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A review of manual methods of traditional biofeedback for improving brain and body health and fitness

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Abstract: Manual biofeedback is applicable for clinical use with some components as a beneficial lifestyle routine. These approaches include simple, low-cost, effective methods that can be applied quickly in the clinical setting with the potential to provide rapid and significant improvements in physical and mental health. Three separate types of manual biofeedback are detailed:

1) EMG-type biofeedback employs manual muscle testing and is useful for both assessment and treatment of brain, spinal cord, and local injuries that cause sensorimotor deficits associated with neuromuscular dysfunction;

2) EEG-type manual respiratory biofeedback addresses brain and body function through the promotion of alpha brain waves using short (~5-minute) deep-breathing exercise sessions shown to improve cardiovascular and autonomic function with potentially far-reaching health effects; and

3) Heart rate exercise training is a biofeedback approach employing simple wearable technology to help prevent physical, biochemical, and mental-emotional stress common in sports, while improving fitness performance and reducing the accumulation of excess body fat that raises the risk of chronic disease and infection.

Manual versions of tradition biofeedback are directly relevant and applicable to various clinical practice approaches including in-office patient care, rehabilitation, follow-up in-home care, and lifestyle recommendations. With the capability to influence a wide range of brain and body health and fitness, manual biofeedback is a low-cost, time-saving natural approach. In addition to a potential clinical research topic, it also has important healthcare and public health implications. Manual biofeedback can complement many types of manual therapies and play a role in preventative care.

Indexing Terms: EMG; EEG; neurofeedback; manual biofeedback; manual muscle testing; respiratory biofeedback; heart rate training.

Introduction

Natural biofeedback is an integral part of the human nervous system, with our earliest ancestors relying on it for survival. Examples included the adaptation process, such as sensing uncomfortable temperatures that led to adaptive clothing, shelter, and fire, and walking on rough surfaces leading to wearing protective footwear. The concept of biofeedback has ancient antecedents as Indian Yogis practiced a form of it through yoga and transcendental meditation. (1)

… heart rate training offers numerous more specific interrelated brain and body benefits. Maffetone provides details on his maximum aerobic function heart rate (MAF HR) which is clinically effective …'

The concept of biofeedback refers to biological feedback based on an increasing awareness that helps control or regulate physiological processes not previously controlled. (2) It was originally thought that the autonomic nervous system (ANS) and its sympathetic and parasympathetic subdivisions only functioned automatically, involuntary, and out of our control.

This was challenged by research psychologist Neal Miller beginning in the 1930s, and the concept of biofeedback was born. (3) Eventually it would be discovered that not only could operant conditioning of various ANS functions be achieved and measured but other areas of the brain and body could as well, including the hypothalamic-pituitary-adrenal (HPA) axis, motor control of impaired skeletal muscles, and different brain states of consciousness. Mowrer (4) may have been the first to develop simple clinical biofeedback technology for use as an alarm-based device for treating enuresis. The term biofeedback was coined in the 1960s by scientists using computer technology to train subjects to consciously alter brain and body function.

This paper describes biofeedback as a multidisciplinary approach that can help address a wide range of physical, biochemical, and mental-emotional health and fitness conditions, and play a role in prevention. It is used clinically by various type of practitioners, including during rehabilitation and follow-up in-home care, and by many individuals for self-care.

Patients and individuals perform two basic types of care for themselves at home. In this article, two definitions of self-care are used to address specific health and fitness issues. One is practitioner-recommended care at home called '*follow-up self-care*' that may include employing certain physical movements for neuromuscular rehabilitation, deep breathing for relaxation, or dietary recommendations. A second is initiated by an individual and called '*self-care*', which may include following certain exercise routines, taking meditation classes, or adopting dietary changes.

Biofeedback is a technique applied to help patients and individuals, adults and children, learn to better control specific aspects of brain and body function to improve health and fitness by influencing the ANS, the neuromuscular system, brain waves that reflect different states of consciousness, and the HPA axis. (56, 7, 8, 9) Specific uses have been applied to neuromuscular impairment (smooth, cardiac, and skeletal) associated with brain, spinal cord, and local injuries, including rehabilitation following stroke and cardiac events; depression, anxiety, dyslexia, and other mental health conditions; gastrointestinal control; and others with goals of reducing pain, physical and mental disability, and managing the adverse effects of stress. In addition, individuals apply biofeedback to reduce urinary incontinence, for relaxation, and to monitor heart rate during exercise to enhance fitness and prevent injury.

