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Chapter

Biofeedback in Clinical Psychology: Modalities and Perspectives

Valeska Kouzak, Aloysio Campos da Paz Neto and Ivo Donner

Abstract

Biofeedback is a technique of self-regulation applied by health professionals in order to reshape a series of physiological information based in health parameters diminishing psychopathological symptoms and improving cognitive performance. The biofeedback technique is widely recognized in many countries, leaving no doubt about its effectiveness and applicability. In clinical psychology, biofeedback has been applied effectively to psychophysiological conditions such as anxiety, depression and ADHD. This chapter has the aim to elucidate the techniques applied to clinical settings, where psychophysiological conditions are more prone to be treated with biofeedback. Moreover, this chapter also evaluates the advances of the technique and possible future directions.

Keywords: neurofeedback, HRV, GSR, anxiety, depression, ADHD

1. Introduction

Biofeedback has begun in the early 60's as a result of the convergence of diverse and relatively recently established fields, such as bio-engineering, physiology and psychology. Firstly, biofeedback emerged as a technique of stress control when studies relating psychological condition and physical disease emerged more vigorously. Afterwards, with the development of self-regulation techniques for managing physical and emotional burden, biofeedback became more sophisticated in its applications and methods.

Technological advances in instrumentation led to more objective measurements of physiological signals, and the measurement + feedback of a subject's performance has been established to improve capacity to control one's own signals [1]. This way, the organism's immediate response has been used as a live indication of self-regulation during training.

Diverse instruments have been applied to self-regulation, such as skin conductance response, body temperature, cardiac frequency, respiratory frequency, electroencephalography (EEG) [2], and recently, functional magnetic resonance imaging. The combination of these instruments with theory grounded biofeedback's basic principle, which is to provide awareness about one's physical condition - creating a self-awareness loop - and through the technology, allow psycho-physiological self-control. Hence, biofeedback provides an organism with a self-referential information feedback to be adjusted according to personal needs [3].

In this sense, it is important to make a distinction between treatment and training: treatment is a process in which an individual expects an external agent to provide the change for release or suppression of symptoms; on the other hand, training asks the individual for their voluntary participation to the same outcome. In this chapter biofeedback is considered a training protocol [4] as it requires an active participation of the patient in the process.

This technique is characterized by a multidisciplinary and heterogeneous application, and in psychology, biofeedback is applied to relive symptoms of many psycho-physiological diseases, such as ADHD, anxiety, depression, among others [5–9]. Besides that, nowadays biofeedback is also applied as technique for stress reduction in non-clinical population - mainly those that have in their routine highly demanding situations of emotional control - such as athletes, police-officers, the military, executives, students, musicians, for increasing their performance [10–12].

Moreover, there are studies that seek to evaluate the effects of neurofeedback training in cognitive and neuro-psychological abilities. Neurofeedback is a form of biofeedback that regulates cortical activity using EEG feedback of brain waves. Results so far as 2020 have demonstrated an increase of attention [13], working memory [14] and executive function performance [15] in cognitive and neuro-psychological abilities.

As a multidisciplinary area, biofeedback education and training for professionals are diverse, existing in the forms of workshops and as university courses. Hence, in order to regulate the quality of practitioners, societies have been created, such as the Biofeedback Certification International Alliance (BCIA) - one of the most widely known and recognized - to evaluate and regulate the knowledge and practice of professionals, and provide support for them and their patients.

In summary, the current chapter has the objective to briefly explain through examples of biofeedback techniques how biofeedback has been used in psychology to ameliorate psychophysiological symptoms of diverse pathologies, as well as how it has been used as an instrument to reduce stress and enhance performance.

2. Basic principles of psychophysiology

The autonomic nervous system (ANS) is a regulatory part of our nervous system that works to ensure homeostasis - the maintenance of our body's balance. Therefore, vegetative activity is regulated by the ANS. Body temperature, respiration rate, heart rate, digestion, secretions and muscles are regulated by the ANS's activity unconsciously in order to keep the body alive [16].

The ANS is controlled by the central nervous system (CNS) from sub-cortical areas (hypothalamus, brain stem, spinal cord and others) but some cortical areas also control its activity. Hence, ANS activity is not completely involuntary [17].

