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Applied Psychophysiology: Beyond the Boundaries of Biofeedback (Mending a Wall, a Brief History of Our Field, and Applications to Control of the Muscles and Cardiorespiratory Systems)[1]

Paul Lehrer[2]

The field of applied psychophysiology overlaps a number of others, from behavioral and psychosomatic medicine to Eastern disciplines and complementary medicine. Although the proliferation of societies and professional identities across these fields emphasizes this diversity, it also may hinder growth. The history of our field is one of innovation, often at odds with conventional wisdom and practice. It is important that this innovativeness not be sacrificed in a justified quest for professional respectability. This paper reviews the earliest research in biofeedback and applied psychophysiology, and modern applications and interpretations in the areas of muscular and autonomic control, including progressive relaxation and heart rate variability biofeedback, and draws parallels to disciplines of Yoga, QiGong, and Zen practices and their psychophysiological effects.

KEY WORDS: societies; behavioral medicine; self-regulation; advocacy; costs; progressive relaxation; heart rate variability biofeedback.

> Something there is that doesn't love a wall,
> That sends the frozen-ground-swell under it,
> And spills the upper boulders in the sun,
> And makes gaps even two can pass . . .
>
> I let my neighbor know beyond the hill;
> And on a day we meet to walk the line
> And set the wall between us once again.
> We keep the wall between us as we go . . .
>
> There where it is we do not need the wall:
> He is all pine and I am apple orchard.
> My apple trees will never get across
> And eat the cones under his pines, I tell him.
> He only says, 'Good fences make good neighbors' . . .

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[2]Department of Psychiatry, Robert Wood Johnson Medical School, University of Medicine and Dentistry of New Jersey, 671 Hoes Lane, Piscataway, New Jersey 08854; e-mail: lehrer@rwja.umdnj.edu.

Before I built a wall I'd ask to know
What I was walling in or walling out,
And to whom I was like to give offense . . .

Something there is that doesn't love a wall,
That wants it down.' I could say "Elves" to him,
But it's not elves exactly, and I'd rather
He said it for himself.

— Robert Frost, *Mending Wall*

A great poem tells us something about ourselves and our world. It makes us aware of a truth. All of us as psychotherapists know the importance of boundaries. When personal and professional boundaries are violated we all suffer; but boundaries can also hem us in. The notion that we, as a field, must examine and transcend the boundaries of biofeedback is not a new one, having been proposed by some of the founders of our field, when it was still quite young (Green & Green, 1977).

Good boundaries are embedded in our code of ethics. When they are violated our clients suffer, our credibility suffers, and we all suffer. Gaps do occur in them when we allow exceptions to restrictions on dual relationships or institutional review board procedures. These boundaries crumble only at our peril.

Some other boundaries are inevitable, such as jurisdictional and national boundaries. Our profession is regulated differently across various borders. Insurance and licensing differ; the rules and covered benefits differ, including who may perform biofeedback, for what conditions, and, often, with what reimbursement. These borders are deeply imbedded in our national and international systems. They sometimes create conflict, often curtailing the influence of our national society in shaping regulations that affect us. This is the province of local organizations—yet local groups often lack the organizational power and expertise to take effective action. Only cooperative action can work, but it is often difficult to figure out how to make this happen. Also overlapping professional groups have expertise on particular parts of our own practice. It works best when all groups see that and come together with a common agenda, and make this a priority. As Frost said, "I'd rather he said it for himself."

But sometimes the proliferation becomes a burden. Table I shows the organizations to which I personally belong, and whose meetings I would like to attend regularly. Table II summarizes what these groups fence in and out, and Table III summarizes what we may be walling in and out. Of course dues become burdensome, and societies inevitably meet at overlapping times of year. The proliferation exaggerates the narrowest denominators of professional and disciplinary distinctions among us. On the other hand, this allows us

Table I. Overlapping Organizations

AAPB	New Jersey Psychological Association
Northeast Society	American Psychiatric Association
BCIA	International Society for the Study of Tension in Performance
Association for Advancement of Behavior Therapy	American Thoracic Society
International Stress Management Association	New Jersey Thoracic Society
International Society for Applied Respiratory	Society for Behavioral Medicine
International Society for Neuronal Regulation Psychophysiology	Society for Psychophysiological Research
American Psychological Society	American Psychosomatic Society
American Psychological Association	

Table II. Some Things That Various Societal Boundaries Fence In and Out

Disciplinary boundaries	Distinctions between disciplines
Psychophysiology	Brain vs. body
Applied psychophysiology	Biofeedback vs. meditation
The lung	Relaxation vs. self-hypnosis
The heart	Heart rate variability vs. breathing
The brain	Yoga vs. QiGong vs. biofeedback
Psychology	Psychology vs. medicine vs. nursing vs. education vs. physical therapy
Medicine	Research vs. Practice
Biofeedback	
Behavior therapy	
Cognitive behavior therapy	
Hypnosis	
Complementary/alternative medicine	
Behavioral science	

greater control of program content and advocacy, and greater specialization can foster growth in knowledge, and more focused advocacy and intellectual debate. The problem becomes compounded when personal gain and political agendas become entwined with institutional structures, as they nearly always do. When does Frost's warning apply: "My apple trees will never get across and eat the cones under his pines, I tell him?" I think that the time is now, particularly as budgets and resources dwindle, adding strain to both science and practice, and cutting attendance at many national and international meetings. The interests of these various societies are, after all, interconnected, as are the parts of our bodies.