The primary approaches used in biofeedback include:

- Technology-based methods that use sensors, usually a surface electrode on the skin above a muscle or the scalp near certain brain areas, that senses and amplifies electrical activity and sends the information to a computer in visual and or auditory forms for patient response. (In some research and specialty clinical practices fine-wire electrodes are inserted into muscles);
- Manual forms of biofeedback do not rely on technology. Instead, instructions to move muscles are given by the practitioner, who also senses muscle activity, often employing manual muscle testing, and relays information to the patient for response; and
- In-home care following treatment encourages patients to move previously underused or unused muscles during daily activities. Self-care by many individuals includes the use of wearable heart rate monitors to help guide exercise, and the sensing mental states during deep breathing exercise or meditation.

The implementation of various biofeedback techniques offers practitioners the ability to individualise the process of brain and body assessment and therapy for better patient outcomes, and to recommend personalised lifestyle recommendations. While much of the high-tech EMG and EEG biofeedback is used in the field of research and specialty clinical practices, many practitioners in other fields use manual forms of biofeedback to complement their existing practices. As a low-cost, simple method, it can be implemented over a short period of time in the clinical setting. Especially in the application of EMG-type biofeedback, it incorporates the ideas of skeletal muscle imbalance, and the use of manual muscle testing, itself a biofeedback tool, which, for over a century has been a mainstay in physical muscle therapies. (10, 11) Separately, beginning in the early 1960s, clinicians Vladimir Janda and George Goodheart began developing their clinical methods that employed manual muscle testing during the assessment and treatment of muscle imbalance in patients with physical impairments. (12)

The definitions of biofeedback as described extensively in the research and clinical literature has been challenged as neurologically unclear. (13, 14, 15) Because human movement is performed dynamically the central nervous system routinely adapts kinetically and kinematically to accommodate motor tasks that are both predictable and unpredictable, and proposed to take the forms of feed-forward (proactive) and or feedback (reactive) strategies. In short, there is no unified theory of how these two concepts participate in translating sensory input into motor events. Despite these issues, mostly debated in the research arena, its clinical application is unchanged and unaffected, and this paper will continue using the general term biofeedback.

Types and uses of Biofeedback

In addition to briefly introducing two traditional forms of EMG and EEG biofeedback, three forms of manual biofeedback are presented that are more applicable in clinical practice and by individuals for follow-up and self-care. (5, 6, 7, 8, 9, 16, 17) Traditional biofeedback requires the use of computer and other technologies with a higher degree of operator skill. EMG biofeedback is applicable for patients with a wide range of neuromuscular impairment, and EEG, also called neurofeedback, is used in those with mild to severe brain impairment. In addition, the three types of manual biofeedback, which do not require technologies, include:

- EMG-type biofeedback that employs manual muscle testing and is directed at a wide range of neuromuscular impairments;
- EEG-type or respiratory biofeedback associated with deep breathing to promote various brain and body benefits; and
- Heart rate exercise training that requires a simple wearable heart monitor.

All these types of biofeedback are outlined in Figure 1 (next page).

Traditional EMG biofeedback

Most traditional EEG biofeedback is used for the assessment and treatment of sensorimotor deficits which range from mild to severe. Mild muscle imbalances may be associated with such problems as a sprained ankle, low back pain, and head or neck pain. Severe impairment, also associated with a very similar neurological pattern of muscle imbalance, is associated with brain or spinal injuries due to trauma or disease, such as severe head or spinal trauma, including injury from birth trauma, stroke, muscle loss and weakness during aging, or prolonged bed rest or physical inactivity.

The range of mild to severe clinical situations is associated with muscles that are often referred to as so-called weak and tight. In an abnormal condition, tightness exists in the antagonist of the weakness (9, 18).

Figure 1: An overview of traditional and manual biofeedback types with their associated factors and applications.

Types	Associated Factors	Applications
TRADITIONAL BIOFEEDBACK		
EMG Biofeedback.	Technology based.	Wide range of mild to severe neuromuscular impairment. Research and clinical based.
EEG Biofeedback. (Neurofeedback)	Technology based.	Wide range of mild to severe brain impairment. Research and clinical based.
MANUAL BIOFEEDBACK		
EMG-type.	No technology required. Manual muscle testing.	Clinical treatment of wide range of mild to severe neuromuscular impairment. Rehabilitation.
EEG-type. (Respiratory biofeedback)	No technology required. Deep breathing.	Brain-body benefits. Increased production of alpha brain waves. Clinical and self-care.
HR exercise training.	Wearable HR monitor.	Improved exercise performance, prevent injuries, reduce body fat. Clinical, coaching, self-care.