The ANS can be divided in two pathways:

a. Sympathetic Pathway: responsible for increasing body activity. To that end, the Sympathetic Pathway is also responsible for our fight-or-flight response, such as increased heart rate frequency, sweat and respiration, or promoting muscular contraction.

b. Parasympathetic Pathway: responsible for decreasing body activity. To that end, the Parasympathetic Pathway promotes relaxation of our body, such as decreasing heart rate frequency and respiration or allowing muscular relaxation.

Sympathetic and parasympathetic pathways work together to coordinate organism function, activating and deactivating over time to maintain body balance.

The balance between sympathetic and parasympathetic pathways may be briefly explained by the relation between respiration sinus arrhythmia (RSA), that is, the influence of sinuatrial node of the heart by inhaling and exhaling movement in heart rate frequency. Therefore, when individuals inhale their heart rate frequency increase and when they exhale their heart rate decrease, leading to a continuous sympathetic and parasympathetic activity, activating and deactivating our body [1]. However, when changes in our homeostasis happens, more sympathetic activity is required, changing our respiration for a fast paced and higher inhalation, consequently our heart rate frequency increase, our muscles contracts, our body temperature decrease, among others physiological changes. As soon as individuals recognize and classify the stressor being a threat or not, the balance can be restored [17].

Biofeedback works by regulating the ANS response to the environment, providing balance between sympathetic and parasympathetic responses. Consequently, another important concept associated to biofeedback is stress [18]. Stress can be defined as a body response to external or internal changes affecting homeostasis. The cause of stress is defined as the stressor. Usually, stress is associated to a negative stressor. However, stressors can be all things that affect organism balance, there existing positive stressors as well (i.e: marriage, born of a child, graduation presentation). Generally, a stressor can be physical (i.e: broken bone), metabolic (i.e: diabetes), biological (i.e: Virus), mental (i.e: depression), social (i.e: divorce) and cultural (i.e: civil war) [18].

Biofeedback can create awareness of this relationship between stressors and body response, helping individuals to regulate their conditions and foster well-being.

3. Modalities and perspectives

In this section we intend to provide the most common modalities of biofeedback, equipment and the perspective of how it has been applied to manage the psychophysiological conditions. The modalities are presented in following order:

1. Galvanic Skin Response (GSR);

2. Temperature Biofeedback;

3. Respiratory biofeedback;

4. Surface Electromyography Biofeedback (sEMG);

5. Heart Rate Variability Biofeedback;

6. Electroencephalography (EEG) Biofeedback or Neurofeedback;

7. Functional Magnetic Resonance Neurofeedback (rt-FMRI);

8. Functional near-infrared spectroscopy (fNIRS) Neurofeedback.

3.1 Galvanic skin response (GSR) biofeedback

One of the first equipment used to demonstrate the correlation between mood alterations and physiological changes was the Galvanic Skin Response (GSR). The physiological principle that ground this equipment is the direct correlation between stress and autonomic response of sweat by the organism. That is, the higher is the stress, higher is the sweat of the organism, and vice-versa.

Since sweat is a compound of mineral salt and water, and an excellent electrical conductor, its secretion enhances galvanic skin conductance, which can be measured by two ultra-sensitive sensors to electric current [19].

GSR works based on the following arrangement: the device produces a non-invasive electrical current of a minimal value, imperceptible to the organism, that varies according to skin resistance change with the sweat excretion amount [1]. This electrical current might be converted in sounds and/or images that modify according to amount changes in skin sweat. In other words, in a sound feedback, the device might emit different sound frequencies according the skin conductance, such as:

a. A high-pitched sound is emitted when there are an increase of the sweat amount;

b. A bass sound is emitted when there is a decrease of the sweat amount.

Consequently, the bass sound would correspond to lower levels of anxiety and pitched sound would correspond to higher levels of anxiety. Hence, the sounds allow the representation of subject's physiological response in relation their own levels of anxiety and stress [20].

The GSR biofeedback training has been applied to manage stress in anxious patients [21], medication resistant epilepsy patient [22] and athletes [23]. In clinical setting, this modality is usually applied with other biofeedback technique, such as temperature biofeedback or respiratory biofeedback.

3.2 Temperature biofeedback

This biofeedback technique uses body temperature as a parameter, with measurements in the majority of cases from the extremities of superior members - usually fingers tips or hands. Body temperature is also regulated by autonomic response, and a reduction of blood flow in these areas is an indication of high stress level whereas passivity is related to higher temperature. Therefore the relationship between body temperature and stress is inverse: the higher is the stress, the lower is the body temperature [24].