Applied psychophysiology itself has often operated "beyond the boundaries" of traditional disciplines. Although this often made us appear "fringy," it also was the source of excitement and energy in our field (Table IV). When describing the admissions requirements of our clinical psychology program, one of our colleagues once accused me and our program as being "elitist" in its admissions requirements. Although I prefer the word "elite," this incident reflects a characteristic of our field and the people who enter it: we are nonconformists. We do not work in one of the "traditional" disciplines, with a long history of academic, cultural, and corporate support.

The right column in Table IV shows some of the characteristics generally applied to the field of medicine. Although we may aspire to some of these traits, might we give up

Table III. What Proliferation of Societies Walls In and Out

Walling in	Walling out
Subspecialty identification	Members
Control over program	Schedule and financial conflicts
Set intellectual agenda	Credentialling and education
Control over advocacy	Cross-fertilization
Research	Political power
Clinical regulation	Cost of supporting the priorities of others
Professional identification	
Establish standards of professional practice	
Power of credentialling	
Professional identity	
Standards of practice	

Table IV. Contradictions Between Goals and Needs of Applied Psychophysiology: Which Is Applied Psychophysiology?

Which are we?	
This?	Or this?
Innovative	Traditional
Willing to use previously untried methods	Worthy of third-party reimbursement
Unconventional	Scientific
Nonestablishment	Ancient ethical tradition—“primarily do no harm”
Alternative	Responsible
Unregulated	Self-sacrificing
“Fringy”	Trusted
Welcome to new ideas and innovation	Worthy of research support
Speculative	Conservative
Controversial	Research-based
Attracts the scruffy risk-takers	Traditional
	Conventional
	Establishment
	Prestigious
	Lots of available well-paying positions
	Attracts the beautiful and powerful
	Demand for services
	Attracts research grants and contracts

something in the process (left column in Table IV)? Indeed, the very things that make us exciting include that much of our work is, from a medical perspective, “experimental,” and therefore, perhaps, less entitled to third-party reimbursement, public trust, or even support in large-scale clinical trials. This also may differentiate us from other overlapping societies, and constitute one of the “walls” between us. Such activity requires a different mind-set and temperament from that prevalent in more established disciplines. Robert Frost had something to say about this choice too:

> Two roads diverged in a yellow wood,
> And sorry I could not travel both.
> And be one traveler, long I stood
> And looked down one as far as I could
> To where it bent in the undergrowth;
> Then took the other, as just as fair,
> And having perhaps the better claim,
> Because it was grassy and wanted wear; . . .
>
> Yet knowing how way leads on to way,
> I doubted if I should ever come back.
> I shall be telling this with a sigh
> Somewhere ages and ages hence:
>
> And I—
> I took the one less traveled by,
> And that has made all the difference.
>
> — R. Frost, *The Road Not Taken*

Taking the less traveled road is more exciting and innovative, but it also may not be very smooth.

In a quest to consolidate our professional status, the AAPB board has recently declared applied psychophysiology as an independent profession. Although born primarily of the psychology, we have mostly been orphaned, with few psychology graduate programs teaching our discipline. We thus have published our own code of ethics, are in the process of revising a series of white papers reviewing empirical evidence for various applications, are adopting an updated set of practice standards, and have an established credentialing board (the Biofeedback Certification Institute of America, BCIA). Several graduate programs are now teaching curricula based on BCIA's blueprint of the knowledge base of our field. Although we mostly reside on the left column of Table IV, we are fast developing some characteristics of the right column. As in all new professions, however, we are met publicly with some skepticism, little knowledge, restricted reimbursement for services, and no licensures. But in Schopenhauer's (1819) words,

> . . . To truth only a brief celebration of victory is allowed between the two long periods during which it is condemned as paradoxical, or disparaged as trivial. The author of truth also usually meets with the former fate. But life is short, and truth works far and lives long: let us speak the truth.

How we got where we are. One of the first published biofeedback experiments was by the Columbian psychologist Ralph Hefferline (Hefferline & Perera, 1963). He had an academic interest in studying whether the "unconscious" could be studied experimentally—a radical idea in its time. He applied operant conditioning to a subliminal thumb twitch, and found that, in fact, the laws and patterns of operant behavior were clearly evident in a subject's ability to control this physiological event, while having no awareness of what, in fact, was being controlled.

Early research on operant conditioning of autonomic nervous system activity was clearly considered to be a ridiculous undertaking. It had generally been assumed that the autonomic nervous system and emotion were controlled only through classical conditioning. This dichotomy was a cornerstone Mowrer's then widely accepted "two-factor theory of learning" (Mowrer, 1951). In the latter theory, something akin to classical conditioning controlled "drive," which was a critical ingredient in learning of voluntary behavior, although the latter applied only to overt muscular, and sometimes mental activity.

Nevertheless a few intellectually brave souls challenged these apparently self-evident conclusions. Kimmel and Hill (1960) reported successful operant conditioning of the palmar skin conductance response. Close in time, Shapiro and his colleagues (Shapiro, Crider, & Tursky, 1964), working at the same institution as Skinner (Harvard), similarly reported successful operant conditioning of palmar skin potentials. They later expanded their work to demonstrate fine-tuned control of skin potential responses using multiple schedules of operant reinforcement in humans (Shapiro & Crider, 1967). It was in this environment that I was first introduced to biofeedback.

One of the great unsung heroes of biofeedback was Lee Birk, a young psychiatrist working with Shapiro, who literally risked his life to demonstrate that operant learning of autonomic behavior could occur independently of coexisting muscular activity (Birk, Crider, Shapiro, & Tursky, 1966). Although previous research in their laboratory had failed to find any correlations between autonomic changes and changes in muscular activity, the latter had never been completely excluded as a mediator, because all muscles could not be measured simultaneously. Birk therefore had himself partially curarized, to the point where artificial ventilation was required. Even with most muscular activity blocked at the neuromuscular juncture, he found that he could exercise voluntary control over the skin potential response, even when muscular control was blocked almost entirely.