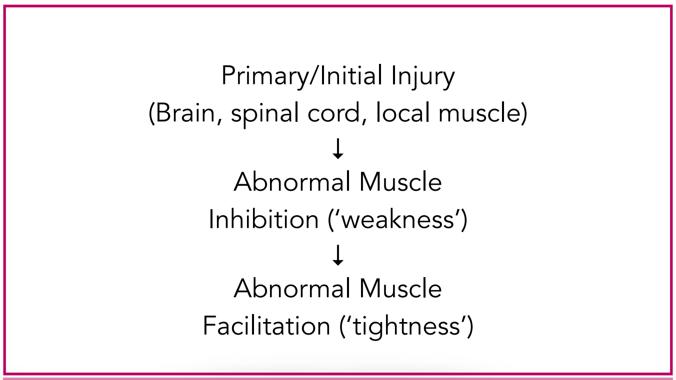
However, these terms are inaccurate. '*Muscle function*' refers to the normal movement of muscles with the appropriate balance of inhibition and facilitation, regardless of strength and power. '*Muscular strength*' is the maximum force generated by the muscle, often determined by the maximum weight a person can lift at one time. (19) This is associated with how many muscle fibres are contracted at once rather than the size of the muscle.

A feature of EMG biofeedback is in helping the motor cortex contract more muscle fibres as described below (this being a reason why a person with smaller muscles can be stronger than someone with large bulky muscles). The definition of '*power*' includes a time component; '*power*' is the combination of strength and speed of a movement. Strength and power are different neuromuscular functions from those of inhibition and facilitation; even a very powerful weightlifter can have muscle inhibition, and the weakest elderly patient can have muscle facilitation. More accurate terms for weak and strong include neuromuscular inhibition and facilitation, respectively. (19)

As the central state of the alpha motoneuron reflects multiple inhibitory and facilitation effects, the outcome is either inhibition or facilitation. Likewise, there is normal muscle inhibition and facilitation during healthy movement, for the biceps to contract (facilitate), for example, the triceps must relax (inhibit). These normal neuromuscular patterns occur throughout the body during normal movement.

'*Muscle imbalance*', however, is abnormal and is the combination of abnormal inhibition and abnormal (over) facilitation. It has long been observed that patients with relatively minor imbalances such as chronic low back pain exhibit the same patterns of muscle imbalance as patients with upper motor neuron lesions of brain injury, albeit to a much smaller degree .(18) Moreover, many clinicians consider abnormal inhibition as the primary deficit in muscle imbalance, which causes secondary abnormal facilitation. Following assessment of muscle imbalance, EMG-type biofeedback therapy is usually directed at muscle inhibition. Figure 2 shows this neurological model of muscle imbalance.

Figure 2: A neurological model of muscle imbalance



Extreme conditions of abnormal over-facilitated muscles are generally referred to as hypertonic, with various terms such as spasticity, dystonia, and rigidity often used. Differentiating between these states in clinical practice is very difficult (20). Hypertonic muscles are usually associated with an injury to the motor pathways in the cortex, basal ganglia, thalamus, cerebellum, brainstem, and/or spinal cord (21). In the past, treatment directed at hypertonic muscles have included stretching, surgery, and biofeedback, and are generally less successful in improving overall long-term function of the opposing abnormal muscle inhibition (22). An alternative approach addresses abnormal muscle inhibition to improve its contractibility that can help neurologically reduce excess facilitation of its agonist (5, 6, 23, 24), which can often follow a single treatment (9, 25). This often employs manual muscle testing and has clearly demonstrated significant improvement in mild to severe neuromuscular impairment, including those from chronic spinal- and brain-injured patients. This approach may work through enhancement of neural plasticity or other neurological mechanisms, with sensory activation, including visual, auditory, and proprioception, commonly stimulated during EMG-type biofeedback sessions, helping to enlist unused or underused synapses for motor control creating new sensory engrams (26, 27, 28).

