. A specific example for this process is offered by McCraty, Atkinson, Tiller, Rein, and Watkins (1995), who suggest that it is the psychological states of appreciation and compassion that lead to low-frequency heart rate fluctuations. They state,

> It is important to emphasize that coherence is associated with positive emotions independent of conscious alterations in one's breathing rhythm. In our earlier studies, which were focused on the physiological correlates of different emotional states, instructions to subjects purposely made no mention of altering breathing rates or depths. We found that when sustained positive emotional states were maintained, increased heart rhythm coherence and entrainment between the heart rhythm, blood pressure rhythms, and respiratory rhythms emerged independent of any conscious alterations in breathing pattern. (p. 37)

The focus on the patient's emotional state is integral to the third model of biofeedback (see Figure 1C), which focuses simultaneously on physiological readings and cognitive/emotional states.

The plausibility of these different models can be demonstrated in other classical biofeedback parameters such as electrodermal activity (EDA). The need to increase EDA has been shown in several contexts, such as epileptic seizure reduction (Nagai, Goldstein, Fenwick, & Trimblea, 2004) and sustained attention (O'Connell et al., 2008). In all of these cases, clinicians must train their patients to increase sympathetic arousal. The way to achieve this EDA elevation can be based on the biofeedback models presented. Using Miller's conceptualization, the clinician can simply supply positive feedback to reinforce the patient's ability to achieve a reduction in skin resistance. Alternatively, as suggested in Model 2, the clinician might teach the patient various behavioral methods to increase their EDA (rapid breathing, increasing muscle tension, etc.). Or, as described in the third model, the clinician could elicit emotions and cognitions that produce sympathetic arousal.

To summarize, Miller's model of operant conditioning remains relevant alongside newer models that have expanded the role of the practitioner and added a large repertoire of self-regulation techniques, borrowed from behavioral, cognitive, and psychodynamic methods. In what follows, we will review the expansion of the role of the other in newer models and examine their relation to Miller's original model.

The Role of the Other in Biofeedback Training: A New Conceptualization and a Suggestion for a New Model

The following discussion addresses the process of the gradually increasing clinician involvement from nonexistent, as in Miller's model, to, as offered by the model presented, a fully present partner, active within the therapeutic interaction. In this model, the interpersonal space that emerges becomes the source, and focus, of the therapeutic process. The model derived from Miller's set of experiments (Figure 1A) concentrates on the physiological processes of the body. It emphasizes learning concepts such as stimulus, reinforcement, and the contingency between stimulus and response. The therapist is not essential, and the subjective process experienced by the patient is largely ignored. The practitioner who uses concepts derived from Miller's experiments places primary importance on conducting as many trials as possible and on ensuring that the patient learns the contingency between their physiological responses and the external feedback. As we will see, while the gradual increase in clinician involvement departs from Miller's model, on another axis there is actually a return to direct stimulus response learning of physiological self-regulation.

The model of stress management coaching (Figure 1B), similar to Miller's model, emphasizes a process of learning and practice in the physiological realm, yet here two people are involved. Regardless, the practitioner's role is limited to the teaching of relaxation methods. Muscle relaxation, breathing techniques, and autogenic training are employed to enhance physiological self-regulation. As in Miller's original model, here the focus of the therapeutic process is the enhancement of the patient's self-regulation of bodily states.

The third model (Figure 1C) further departs from Miller. Both the role of the practitioner and the use of the physiological screen are expanded. This model incorporates the client's thoughts during the session and the basic assumptions (sometimes hidden) that affect the client's views about his or her ability to self-regulate. Here, a metaphoric screen, the "cognitive/emotion screen," is introduced. Clients share their thoughts with the therapist or voice "what went on in their mind," and both the therapist and client observe this process in relation to the physiological data screen. Whereas working with the physiological screen involves repeated practice, working with the subjective experience requires a significant amount of discussion. Indeed, the focus within this model is on the relationship between subjective content (thought/images) and objective measurement (physiology).

The three models described focus on the client as the source of self-regulation. The role of the practitioner, if existing at all, is to assist the client in the search for self-regulation techniques. Can there be other sources of regulation? The final model discussed suggests that the role of interpersonal interactions may in fact be a powerful regulatory mechanism that can further expand the biofeedback models.

Biofeedback Models That Enhance the Regulatory Capacity of Interpersonal Interactions

Psychotherapy appears to be moving from one-person psychology toward two-person psychology, which emphasizes the significance of the interplay between two subjects and the importance of an interpersonal approach. This is augmented by scientific studies that are beginning to elucidate the regulatory role of interpersonal interactions (e.g., animal studies [Hofer, 2006], parent-infant studies [Tronick, 2005], couples studies [Gottman & Levenson, 1992]). Of interest is how understandings gained from these studies can be used to enhance the regulatory capacity of interpersonal interactions in the biofeedback paradigm.