The Work of Edmund Jacobson. Despite Birk's startling findings, there is considerable evidence that respiration and muscular activity are important mediators of autonomic activity. My other great mentor in psychology, Edmund Jacobson, had demonstrated early in the twentieth century that systematic reduction in skeletal muscle tension, using the method of progressive relaxation, was capable of producing profound effects on autonomically mediated activity, and could be used clinically to treat various conditions characterized by excess "neuromuscular tension," including anxiety, hypertension, and "spastic colon" (now called irritable bowel syndrome; Jacobson, 1938, 1970). His classic book, *Progressive Relaxation* (Jacobson, 1938) still bears reading. In it he describes a number of far-reaching studies *conducted in the 1920s*, including fluoroscopic studies of the esophagus and colon before and after relaxation training (Jacobson, 1938, pp. 357–394), giving irrefutable evidence for relaxation of intestinal spasms. Influenced, to some extent, by Lange and James' peripheralist theories of emotion ("we are happy because we laugh . . . we are sad because we cry . . . etc; Lange & James, 1967), Jacobson concluded that emotions and, indeed, all human thoughts were inseparable with muscular activity that accompanies them (cf. Jacobson's last book, an interesting but obscure volume; Jacobson, 1982).

Jacobson's relaxation method was quite detailed, much more similar to modern methods of surface EMG biofeedback than to the various "progressive relaxation" methods currently used by behavior therapists (Lehrer & Carr, 1996; Lehrer, Woolfolk, & Goldman, 1986). It emphasized muscular learning over perceptions of relaxation, and avidly avoided use of suggestion, to the point where the therapist did not even tell the trainee where in the body to expect to feel muscle sensations. Using the method of "diminishing tensions," where deliberate tension was progressively lessened to almost imperceptible levels, Jacobson taught his patients to become aware of residual tension or "muscle tonus" that remained in a supposedly relaxed muscle (Jacobson, 1938, pp. 220–269). He did not believe, as do many more recent contributors to the field (e.g., Bernstein & Carlson, 1993) that tensing a muscle produced consequent relaxation after tension release, but used muscle tension only as a didactic device, to teach more sensitive perception of muscle sensations, and to help people acquire control. A study from our own laboratory verified his observations. We found surface EMG evidence that muscle tension in the facial area persists after several seconds of tension followed by immediate deep relaxation (Lehrer, Batey, Woolfolk, Remde, & Garlick, 1988). We also found that repeated tense-release cycles did not, by themselves, increase the correlations between surface EMG and self-rated muscle tension, suggesting that repetitions of these cycles with a high level of muscle tension does not, by itself, improve awareness of muscle tension. This is consistent with our clinical observations that training to recognize *very low* levels of induced muscle tension is necessary to obtain this skill, although this has not been systematically examined.

Birk's human curare findings and those of other human curare studies had had far-reaching implications for the acceptance of Jacobson's approach. For example, Davison (1966) argued influentially that these findings disproved Jacobson's peripheralist theories, because anxiety could persist despite the lack of muscle tension. This argument provided the theoretical rationale for abandoning Jacobson's physiological emphasis in treating anxiety disorders, and gave way to a more cognitive approach to anxiety management, which has been the dominant theme in behavioral treatment of anxiety since that time. This tendency created changes in commonly used applications of Jacobson's method, particularly to psychiatric problems. This was perhaps in response to the Stanford influences of the day (the great hypnosis researcher, E. Hilgard, and the pioneering proponents of behavior therapy, J. Wolpe and A. Lazarus). Strong elements of suggestion were incorporated into the technique in Bernstein and Borkovec's widely influential manual (Bernstein & Borkovec, 1973). Not everyone accepted this argument, however. McGuigan (1978, p. 95) pointed out that people were never fully curarized in the human studies. Also, the curarized state is undeniably unnatural; the fact that anxiety *can* occur without muscle tension does not mean that it *does* so occur in the intact individual. Indeed, physiological researchers have long commented on the close association between muscle tension and the sympathetic nervous system confirms that muscular activity is an important component in a complex feedback loop that stimulates and maintains sympathetic arousal (Vallbo, Hagbarth, Torebjork, & Wallin, 1979; Wallin & Nerhed, 1982), which figures as an important component in anxiety and emotion (Gellhorn, 1970) as well as in stress-related disease (Mills & Dimsdale, 1993).

Jacobson was a firm believer in self-control of the body, without external aids. Therefore, just as he rejected suggestion as a training method, he also rejected the use of tape recorded instructions, and even of surface EMG biofeedback. The latter was true despite the fact that he, along with a group of scientists from Bell Laboratories, was inventor of the first "integrating neurovoltmeter," capable of measuring EMG signal to amplitudes as low as 1 μV peak-to-peak: A level that still is at the fringes of capability for commercially available biofeedback devices (Jacobson, 1940). (Note that this first device required a rather large room, crammed with relay racks filled with electronic equipment.) In his opinion, it is self-defeating to require the external aid of such devices. The purpose of progressive relaxation training, according to Jacobson, is to learn a skill, rather than to have relaxation "induced" by other means. To this end, he also rejected the use of music or even relaxing surroundings. He trained me in his method from a room on the third floor of New York's old Commodore Hotel, situated next door to Grand Central Station. The exhaust pipes of large trucks almost reach window level at that time, and noise from skyscraper construction projects across the street lent a malodorous and cacophonous ambience to the proceedings Jacobson never regarded these as barriers to learning relaxation. He conducted training with the trainees sitting either on a couch or a straight-back chair; never from a recliner. He was also merciless about practice. He required a continuous hour per day. Complaints were met with orders to wake up an hour earlier and practice in bed. Jacobson argued that an hour of relaxation practice at that time provided better rest than an extra hour's morning sleep.