Traditional EEG biofeedback

Also called neurofeedback, EEG biofeedback is a non-invasive technique for remodelling brain function. (54) It relies on obtaining information from surface electrodes on the scalp to measure different brain waves that reflect cortical function and different states of consciousness. The electrical activity can be recorded and observed on a computer helping clinicians make an assessment about dysfunction (or make a diagnosis), and help patients mentally respond to what they see and/or hear. Traditional EEG biofeedback has been used to treat a wide spectrum of both neurological (including muscular) and mental conditions, from poor concentration and attention disorders to depression, epilepsy, and post-traumatic stress syndromes in both adults and children. (29, 30, 31)

An important feature of EEG biofeedback is helping individuals recognise and control different states of consciousness as reflected by specific brain waves. All waves are generated simultaneously with specific amplitudes and frequencies, and waves with too low or too high a frequency are considered abnormal. (29) Specific brain waves that appear at the wrong times are also abnormal; for example, delta sleep waves while driving, or beta waves promoting excess activity during the night or when meditating. While several waves are recognised and used for EEG biofeedback, the characteristics of the four most common ones are highlight below:

- Beta waves reflect an active busy brain from environmental or internal stimuli. This includes internal or external chatter and increased stressful emotions. While they are often reduced during motor stimulation, their appearance during exercise, sleep, meditation, or music listening may be considered abnormal;
- Alpha waves appear during more intense concentration, creativity, deep thinking, and focus on inner awareness. Alpha waves often appear when eyes are closed, during music listening, and during meditation. Increasing alpha can reduce the stress hormone cortisol, increase relaxation, reduce anxiety, and improve mental capacity;
- Theta waves are associated with memory and making associations, and often appear consciously during deep meditation and briefly at the onset of nighttime sleep. Children are frequently in a dreamy theta state; and
- Delta waves appear during deep sleep, and are associated with nighttime rest and regeneration, and the biological clock. The appearance of delta during the day often implies a sleep disorder.

One goal of traditional EEG biofeedback is to help patients produce more or less of certain brain waves as part of the process of learning to shift into other brainwave states of consciousness more easily. EEG biofeedback is a very detailed assessment process with the capacity to enhance certain waves and reduce others. However, because alpha waves can reduce stress hormones, promote relaxation and positive emotions, relieve depression, and overall improve emotional, behavioural, and cognitive functions, including memory, this is often an important therapeutic focus. (32, 33) While achieving the alpha state through various forms of deep breathing and meditation has been popular for hundreds of years, the precise role alpha waves play in cognitive, psychomotor, psycho-emotional, and physiological aspects of life is not yet clearly agreed upon or defined as to what constitutes alpha activity. While traditional EEG biofeedback is a specialty practice, its key clinical components can be used manually without equipment using deep breathing exercise to help enhance brain and body health. (16)

Manual biofeedback: EMG-type

As a simplified but effective form of EMG biofeedback, manual biofeedback does not use a computer, surface electrodes, or other technologies. Instead, it relies on the practitioner's use of manual muscle testing for both assessment and treatment. (9) Feedback is provided to the patient by the practitioner to help train their sensorimotor system and guide the session.

The key clinical assessment and therapeutic actions and benefits described in the above section on traditional EMG biofeedback also apply to EMG-type manual biofeedback. (9) Some clinical advantages of manual biofeedback include providing patients with more direct and immediate sensations regarding the ability to contract an impaired muscle; encouraging them to actively use their own sensory and motor systems rather than relying on external electronic equipment; and help improve patient compliance with home follow-up training of the muscle and full body movements in real-life physical activity. In addition, many muscles can be tested manually; with traditional EMG, numerous muscles are not accessible to surface electrodes, including the *iliopsoas*, *piriformis*, some rotator cuff muscles, *tibialis posterior* and others that require fine-wire electrodes (an invasive procedure and not within the legal scope of practice for many practitioners). The additional cost and time of using traditional EMG versus manual biofeedback can also be significant.

Another important benefit of manual EMG-type biofeedback includes the patient's active participation and motivation during a session. This occurs with more verbal, visual, tactile, and proprioceptive communication that is more personal than responding to a computer. Most tradition EMG biofeedback is associated with static therapy which may have much less clinical value compared with an active treatment, which demonstrates improved outcomes. (34, 35, 36) Huang, et al (27) reviewed numerous EMG studies and concluded that the effect of static-oriented biofeedback training on the patient's daily life, such as walking, eating, reaching, etc., appeared less effective.