In other words, when blood vessels contract due to stress increase, blood flow and therefore temperature diminishes. On the other hand, when the individual is relaxed, there is a vasodilation and an increase of blood flow and therefore of temperature.

The temperature biofeedback technique is used for relaxation, being a quickly responsive indicator, very sensitive to stress variation [21]. This biofeedback training can also be arranged to provide sound feedback. For instance, if the individual needs to manage stress, a higher pitch sound is played for low temperatures and a bass sound for higher temperatures.

In summary, the skin temperature biofeedback consists in regulating the body temperature in order to change the autonomic system. It is rarely used alone in

clinical setting, which most of the time is associated with other technique such as respiration biofeedback to reduce stress symptoms in anxious patient.

3.3 Respiratory biofeedback

Another technique of biofeedback is the respiratory. It has the aim to improve ventilation capacity, facilitate carbon dioxide elimination, and develop relaxation skills to manage stress and other symptoms [25]. This technique is fundamental because it allows an indirect modulation of the autonomic nervous system, mainly because inspiration activates the sympathetic pathway and mobilizes the organism for action; on the other hand, expiration stimulates the parasympathetic pathway, that is involved in homeostatic process (psychophysiological balance) and general body relaxation [1, 16, 26].

Respiratory biofeedback training can be done using belt-coupled sensors over the thorax circumference and/or abdominal circumference to register data and repass it to an encoder that will present information in a comprehensive by way of a computer, through bars, graphic, counters, percentage, or even a sound.

To that way, the professional and patient will be able to analyze the respiratory frequency (number of respiratory cycles per minute) and the respiratory amplitude (volume of air change) facilitating the regulation of anxiety symptoms for instance [1, 25].

In addition, it is important to observe that the thorax belts or abdominal belts contribute to the muscular contraction perception, as lungs are dependent on other muscles to breathe. Therefore, respiratory biofeedback technology is able to analyze abnormal respiratory cycles, such as:

a. Tachypnea (fast respiration, superficial, with high frequency) and;

b. Hyperventilation (deep, fast respiration, with increase of respiration frequency and volume).

In both cases, the fast respiration results in unbalanced entrance of carbon dioxide and oxygen in the blood, and in diminishing carbon dioxide, the blood becomes alkaline. That is, the balance of calcium and potassium in cellular membranes is modified and lead to muscular and nervous dysfunction, such as mental fatigue, migraine, dizziness, syncope among others [27, 28].

Respiratory biofeedback is a technique that can be associated with other biofeedback techniques to improve treatment effects on humor disorder, anxiety, cardiovascular and neurological disease, cognitive and physical performance.

3.4 Surface electromyography biofeedback (sEMG)

Surface electromyography measures electrical activity of muscles by sensors placed over the skin, where the activity should be measured. Muscular tension signs captured by electrodes are translated in sounds and images, similar to GSR biofeedback. Therefore, depending of the training, the following arrangement can be proposed:

a. To problems related to muscular tension, for instance temporomandibular joint muscle tension, the feedback is related to facial muscle relaxation. The feedback might be a pitched sound for muscular tension, and when the muscle is relaxed, it might be a bass sound.

b. To problems related to flaccid muscle, for instance neurological lesion that induces to muscle tone loss, the feedback is related to muscle contraction for strengthening tone. That is, when the muscle is contracted the feedback might be a bass sound, on the other hand when the muscle is relaxed, than the feedback might be a pitched sound.

Consequently, the sEMG biofeedback is used not only for general relaxation training, but also to treat facial paralysis or movement rehabilitation in cases of brain damage.

3.5 Heart rate variability biofeedback

Heart rate variability describes oscillations between heart rate over consecutive intervals, that is, a R-R wave cycle, controlled by autonomic nervous system (ANS) over the sinusoidal node. The cardiac frequency is regulated by sympathetic and parasympathetic pathways. In other words, the increase of cardiac frequency is related to a higher action of sympathetic pathway and the decrease of cardiac frequency is related to a higher action of parasympathetic pathway. Heart rate variability demonstrates heart health, as it is not expected that the heart keeps the same frequency, but instead might be able to adjust to adverse condition that is presented to the individual [29].