The emphasis on internal control in Jacobson's method corresponds well with the findings of later research on personality predictors of success with various stress-management methods. Patients who score high on the psychological dimension of internal control tend to do better with relaxation therapy than with biofeedback, as do persons high on hypnotic susceptibility. However, persons low on either of these dimensions tend to do better with biofeedback (see review by Lehrer & Woolfolk, 1993b). Also, studies of "derivative" progressive relaxation methods (which provide less intensive training in muscle control and include suggestion and even some overtly hypnotic components) tend to produce fewer autonomic and more muscular effects than autonomically oriented methods such as autogenic training or thermal biofeedback (Lehrer & Woolfolk, 1993a). Such research has not been done using Jacobson's method. Thus far, only two unpublished studies have compared Jacobson's method with these derivative methods (Snow, 1978; Turner, 1978), finding a few small but significant advantages for Jacobson's method among populations of healthy college students. These studies probably minimized the difference in effects because of large “floor” effects in this group, who mostly can relax quite deeply without training. In Jacobson’s studies, only patients with neuromuscular tension problems tend to have great difficulty relaxing without instruction. Athletes and persons trained in body control tend to learn the method most easily, whereas relaxation comes faster and more completely among patients trained in the technique than even among untrained athletes (Jacobson, 1934, 1936). In our own laboratory, we have verified that progressive relaxation training produces little incremental physiological effect on autonomic reactivity among healthy people (Lehrer, 1972, 1978), but strong autonomic effects among anxious patients (Lehrer, 1978), particularly when performed in vivo (rather than by tape recording), but producing greater muscular and smaller cardiac effects than autogenic training (Lehrer, Atthowe, & Weber, 1980; Shapiro & Lehrer, 1980), and greater muscular but smaller cognitive effects than mantra meditation (Lehrer, Schoicket, Carrington, & Woolfolk, 1980; Lehrer, Woolfolk, Rooney, McCann, & Carrington, 1983; Woolfolk, Lehrer, McCann, & Rooney, 1982).

Jacobson’s own work in relaxation began with an interest in philosophy and the “experience of thinking.” In one of his earliest papers (Jacobson, 1910), he showed how thought almost inevitably involves somatic sensations. Later, he and his protege, F. J. McGuigan conducted experimental studies of thinking, and found, indeed, that thought was almost inevitably associated with muscle tension, particularly in the facial area (Jacobson, 1932, 1938, pp. 164–189; McGuigan, 1978). In his clinical approach, he insisted that “intrusive thoughts” would inevitably disappear during complete relaxation of muscles in and near the mouth, vocal apparatus, and eyes.

In some of the more colorful scientific and personal controversies of the time, Jacobson rejected (and was rejected by) such great contributors to psychology as Hugo Munsterberg (Jacobson, 1977), whom he accused of suppressing data that conflicted with his theory, William James, whom he considered to be an antiempiricist who suffered from many stress-related ailments but whom he nevertheless quotes to help confirm his own peripheralist theories of mental effects and emotion (Jacobson, 1938, pp. 167, 207–209), Edward Titchener, whom, he once confided in me, was a good tennis player but bad introspectionist, and Johannes Schultz (Schultz & Luthe, 1969), whose method of autogenic training he thought was ineffectual, and who, he once told me, must have been a Nazi sympathizer—who refused to dine with him during a visit to Chicago because he (Jacobson) was Jewish. On the other hand, he always spoke with the greatest respect of the great physiologist, Walter Cannon (Cannon, 1937), who was one of the earliest physiologists describing the fight–flight reflex and principles of homeostasic balance in the autonomic nervous system. Similarly, there was much mutual admiration with the physiologist Ernst Gellhorn (Gellhorn, 1958), who described the interactions among the musculoskeletal system and both branches of the autonomic nervous system, through hypothalamic mediation. Also, when applying his methods to patients suffering primarily from phobias and other anxiety conditions, he often referred to the contributions of Wolpe (1958).

Respiratory Training and Heart Rate Variability Biofeedback. In addition to muscular control, respiration is the other physiological function with pervasive physiological effects that is easily trainable. This has long been known by practitioners of various Eastern meditative techniques, all of which make major use of respiratory maneuvers, primarily involving slow deep breathing. Work in our laboratory has focused on biofeedback training of heart rate variability, which can be directly influenced by breathing.

My own interest in respiration derived from the use of respiratory sinus arrhythmia (the heart rate fluctuations that accompany breathing) as a noninvasive measure of parasympathetic activity in psychophysiological studies (Katona & Jih, 1975). During a visit to St. Petersburg, Russia, in 1992, I discovered the active biofeedback clinic of the Biosvyaz Corporation under the direction of Alexander Smetankin, where children with asthma were being trained to increase respiratory sinus arrhythmia as a method to control asthma. This use was a great surprise to me, because increased parasympathetic arousal ordinarily produces bronchoconstriction (Nadel & Barnes, 1984), and hence, in my mind, should have been *countertherapeutic* for asthma. Consistent with this, a study of relaxation therapy in my laboratory found evidence for relaxation-induced bronchoconstriction in asthma (Lehrer et al., 1994), associated with decreases in heart rate and increased respiratory sinus arrhythmia (Lehrer, Hochron, et al., 1997); and other studies found evidence for *bronchodilation* during an activating mental arithmetic task, associated with increased heart rate and decreased respiratory sinus arrhythmia, both among asthma patients and in healthy individuals (Lehrer et al., 1996).