As an active technique, manual EMG-type biofeedback can help address the entire neuromuscular loop. (9) On the motor side, this includes the motor cortex, the upper and lower motor neurons, the motor end plates, and other components; the sensory side includes proprioceptive elements within the muscle, joints, and skin, and back up to the sensory cortex. Successful treatment of abnormal muscle inhibition can help improve function of these mechanisms, along with voluntary muscle function, skilled motor tasks, posture and gait, and others that can help reduce disability and improve quality of life.

Manual muscle testing (MMT)

Manual muscle testing plays an important role in EEG-type biofeedback, with test results sometimes categorised on a scale of 0 to 5: (11)

0 – no contraction.

1 – trace of muscle movement, but no limb or joint movement.

2 – minimal movement but not against gravity.

3 – movement against gravity but not against resistance by the examiner.

4 – movement against minimal resistance by the examiner.

5 – movement against resistance (so-called "normal").

In patients with brain and spinal cord injury, abnormal muscle inhibition typically ranges from 0 to 4 with many categorised as 0 and 1. Common local muscle injuries typically are in the scale range of 2 to 4.

The focus of manual muscle testing is often for specific muscles, isolated from others of similar actions by positioning limbs or other body parts. However, sometimes incorporating a muscle group, such as the hip flexors, may be more practical as it helps mimic common day-to-day physical activity, an important component of rehabilitation. Wolf (36) refers to this as conditioning the entire reflex rather than an individual muscle.

An easier alternative scale, especially for those less familiar with muscle testing, assesses muscles as either normal or abnormal. The normal response to a muscle test (normal facilitation) is successful contraction despite the stress placed on it in the form of an opposing force by the practitioner. In an abnormal response (abnormal inhibition) the muscle is unable to initiate or maintain its normal contraction while being tested. A muscle test that elicits pain not allowing the patient to perform the test is considered abnormal as well.

Before outlining the assessment and treatment details for EMG-type manual biofeedback, here are two brief hypothetical cases to help highlight these concepts:

- Case 1: A patient with a history of stroke has an over-facilitated biceps muscle and abnormally inhibited triceps muscle, with the elbow and shoulder tightly maintained in flexion. EMG-type manual biofeedback is applied to the triceps muscle to help improved its ability to contract and reduce the excess facilitation of the biceps. Even mild degrees of success can improve posture and movement of the elbow and shoulder joint.

- Case 2: A child with brain injury is unable to stand unaided in a normal posture with feet flat on the floor, as the ankle is maintained in a tight plantar-flexed state. Abnormal inhibition of the tibialis anterior muscle may not allow ankle dorsiflexion and maintains over-facilitation of the posterior calf muscles. Treatment and improvement of the tibialis anterior can reduce posterior calf over-facilitation and improve dorsiflexion, increasing the ability to place the feet flat on the ground.

Assessment of neuromuscular function includes manual testing muscles that may be associated with the patient's disability. For example, the patient has an abnormally inhibited *triceps* muscle from Case 1 above, or *tibialis anterior* from Case 2.

Treatment of neuromuscular dysfunction employs the same action as the manual muscle test as described below:

- First the practitioner demonstrates to the patient the specific movement that needs to be made, such as extending an elbow as in Case 1. As the practitioner's muscles contract to move the elbow joint, the patient makes a strong association between visualisation and the brain's mirror neurons (i.e., seeing someone else move triggers our own brain to begin moving the body similarly); (37)
- The practitioner passively and gently moves the patient's limb as much as possible mimicking elbow extension. This can help stimulate proprioception from the joint(s) and surrounding areas;
- The practitioner physically stimulates the skin and soft tissue around the abnormally inhibited muscle (such as the *triceps*), providing both superficial and deep tactile pressure for additional stimulation/proprioception; and
- The practitioner positions the arm in the same way as during the initial manual muscle test, then asks the patient to contract the muscle and resist counter pressure (identical to a muscle test). Once the patient contracts, the practitioner should use at least equal counter pressure. Initially, it may be difficult for the patient to create any muscle activity. However, in most individuals some small amount of muscle contraction takes place quickly, sometimes within one to two minutes in more severe cases.

Once noticeable muscle movement occurs, a completed neurological loop has been stimulated, and the practitioner can continue to slightly increase force to help enlist more muscle fibres to contract. After a few seconds of contraction, rest, then repeat the process throughout three or four points in the muscle's range of motion, with at least a few seconds rest in between. The process can be fatiguing for the patient, especially if the muscle has not contracted in any significant way for a long time.