Heart rate variability training is accomplished when the cardiac rhythm enters in consonance or synchronicity with the respiratory rhythm, increasing the amplitude of heart rate oscillation [29]. This variability is maximized by biofeedback training when six respiratory cycles per minute is achieved, which leads to a sinusoidal wave similar to sinus arrhythmia [30].

The training is accomplished by observation of cardiac frequency waves and respiration and as the waves became consonants, that is, overlapping or "in phase", sound or visual feedback is offered as behavioral reinforcement.

Heart rate variability biofeedback is related to decreased symptoms of many clinical conditions such as anxiety, depression, post-traumatic stress disorder, insomnia, alcoholism and addiction, mostly because it provides a feeling of well-being [2, 31].

Besides that, in studies of increasing performance, the sensation of well-being induced by the heart rate training demonstrated to be positive for professional musicians and dancers [32].

3.6 Electroencephalography (EEG) biofeedback or neurofeedback

In the beginning of the 20th century, Hans Berger, a German Neuropsychiatrist, investigated cerebral electrical activity in dogs and other species. From 1920 onward, Berger's studies evolved, and through modifications in electrodes and decoders, it was possible to finally use an electroencephalogram in humans in 1924, when Berger used it for the first time despite technical limitations. In 1930, Berger published his data about brain wave frequencies registered in his research, in which he named brain waves in accordance with Greek letters "alpha" and "beta" [33, 34].

During many years such knowledge of brain waves had mainly been for laboratory use. Until the evolution of equipment, applications were unknown.

At the 60's, Barry Sterman investigated brain waves patterns in training cats via a behavioral technique called operand conditioning, in which the animal response of pressing a bar is increased in frequency according to positive reinforcement, which

could be food for instance. Sterman realized that when cats are prepared to press the bar, there was an increase of cortical activity in the sensorimotor area to a pattern of 12–14 Hz, together with a reduction of motor activity followed by muscular relaxation. This pattern of cortical activity is denominated the Sensorimotor Rhythm (SMR) [35, 36].

Brain wave frequencies are today classified in different groups defined by frequency bands and named as:

- Delta (1-4 Hz)
- Theta (4–7 Hz)
- Alpha (8-13 Hz)
- Beta (13-)
- Gamma (21-45 Hz)
- SMR (12–15 Hz) in sensorimotor area [36].

Moreover, each frequency is associated to specific cognitive, emotional and behavioral states. Delta waves are associated with sleep; Theta and Alpha waves are associated with working memory, attention and creativity; Beta waves are associated with intensive cognitive activity and memory; Gamma waves are associated with cognitive integration [8, 25].

The EEG Biofeedback training is also called neurofeedback, and can be defined as the operant conditioning of brain waves activity by EEG. That is, neurofeedback is the behavioral, cognitive or emotional training during electrophysiologic activity evaluation. This measure provides a feedback to the subject of their own performance, and, as consequence, provides awareness of their own state and of how to efficiently achieve an objective. [37].

The neurofeedback arrangement is based on electrodes that are placed in the scalp according to international 10/20 system, a converter decomposing the electrical activity from cortical neurons in frequency bands as stated above, and a software transforming raw information into computer actions (movie, games or music) for the training goal. For instance, if an individual has the aim to train attention, a protocol might be applied in the central cortex - therefore an electrode is placed at the Cz area - and software is programmed to only provide feedback when increased activity is detected in a band frequency related to increased attention (i.e. SMR) [38, 39].

Neurofeedback training became very popular and many researchers and clinicians had the opportunity to add and validate data and results. Neurofeedback is nowadays tested as a tool to treat ADHD and seizure with specificity and efficacy. Therefore, Neurofeedback studies to treat ADHD and seizure have demonstrated statistical significance in comparative studies such as patient-placebo, neurofeedback-medication, and neurofeedback-other treatments in more than two studies [40]. Neurofeedback is also becoming frequently applied in clinics to treat other pathologies with psychophysiological basis, such as, anxiety, depression and insomnia [9, 41, 42].

Therefore, the existing references are sufficient to reinforce its clinical use as tool and its increment in research, mainly in the USA, Canada and some European countries, such as England, Spain, Italy, Sweden and Austria [6, 36].

3.7 Functional magnetic resonance neurofeedback (rt-FMRI)

Another form of neurofeedback is by Functional Magnetic Resonance Image (FMRI), that offers data of cerebral activity from hemodynamic signal - Blood Oxygenation Level-Dependent (BOLD). Neurofeedback by FMRI is called real time Functional Magnetic Resonance Image (rt-FMRI) and has the advantage of providing training in deeper and specific regions of the brain and needing fewer sessions. Although it is a new technique, it results have been significant [43] in cognitive training.