However, demonstrations of efficacy for asthma at the Biosvyaz clinic were quite convincing to me; and eventually Smetankin and I coauthored a study of 20 successive asthma cases from their clinic, showing marked improvement in pulmonary function among unmedicated children with mild asthma (Lehrer, Smetankin, & Potapova, 2000), later replicated in a small controlled study in my laboratory (Lehrer, Carr, et al., 1997), and in a larger clinical trial (in a paper currently under review).

The rationale for these effects had escaped me, despite long discussions with Steven Porges about his “polyvagal” theory (Porges, 2001), and ample evidence that, in addition to reflecting vagal activity, respiratory sinus arrhythmia (and, indeed, heart rate variability *in general*) is a strong indicator of adaptive capacity, homeostatic control, and other indications of functional capacity (e.g., survival after myocardial infarction, Bigger, Fleiss, Rolnitzky, & Steinman, 1992; youth, Liao et al., 1995; aerobic fitness, Hedelin, Wiklund, Bjerle, & Henriksson-Larsen, 2000; absence of anxiety, Thayer, Friedman, & Borkovec, 1996; or depression, Thayer et al., 1996; Yeragani, Balon, Pohl, & Ramesh, 1995; and many other indicators of health, survival, and resistance to physical and emotional stress, Friedman & Thayer, 1998; Porges, 1992). We have theorized that the amplitude and complexity of rhythmical fluctuations in heart rate is related to the number of functioning “backup” systems for maintaining cardiovascular stability and adaptiveness (Giardino, Lehrer, & Feldman, 2000).

The critical links were eventually explained to me by Evgeny Vaschillo, a collaborator of Smetankin’s, and then Director of the physiology laboratory at the Lesgov Academy for Physical Culture, the Olympic training center in St. Petersburg. In a series of studies, he induced heart rate oscillations at specific frequencies using biofeedback, and performed transfer function analyses of heart rate, blood pressure, and respiration at various frequencies. He found that high-amplitude oscillations in heart rate could be induced only at specific resonant frequencies inherent in heart rate oscillations (at ∼0.1 Hz), and that these corresponded to the effects of biofeedback (and perhaps respiration) on the baroreflex system[3] (cf. Vaschillo, Lehrer, Rishe, & Konstantinov, 2002). He noted that, at each individual’s

[3]The baroreflexes are one of the important mechanisms for regulation of blood pressure. As blood pressure rises, stretch receptors in the aorta and carotid sinus trigger decreases in heart rate and vasodilation. The opposite effects occur as blood pressure decreases. This activity induces a regular oscillation in heart rate of about 0.1 Hz.

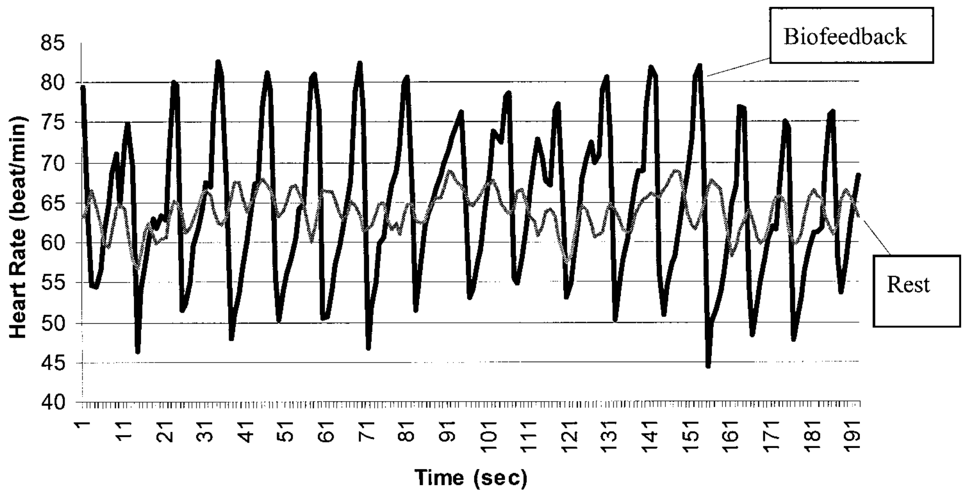

Fig. 1. A typical recording of oscillations in heart rate at rest and during biofeedback.

specific resonant frequency, heart rate and blood pressure oscillated 180° out of phase with each other, whereas heart rate and respiration were in phase (0°). Thus, when the individual inhales at this frequency (~6 breaths/min) inhalation is accompanied by an increase in heart rate, but a decrease in blood pressure. The decrease in blood pressure then produces baroreflex action that induces a *further* increase in heart rate. The opposite occurs during exhalation. The resultant effect is a very large oscillation in heart rate (see Fig. 1), accompanied by a large increase in amplitude of the baroreflex response. Vaschillo reasoned that the frequent high-amplitude activation of the baroreflexes might be expected to increase the efficiency of these reflexes. We have since demonstrated that, in fact, baroreflex gain is increased during biofeedback practice, as well as *at rest* after about 10 weeks of training with daily home practice (Lehrer et al., in press).