Total treatment time varies with each patient based on how many muscles are treated, and fatigue. End the session before the onset of significant fatigue as further training may be counterproductive. In very difficult cases, more time may be required to obtain an initial muscle response. The severity of injury is not necessarily associated with a lack of initial response. Once an impaired muscle begins functioning, it is important for patients to use that function in their daily life, as most can reproduce it again on their own. For difficult cases a support person can be enlisted once or twice daily for in-home care to mimic the resisted movements made by the practitioner.

Another specific form of manual biofeedback is used as self-care by individuals seeking to improve the function of impaired pelvic floor muscles. The problem is often caused by excess weight gain, pregnancy, trauma, brain and spinal injuries, and surgery, and can cause urinary or fecal incontinence, sexual dysfunction, and pain. The most common and successfully employed technique is the *Kegel* exercise, a method detailed by the U.S. *National Institutes of Health's National Library of Medicine*. (38)

Manual biofeedback: EEG-type/respiratory biofeedback

Like traditional EEG biofeedback, EEG-type manual (respiratory) biofeedback can promote improved brain function through the increased production of alpha waves. This occurs using deep-breathing exercises and offers a wide range of potential health benefits that includes managing pain, improving respiratory-related dysfunction, and increase spinal stability. (39, 40, 41)

Employing simple and short (i.e., 5-minute) deep-breathing exercise sessions that contract respiratory muscles can quickly help expand the lungs and chest, influence the chambers of the heart and blood vessels, stimulate sensory nerves that influence the ANS, influencing the heart rate, blood pressure, breathing, and the entire cardiovascular system. (17, 42, 43, 44) This has been shown to reduce anxiety, improve blood glucose, lower blood pressure, reduce sleep apnea, improve endothelial function, reduce arterial stiffness, and decrease oxidative stress and systemic inflammation. These benefits are like those obtained during exercise training. While meditation and other deep-breathing activities tend to be shorter in duration than exercising, the results of Craighead et al (17) demonstrated significant benefits from deep-breathing at 75% maximum lung volume for about five minutes six days per week for six weeks. In addition, follow-up measures showed the benefits persisted for many weeks after the study. It is not known whether the healthy changes occurred from deep breathing's effect on muscles, other systemic effects such as increased oxygenation, by promoting alpha waves, or a combination of effects.

The 5-minute Power Break

Combining other factors that encourage alpha wave promotion into a single 5-minute respiratory biofeedback session has been long used by the author for patient use and self-care. Below is a synopsis of this recommendation, called the 5-minute power break:

- Sit or lie down and relax
- Eyes closed and relaxed
- Hands or crossed arms relaxed on the upper abdomen
- Breathe slowly and deeply: Inhale with diaphragm and abdomen for 5-7 seconds, obtaining slight chest expansion for the last 1-2 seconds. Exhale for the same time with a mild contraction of pelvic floor muscles for the last 1-2 seconds
- Listen to enjoyable music for about five minutes (headphones or earbuds are best).

Recommendations for using the 5-minute power break include daily, or as often as desired or needed. It is very important to avoid the beginning of falling asleep implying delta (sleep) wave production. This could be indicative of a sleep disorder. In this case, five minutes maybe too long and it's best to stop before sleep onset. Even one or two minutes of alpha can be healthy. Gradually work up to five minutes as your brain learns to stay in alpha.

A notable clinical observation I made after extensive use of manual biofeedback, traditional EEG, and traditional EMG biofeedback, is the inability of some patients to produce alpha waves. While associated with high levels of the stress hormone cortisol and abnormal blood sugar levels, (32, 33) specific muscle imbalances may also impair alpha production. These include those innervated by cranial nerves, primarily the *upper trapezius*, the *sternocleidomastoid* and other neck flexors, and those associated with the *temporomandibular* joint. Improving these muscle impairments as described in this paper resulted in the ability of most patients to produce alpha waves. Cranial nerves play an important role in cognition and behaviour (45) and the study by Craighead et al (17) references one side effect of deep breathing as neck pain, which may add credibility to this observation.