The principle behind FMRI neurofeedback is that magnetic resonance captures changes in blood flow during brain activity and feedback on this change can be offered to the individual. In neural activation, metabolic demand increases, and consequently, oxygenated blood increases to regulate the de-oxygenated arterial blood. The increase of oxi-deoxyhemoglobin also increases the resonance signal around the activated nervous tissue, so the target area is indicated and a feedback is provided about this event.

FMRI neurofeedback is highly spatially precise. On the other hand, it lacks temporal precision, and therefore to capture an image it is necessary to wait for the neuronal dynamics to happen, which takes a few minutes. This makes the FMRI feedback slower than EEG. Therefore, the protocols used in FMRI neurofeedback must contemplate this temporal delay [44]. It is a new technique that has proposed protocols so far to improve performance, as it requires a very stressful environment to accomplish the training, which is the magnetic resonance machine, usually in hospitals.

3.8 Functional near-infrared spectroscopy (fNIRS) neurofeedback

The register by functional near-infrared spectroscopy (fNIRS) is similar to the magnetic resonance in that brain activity is captured from a BOLD signal. However, it differs in that the hemodynamic changes are registered by an infrared light spectrum only able to capture activity from layers closer to scalp [45].

The arrangement for this technique consists of a belt with fNIRS sensor placed over the scalp, and a computer feedback provided when individuals achieve the training goal.

Moreover, neurofeedback training by fNIRS is also recent and has been applied to treat depression [46] and improve cognitive performance [47]. It has the advantage of being more accessible, as it involves simpler equipment and less medical environment compared to rt-fMRI.

4. Performance optimization biofeedback

Nowadays, as the biofeedback class developed and became used in diverse applications, research about its use in non-clinical populations [48], such as with athletes, musicians, dancers and executives, have the aim to increase cognitive and physical performance [32]. Becoming an efficient tool to sports psychologists that face the need to help athletes to manage stress in order to better perform [49].

There are also studies that search for neurofeedback training in cognitive and neuropsychological skills. The results, as of 2020, have been demonstrating an increase in attention [13], working memory [14] and executive function [15].

In addition, there are studies in aging populations to provide cognitive reserve as their higher life expectancy increases the need of an active aging population [50].

5. Clinical application in psychology

According to the biofeedback modalities descriptions stated in the third topic of the present chapter, it is possible to enumerate the clinical application of biofeedback in psychology.

Firstly, to manage stress in anxious patient, which has been the most widespread application of biofeedback since the publication of Hardt and Kamiya study in 1978 [5] by managing alpha waves in neurofeedback training, as well as, in Leher protocol training of HRV [51], in which it is achieved when breath and heart rate frequency are consonant.

Secondly, to manage hyperactivity of children ADHD children in SMR protocol developed by Lubar and Lubar [6] and applied consequently to manage attention [9] and associate to metacognitive strategies [7].

Thirdly, with the acknowledge that depression is associate with activation differences between hemispheres, therefore Hammond proposed a training protocol to balance this interhemispheric difference applied frontally in the cortex [41].

Hence, those protocols are examples of successful training that have been applied by many biofeedback clinician as a psychological tool to manage symptoms and decrease suffering. Moreover, it is important to highlight how important is to associate psychotherapeutic approach to training, as understand psychological and psychotherapeutic aspects help clinicians to improve rapport and coping [25].

6. Conclusion

The connection between body and mind is well known in psychology and has been a subject of discussion and academic work. Many mental disorders have their origin in the central nervous system, and on the other hand the environment also has a great impact in our body. Therefore, a biopsychosocial perspective is needed in health professionals, to fully attend individuals that search for clinical health in psychology. To that extend, biofeedback is a tool that highlights the value of body regulation to provide well-being.

The chapter aimed to demonstrated the diverse biofeedback techniques that provide self-awareness and help patients to cope with, and manage, symptoms.

Most of the techniques are applied in regulation of sympathetic symptoms activated by stress, thus being relevant to coping with a highly demanding contemporary life. Self-regulation of stress is connected with the amelioration of anxiety symptoms and attention deficits, while providing better emotional and cognitive awareness.

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