These studies show that the results of heart rate variability biofeedback are far different from just increasing vagal tone and parasympathetic arousal. The technique appears to exercise, and thereby strengthen, one of the body's important homeostatic reflexes. This could have major implications for future applications of biofeedback to various diseases associated with autonomic dysregulation. These include such severe problems as heart failure, risk of recurrence after postmyocardial infarction, reflex sympathetic dystrophy, hypertension, anxiety, depression, diabetes, congenital dysautonomia, and dysautonomias associated with spinal cord injury. Because it acts primarily on homeostatic control mechanisms, rather than on *levels* of sympathetic or parasympathetic influence on various physiological systems, the method may be useful for controlling problems associated with sympathetic or parasympathetic *hypo*activity as well as *hyper*activity. It also is an eminently practical method. People almost invariably show large effects within the first few minutes of training. The skill gradually improves over the first 4 weeks of training. However, measurable effects on the baroreflex do not appear to occur until about 10 weeks of daily home practice (Lehrer et al., in press).

Links to Eastern Meditative Practices. Because of its respiratory focus, this method also has similarities to Yoga, QiGong, and Zen, which also have beneficial health effects

(Kikuchi & Ishikawa, 1993; Mayer, 1999; Raub, 2002; Sancier, 1999). We have found (Lehrer, Sasaki, & Saito, 1999) that, during zazen meditation, Zen monks show changes in respiration and HRV similar to those in HRV biofeedback. Zen monks have very low rates of hypertension and cardiovascular disease. Resonant frequency breathing may be the common antihypertensive component in these methods, although the antihypertensive effect could be explained by other aspects of lifestyle. Although these various Eastern methods include other meditative and physical components, in addition to slowed breathing, we believe that the slowed breathing component may be *an*, if not *the*, effective component in various of these methods, particularly with regard to controlling blood pressure. However, further evaluation of these methods is required, and comparisons to biofeedback evaluated.

What, then, differentiates this biofeedback technique from Yoga, QiGong, or Zen, which all tend to slow breathing rather than biofeedback? Masters of these methods tend to teach people to modulate their respiration rate in ways that naturally produce very large increases in low frequency heart rate variability, much as does heart rate variability biofeedback (Lehrer et al., 1999; Raghuraj, Ramakrishnan, Nagendra, & Telles, 1998). However, these disciplines are not well standardized, and the techniques vary considerably among instructors. They also are rather complex, with many cognitive as well as physiological components (e.g., muscular exercise), each of which may have unique effects. Also, their cultural role in various Eastern religions may make them unacceptable to some Westerners, although more appealing to others. An advantage to biofeedback is that it is simple, replicable, and standardized, and can be learned easily by most individuals. These complex characteristics of Eastern meditative techniques are illustrated by a Zen monk's comment, as I departed from temple from which I had gathered much of my data. He complimented me on a presentation I had made to them on respiratory psychophysiology (an enterprise reminiscent of "carrying coals to Newcastle": that is, presenting data on this topic to a group who considered themselves to be "professional breathers"): "You really know something," he said, "this much" (holding his fingers slightly apart to indicate the small amount that I really do know). Of course, he was correct.

Summary and Conclusion. Our field is both focused and diverse. Applied psychophysiology overlaps with many disciplines, from behavioral and psychosomatic medicine to Eastern meditative practices and complementary medicine. This diversity can both facilitate and impede progress in our field of applied psychophysiology. Our emphasis has been on direct voluntary control of physiology, and its application in a variety of contexts. Major gains have been made, but much remains to be learned. From my perspective, the specific technique of self-regulation we use is less important than the fact that such control is possible. We would be well advised to remain flexible in our practical approach, and to learn from all who can demonstrate major effects.

REFERENCES

Bernstein, D. A., & Borkovec, T. D. (1973). *Progressive relaxation training: A manual for the helping professions*. Champaign, IL: Research Press.

Bernstein, D. A., & Carlson, C. R. (1993). Progressive relaxation: Abbreviated methods. In P. M. Lehrer, & R. L. Woolfolk (Eds.), *Principles and practice of stress management* (2nd ed.), pp. 53–87.

Bigger, J. T., Fleiss, J. L., Rolnitzky, L. M., & Steinman, R. C. (1992). The ability of several short-term measures of RR variability to predict mortality after myocardial infarction. *Circulation*, *88*, 927–934.

Birk, L., Crider, A., Shapiro, D., & Tursky, B. (1966). Operant electrodermal conditioning under partial curarization. *Journal of Comparative and Physiological Psychology*, *62,* 165–166.

Cannon, W. B. (1963). *The wisdom of the body*. New York: Norton. (Original work published 1937).

Davison, G. C. (1966). Anxiety under total curarization: Implications for the role of muscular relaxation in the desensitization of neurotic fears. *Journal of Nervous and Mental Disease*, *143,* 443–448.

Friedman, B. H., & Thayer, J. F. (1998). Anxiety and autonomic flexibility: A cardiovascular approach. Republished from *Biological Psychology*, *47,* 243–263.

Gellhorn, E. (1958). The physiological basis of neuromuscular relaxation. *Archives of Internal Medicine*, *102,* 392–399.

Gellhorn, E. (1970). The emotions and the ergotropic and trophotropic systems: II. The tuning of the central nervous system and its psychological implication. *Psychologische Forschung*, *34,* 67–94.

Giardino, N., Lehrer, P. M., & Feldman, J. (2000). The role of oscillations in self-regulation: Their contribution to homeostasis. In D. Kenney, & F. J. McGuigan (Eds.) *Stress and health: Research and clinical applications*. (pp. 27–52). Amsterdam: Harwood.

Green, E., & Green, A. (1977). *Beyond biofeedback*. New York: Delacorte Press.