Manual biofeedback: Heart rate training

Another manual biofeedback approach is the use of a simple device called a heart rate (HR) monitor. Through continuous evaluation of the exercise heart rate, individuals can become more mindful of excessive exercise stress, and help maintain lower intensities that promote maximum fat oxidation, aerobic system fitness benefits, and overall improved health. (8, 46) This can also help personalise one's exercise program as well. While most exercise recommendations are generic, based on time and distance only, or even trendy (such as '*Just Do It*'™), heart rate training offers numerous more specific interrelated brain and body benefits (47, 48, 49, 50) that include:

- Monitoring exercise intensity to help ensure the oxidation of higher amounts of fat (and lower amounts of glucose). This can help reduce excess body fat (and the associated insulin resistance, chronic inflammation, and immune impairment), precursors to chronic disease and infection, with positive health effects on aging;
- Despite its reported benefits, exercise can also potentially increase physical, biochemical, and mental-emotional stress activating the HPA axis and ANS sufficiently to increase catabolic and stress hormones, inflammatory cytokines, oxidative stress, and other damage. This can significantly reduce rates of fat oxidation, impair aerobic and immune system function, impair athletic performance, promote injury, and adversely affect other aspects of health and fitness, as part of the overtraining syndrome;
- A measurable demonstration of fitness progress which precedes improvements in performance and competition. Examples include the ability to walk, run, cycle, or perform faster at the same lower heart rate over the same distance; and
- Improved function of aerobic muscle fibres, which rely almost exclusively on fatty acid oxidation for energy production and help physically support joints and other body structures.

Beginning in 1977 I researched and developed a heart rate formula to help individuals, coaches, and clinicians address the needs of those who exercise, from beginners to world class athletes, using biofeedback to monitor exercise quality, effectiveness, and progress. (8, 51) This formula, replacing the old 220 version, is called the maximum aerobic function heart rate (MAF HR) and obtained by following the 180-Formula detailed in Figure 3.

It would later be shown that the MAF HR exercise intensity corresponds to the aerobic threshold, first ventilatory threshold, lactate threshold, and the level of maximum fat oxidation (with similar training HR numbers obtained through laboratory treadmill testing). While the MAF HR can be useful for virtually everyone, it does not replace laboratory testing which can provide more data, but requires specialised equipment, a professional staff, and is costly, making these evaluations less accessible for most individuals, including many athletes.

The reduced rates of fat oxidation and poor aerobic function are usually associated with the accumulation of excess body fat called overfat. (52) Between 20-40 percent of individuals who are normal weight and non-obese may still be overfat making the use of body mass index (BMI) inaccurate for assessing body fat. The simplest non-invasive evaluation of body fat is the waist-to-height ratio, with the waist measured at the level of the umbilicus: the waist should be less than half the height, otherwise the patient is considered overfat. It is important to note that the diet, can influence fat oxidation, aerobic function, and body fat content more than exercise itself, as excess or refined carbohydrate intake reduces fat oxidation during rest and activity promoting excess fat storage. (8, 53)

Figure 3: The 180-Formula: Instructions for determining the MAF HR.

1. Subtract your age from 180.
2. Modify this number by choosing one category below that best applies to you:
   a. If you have or are recovering from a major illness (including any operation or hospital stay), are in rehabilitation, have been prescribed any regular medication, or are chronically overtrained, subtract an additional 10.
   b. If you are injured, have regressed, or not improved in training (such as poor MAF Tests) or competition, get more than two colds, flu or other infections per year, have seasonal allergies or asthma, are overfat, are acutely overtraining, or if you have been inconsistent, just beginning or returning to exercise, subtract an additional 5.
   c. If you have been training consistently (at least four times weekly) for up to two years without any of the problems mentioned in a) or b), no modification is necessary (use 180 minus age as your MAF HR).
   d. If you have been training for more than two years without any of the problems listed above, have made progress in your MAF Tests, and have improved competitively, add 5.

The resulting HR is the high end of the HR range with the low being 10 beats below. For example, a 40-year-old in category b) would have an exercise range of 125-135 bpm. Users can self-select any intensity within this range.

Conclusions

As important assessment and therapeutic methods, various forms of biofeedback can play a key role in addressing a wide range of neuromuscular impairment and mental dysfunction. They can also offer in-home or self-care options for patients in rehabilitation, those addressing relaxation through deep breathing, and help improve exercise benefits and prevent related injury and poor health.

Compared to the costly high-tech nature of traditional EMG and EEG biofeedback, manual biofeedback offers a practical alternative and an important complement to a wide variety of approaches for practitioners of different professions and scopes of practice, helping to expand their holistic approach.

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