The framework suggested herein is rooted in a principal aspect of human nature: the interpersonal aspect. It emphasizes the interpersonal space, viewing interaction as a primary vehicle of reciprocal co-regulation of physiological states whereby each individual within the dyad serves as a physiological regulator for the other. Members of a

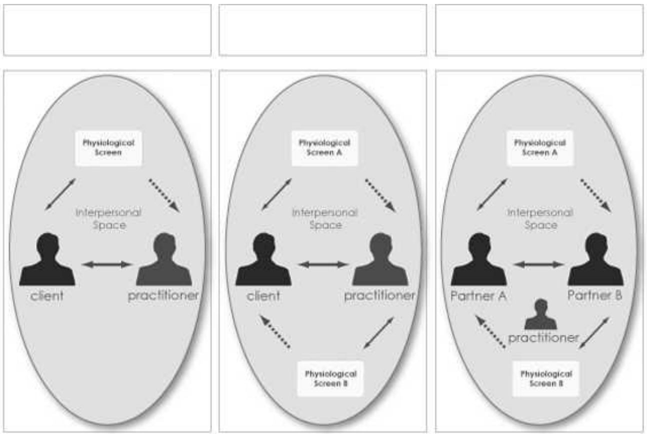

Figure 2. Biofeedback models making use of the regulatory capacity of interpersonal interactions. (A) Presence of the therapist is acknowledged and affects the client's ability to self-regulate. (B) Dyadic biofeedback, the full intersubjective model: Another screen is added, and the therapist's psychophysiological reactions are also displayed. (C) Dyadic biofeedback when the partner is a significant other (e.g., the therapist works with a couple or with a parent and child).

dyad are intertwined; they act and react to each other's behaviors and emotions (Fogel, 1993). This perspective suggests that individual homeostasis—both psychological and physiological—is maintained and regulated in the context of the relationship and, in particular, by the presence of the other. Thus, co-regulation is a function of the relationship itself. The effects of such interactions are determined by the dynamics inherent in each dyadic member and also by the interdependencies between their past histories and the current situation (Chow, Haltigan, & Messinger, 2010). This concept was raised quite early in the development of biofeedback by Ed Taub, who noted that ''perhaps the most powerful factor influencing whether thermal biofeedback learning will occur is the quality of the interaction between the therapist or experimenter and the patient or participant, that is, the 'person factor''' (Sedlacek & Taub, 1996, p. 550).

In biofeedback practice, the interpersonal situation can be envisioned in several different scenarios.

In its primary form, the setup is a conceptual expansion of the third model described above (Figure 2A). The interpersonal context is created by acknowledging the existence of another human being (the therapist) in the room and the subsequent effect of this interpersonal situation on the client's ability to self-regulate. In this scenario, depicted in Figure 2A, there is only one physiological screen in the room, embodying the physiological state of the patient. Although the interpersonal relationship between the therapist and the client is recognized and used in the therapy, the focus of this scenario is still on the individual and the individual's ability to self-regulate.

Suppose another physiological screen is added: that of the therapist. In this scenario, depicted in Figure 2B, the states of internal arousal of both people in the dyad are externalized and embodied by two physiological screens. The situation immediately changes from a personal level to a dyadic level. The interpersonal interaction is expanded such that it no longer affects just one person's ability to self-regulate. It also enables each partner to learn directly how he or she can be regulated (or dysregulated) through one of the most available regulatory resources: human interaction. In addition, each partner in the dyad can learn directly how to enhance the interpersonal space and create more regulatory interaction that will have positive effects on both partners within the dyad. This novel scenario, in which dual physiological screens support mutual co-regulation through interpersonal interaction, is referred to as dyadic biofeedback (DBF).

The physiological screens in this scenario have important, discriminant roles. The first is to enforce the understanding that interaction can have a positive or negative effect on the internal state of both partners—thus, its regulatory impact. The second is to deepen and expand the experience of the other having an internal state. Related to this context is the expanding body of research within relationship studies that stress the role of perceived responsiveness as a cardinal process in relationships (e.g., Reis & Collins, 2004).

The dyad can take several forms; it may consist of the therapist and client, wherein the therapeutic role is to enhance the client's understanding, experience, and usage of the regulatory potential of interpersonal interactions. A more common partner would be a significant other. For example, DBF finds its natural place in couples therapy, wherein a dyad consists of romantic partners and the therapist serves as an external coach. The therapist is still a part of the complex interactional system but is not fully (and physiologically) embedded within it. Another example is a parent and a child interacting and learning to co-regulate through this interaction. As mentioned in the above example, the partial involvement of a coach can be conceived. Yet another intriguing option is to export the biofeedback platform to a wider, real-world situation. With the use of vastly developing telemetric equipment, this option allows people to explore regulation capacities and achieve homeostatic equilibrium in real-world situations, where they are constantly embedded within complex interpersonal situations.

Returning to Neal Miller via the Interpersonal Trail

We propose that DBF stands as an enrichment of the original biofeedback model, presented by Miller's experiments. It expands on the basic assumption that a state of homeostasis is the fundamental requirement for healing, transformation, and subsequent well-being, suggesting there is an optimal arousal level that allows for maximal functioning and interaction. In other words, if Miller's model brought into awareness the possibility of using one's own body to self-regulate, the DBF model uses the interpersonal space and interactional patterns that can facilitate states of co-regulation. It is important to note that within the interpersonal model, the concept of physiological homeostasis/optimal arousal/regulated state is quite different from the stress management biofeedback model (Figure 1B). The stress management models focus mainly on the relaxation state; the interpersonal model strives to create a state that is neither underaroused nor over-aroused—a state that allows for live interaction and creativity, but doesn't lead to anxiety. We would like to suggest that these physiological states of optimal activity have a broader implementation in real-world situations.

There is another level on which the DBF model makes a return to Neal Miller's original conception of the biofeedback space. It is the arousal level that is directly manipulated (as in Miller's model) and not the thoughts and feelings (as in the psychological model). Paralleling Miller's model, DBF emphasizes the role of implicit trial and error through which patients learn what it is about what they are saying, or how they are saying it, what in their body and facial movements and in their overall contribution to the interpersonal space is decreasing or increasing the homeostasis of both partners. It allows for real-time training of interpersonal interaction, emphasizing learning through direct observation and active involvement.

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