Hedelin, R., Wiklund, U., Bjerle, P., & Henriksson-Larsen, K. (2000). Pre- and post-season heart rate variability in adolescent cross-country skiers. *Scandinavian Journal of Medicine and Science in Sports*, *10,* 298–303.

Hefferline, R. F., & Perera, T. B. (1963). Proprioceptive discrimination of a covert operant without its observation by the subject. *Science*, *139,* 834–835.

Jacobson, E. (1910). The relational account of truth. *The Journal of Philosophy, Psychology, and Scientific Methods*, *7,* 253–261.

Jacobson, E. (1932). Electrophysiology of mental activities. *American Journal of Psychology*, *44,* 677–694.

Jacobson, E. (1934). Electrical measurements concerning muscular contraction (tonus) and the cultivation of relaxation in man—relaxation-times of individuals. *American Journal of Physiology*, *108,* 573–580.

Jacobson, E. (1936). The course of relaxation in muscles of athletes. *American Journal of Psychology*, *48,* 98–108.

Jacobson, E. (1938). *Progressive relaxation*. Chicago: University of Chicago Press.

Jacobson, E. (1940). The direct measurement of nervous and muscular states with the integrating neurovoltmeter (action potential-integrator). *American Journal of Psychiatry*, *97,* 513–523.

Jacobson, E. (1970). *Modern treatment of tense patients*. Springfield, IL: Charles C. Thomas.

Jacobson, E. (1977). The origins and development of progressive relaxation. *Journal of Behaviour Therapy and Experimental Psychiatry*, *8,* 119–123.

Jacobson, E. (1982). *The human mind*. Springfield, IL: Charles C. Thomas.

Katona, P. G., & Jih, F. (1975). Respiratory sinus arrhythmia: Noninvasive measure of parasympathetic cardiac control. *Journal of Applied Physiology*, *39,* 801–805.

Kikuchi, T., & Ishikawa, H. (1993). Respiratory control in hypertension. In S. Tsutsui, I. Saito, & K. Shirakura (Eds.), *Current biofeedback research in Japan 1993* (pp. 64–71). Tokyo: Japanese Society of Biofeedback Research.

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

Lange, C. G., & James, W. (1967). *The emotions*. New York: Hafner.

Lehrer, P. (1972). Physiological effects of relaxation in a double blind analog of desensitization. *Behavior Therapy*, *3,* 193–208.

Lehrer, P. M. (1978). Psychophysiological effects of progressive relaxation in anxiety neurotic patients and of progressive relaxation and alpha feedback in non-patients. *Journal of Consulting and Clinical Psychology*, *46,* 389–404.

Lehrer, P. M., Atthowe, J. M., & Weber, E. S. (1980). Effects of progressive relaxation and autogenic training on anxiety and physiological measures, with some data on hypnotizability. In F. J. McGuigan, W. Sime, & J. M. Wallace (Eds.), *Stress and tension control* (pp. 171–184). New York: Plenum.

Lehrer, P. M., Batey, D., Woolfolk, R. L., Remde, A., & Garlick, T. (1988). The effect of repeated tense-release sequences on EMG and self-report of muscle tension: An evaluation of Jacobsonian and post-Jacobsonian assumptions about progressive relaxation. *Psychophysiology*, *25,* 562–569.

Lehrer, P. M., & Carr, R. (1996). Jacobson's method of progressive relaxation. In W. T. Roth (Ed.), *Treating the anxiety disorders* (pp. 83–116). San Francisco: Jossey-Bass.

Lehrer, P. M., Carr, R. E., Smetankine, A., Vaschillo, E., Peper, E., Porges, S., et al. (1997). Comparison of respiratory sinus arrhythmia and neck/trapezius EMG biofeedback for asthma: A pilot study. *Applied Psychophysiology and Biofeedback*, *22,* 95–109.

Lehrer, P. M., Hochron, S., Carr, R., Edelberg, R., Hamer, R., Jackson, A., et al. (1996). Behavioral task-induced brochodilation in asthma during active and passive tasks: A possible cholinergic link to psychologically-induced airway changes. *Psychosomatic Medicine*, *58,* 413–422.

Lehrer, P. M., Hochron, S., Mayne, T., Isenberg, S., Carlson, V., Lasoski, A. M., et al. (1994). Relaxation and music therapies for asthma among patients prestabilized on asthma medication. *Journal of Behavioral Medicine*, *17,* 1–24.

Lehrer, P. M., Hochron, S. M., Mayne, T., Isenberg, S., Lasoski, A. M., Carlson, V., et al. (1997). Relationship between changes in EMG and respiratory sinus arrhythmia in a study of relaxation therapy for asthma. *Applied Psychophysiology and Biofeedback*, *22,* 183–191.

Lehrer, P. M., Sasaki, Y., & Saito, Y. (1999). Zazen and cardiac variability. *Psychosomatic Medicine*, *61,* 812–821.

Lehrer, P. M., Schoicket, S., Carrington, P., & Woolfolk, R. L. (1980). Psychophysiological and cognitive responses to stressful stimuli in subjects practicing progressive relaxation and clinically standardized meditation. *Behavior Research and Therapy*, *18,* 293–303.

Lehrer, P. M., Smetankin, A., & Potapova, T. (2000). Respiratory sinus arrhythmia biofeedback therapy for asthma: A report of 20 unmedicated pediatric cases using the Smetankin method. *Applied Psychophysiology and Biofeedback*, *25,* 193–200.

Lehrer, P. M., Vaschillo, E., Vaschillo, B., Lu, S. E., Eckberg, D. L., Edelberg, R., et al. (in press). Heart rate variability biofeedback increases baroreflex gain and peak expiratory flow. *Psychosomatic Medicine*.

Lehrer, P. M., & Woolfolk, R. L. (1993a). Research on clinical issues in stress management. In P. M. Lehrer & R. L. Woolfolk (Eds.), *Principles and practice of stress management* (2nd ed., pp. 521–538). New York: Guilford.

Lehrer, P. M., & Woolfolk, R. L. (1993b). Specific effects of stress management techniques. In P. M. Lehrer & R. L. Woolfolk (Eds.), *Principles and practice of stress management* (2nd ed., pp. 481–520). New York: Guilford.

Lehrer, P. M., Woolfolk, R., & Goldman, N. (1986). Progressive relaxation then and now: Does change always mean progress? In R. Davidson, G. Schwartz, & D. Shapiro (Eds.), *Consciousness and self-regulation* (Vol. 4 pp. 183–216). New York: Plenum.

Lehrer, P. M., Woolfolk, R. L., Rooney, A. J., McCann, B., & Carrington, P. (1983). Progressive relaxation and meditation: A study of psychophysiological and therapeutic differences between two techniques. *Behaviour Research and Therapy*, *21,* 651–662.

Liao, D., Barnes, R. W., Chambless, L. E., Simpson, R. J., Sorlie, P., Heiss, G. (1995). Age, race, and sex differences in autonomic cardiac function measured by spectral analysis ofheart rate variability: The ARIC study. *American Journal of Cardiology*, *76,* 906–912.

Mayer, M. (1999). Qigong and hypertension: A critique of research. *Journal of Alternative and Complementary Medicine*, *5,* 371–382.

McGuigan, F. J. (1978). *Cognitive psychophysiology: Principles of covert behavior*. Englewood Cliffs, NJ: Prentice-Hall.

Mills, P. J., & Dimsdale, J. E. (1993). The promise of adrenergic receptor studies in psychophysiologic research: II. Applications, limitations, and progress. *Psychosomatic Medicine*, *55,* 448–457.

Mowrer, O. H. (1951). Two factor learning theory: Summary and comment. *Psychological Review*, *58,* 350–354.

Nadel, J. A., & Barnes, P. J. (1984). Autonomic regulation of the airways. *Annual Review of Medicine*, *35,* 451–467.

Porges, S. W. (1992). Vagal tone: A physiologic marker of stress vulnerability. *Pediatrics*, *90,* 498–504.

Porges, S. W. (2001). The polyvagal theory: Phylogenetic substrates of a social nervous system. *International Journal of Psychophysiology*, *42,* 123–146.

Raghuraj, P., Ramakrishnan, A. G., Nagendra, H. R., & Telles, S. (1998). Effectof two selected yogic breathing techniques of heart rate variability. *Indian Journal of Physiology and Pharmacology*, *42,* 467–472.

Raub, J. A. (2002). Psychophysiologic effects of Hatha Yoga on musculoskeletal and cardiopulmonary function: A literature review. *Journal of Alternative and Complementary Medicine*, *8,* 797–812.

Sancier, K. M. (1999). Therapeutic benefits of Qi Gong exercises in combination with drugs. *Journal of Alternative and Complementary Medicine*, *5,* 383–389.

Schopenhauer, A. (1819). *Introduction The world as will and representation* [Welt als Wille und Vorstellung]. (1st ed.). Leipzig: F. A. Brockhaus.

Schultz, J., & Luthe, W. (1969). *Autogenic therapy* (6 vols.). New York: Grune & Stratton.

Shapiro, D., & Crider, A. (1967). Operant electrodermal conditioning under multiple schedules of reinforcement. *Psychophysiology*, *4,* 168–175.

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

Shapiro, S., & Lehrer, P. M. (1980). Psychophysiological effects of autogenic training and progressive relaxation. *Biofeedback and Self-Regulation*, *5,* 249–255.

Snow, W. G. (1978). The physiological and subjective effects of several brief relaxation training procedures (Unpublished doctoral dissertation, York University, Canada, 1977) *Dissertation Abstracts International*, *40,* 3458B.

Thayer, J. F., Friedman, B. H., & Borkovec, T. D. (1996). Autonomic characteristics of generalized anxiety disorder and worry. *Biological Psychiatry*, *39,* 255–266.

Turner, P. E. (1978). A psychophysiological assessment of selected relaxation strategies. (Unpublished doctoral dissertation, University of Mississippi, 1978) *Dissertation Abstracts International*, *39B,* 3010.

Vallbo, A. B., Hagbarth, K. E., Torebjork, H. E., & Wallin, B. G. (1979). Somatosensory, proprioceptive, and sympathetic activity in human peripheral nerves. *Physiological Reviews*, *59,* 919–957.

Vaschillo, E., Lehrer, P., Rishe, N., & Konstantinov, M. (2002). Heart rate variability biofeedback as a method for assessing baroreflex function: A preliminary study of resonance in the cardiovascular system. *Applied Psychophysiology and Biofeedback*, *27,* 1–27.

Wallin, B. G., & Nerhed, C. (1982). Relationship between spontaneous variations of muscle sympathetic activity and succeeding changes of blood pressure in man. *Journal of the Autonomic Nervous System*, *6,* 293–302.

Wolpe, J. (1958). *Psychotherapy by reciprocal inhibition*. Stanford, CA: Stanford University Press.

Yeragani, V. K., Balon, R., Pohl, R., & Ramesh, C. (1995). Depression and heart rate variability. *Biological Psychiatry*, *38,* 768–770.