Chapter 9
The Management of Insomnia – Biofeedback

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Abstract This chapter introduces the management of insomnia using biofeedback. A brief overview of the principle, definitions and organizations of biofeedback is provided followed by an overview of insomnia and its physiological underpinnings, and an introduction to the terminology and recorded signals of various instrumentations relevant to the management of insomnia. Finally, the rationales, treatment protocols, and treatment efficacy of selected biofeedback modalities for the management of insomnia are described.

Keywords Biofeedback • Insomnia • Electroencephalography biofeedback • Neurofeedback • Self-regulation • Sleep

9.1 Introduction to Biofeedback

This section gives a brief introduction to biofeedback. The principle, definitions of biofeedback and history of different professional organizations are provided.

9.1.1 The Principle

Biofeedback is a learning therapy based on the operant conditioning paradigm. It is an offspring of instrumental conditioning. It was research on the instrumental conditioning of visceral responses mediated by the autonomic nervous system that prompted the development of applied psychophysiology and clinical

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biofeedback [1]. Until now, biofeedback therapists have relied heavily on such principles of operant conditioning including schedules of reinforcement, shaping, extinction, and fading. Stress research, relaxation therapies and other techniques of stress management are also used in combination with biofeedback [1].

9.1.2 Definitions

Biofeedback is a group of therapeutic procedures that measure, process, and provide information with educational and reinforcing properties to a subject for the purpose of teaching him/her to learn voluntarily control over his/her physiological processes [2]. In these procedures, electronic or electromechanical instruments are used for the precise measurement of autonomic and/or neuromuscular activity underlying the symptoms or conditions and for the display of these measurements to both the participant (i.e., trainee) and the therapist. The feedback display is delivered in the form of analog or binary; auditory and/or visual signals. Applied biofeedback modalities include electromyography (EMG), skin temperature, electrodermal activity (i.e., perspiration), heart rate, blood volume, blood pressure, and electroencephalography (EEG) [2].

Optimally, the two major goals of biofeedback are (1) to teach the trainee how to obtain self-regulatory skills and (2) to institute physiological and behavioral changes.

9.1.3 Professional Organizations

Originally established as the Biofeedback Research Society in 1969, the Association for Applied Psychophysiology and Biofeedback (AAPB) is now a non-profit organization with goals to promote the public's understanding of biofeedback and to advance methods used in the practice of biofeedback.[1] The AAPB offers training courses for those who wish to become a provider of biofeedback and also provides continuing education opportunities for practitioners of biofeedback. Two important AAPB's publications are *Applied Psychophysiology and Biofeedback* and *Journal of Behavioral Medicine*, both of which are Social Science Citation Indexed peer-reviewed journals.

The European counterpart, the Biofeedback Foundation of Europe sponsors education, training and research activities in biofeedback.[2]

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[1]Readers who are interested in learning more about the organization may visit the website: http://www.aapb.org/about_aapb.html. Address: AAPB 10200, West 44th Avenue, Suite 304, Wheat Ridge, CO 80033.

[2]For more information, visit: http://www.bfe.org/contact.html. Address: P.O. Box 555, 3800 AN Amersfoort, the Netherlands.

The International Society for Neurofeedback & Research (ISNR) was founded in 1995 as the Society for the Study of Neuronal Regulations. It was shortened to Society for Neuronal Regulation for simplicity. The name was changed again in 2002 to International Society for Neuronal Regulation and again in 2006 to International Society for Neurofeedback & Research to better reflect the fact that research is a critical function of the society.[3] It is now an international membership organization of professional disciplines conducting neurotherapy and neurofeedback training and research. The ISNR publishes the *Journal of Neurofeedback*. The ISNR became the first professional organization dedicated specifically to neurotherapy.

The Biofeedback Certification International Alliance (BCIA), formerly the Biofeedback Institute of America, was created in 1981. The BCIA is an organization that certifies individuals who meet education and training standards in biofeedback and progressively re-certifies those who advance their knowledge through continuing education. BCIA certification establishes that the individual has met entry-level requirements for the clinical practice of biofeedback. BCIA has three certification programs: General Biofeedback, EEG Biofeedback, and Pelvic Muscle Dysfunction Biofeedback.[4]

9.2 Overview of Insomnia

This section gives an overview of the diagnosis and physiological underpinnings of the etiology of insomnia.

9.2.1 Diagnosis of Insomnia

Insomnia is the most common sleep disorder. It is a heterogeneous complaint reflecting reduced quality, duration, or efficiency of sleep. The most frequently reported insomnia symptoms are difficulty in initiating sleep (sleep-onset insomnia), difficulty in maintaining sleep (sleep fragmentation), early morning awakening, and non-restorative sleep. Insomnia may arise from psychiatric disorders, medical conditions, and drug/alcohol use or abuse, and in these instances is termed comorbid insomnia. Primary insomnia probably accounts for around 15% of chronic insomnia cases. It is more common in women than in men, and the usual age of onset is 20–40 years old [3]. *The Diagnostic and Statistical Manual of Mental Disorders* defines primary insomnia as a disorder in which the predominant complaint is dissatisfaction with quantity or quality of sleep accompanied by at least one

[3] For more information, visit: http://www.isnr.org/mission.cfm.

[4] For requirements on these programs, contact: BCIA 10200 W., 44th Ave, Ste 310, Wheat Ridge, CO 80033-2840. E-mail: info@bcia.org; or visit the website: http://www.bcia.org/index.cfm.

symptom manifesting significantly impaired daytime functioning [4]. To make the diagnosis, one or more of the following sleep complaints must be present: difficulty initiating sleep, difficulty maintaining sleep, early morning awakening with inability to return to sleep, non-restorative sleep, and prolonged resistance to going to bed and/or bedtime struggles (children only). In addition, the sleep difficulty must occur at least three nights per week, last for at least 3 months, and occur despite adequate age-appropriate circumstances and opportunity for sleep. It might be argued that insomnia is a symptom rather than a primary diagnosis, but untreated insomnia will lead not only to increased psychological distress, but also to such clinical conditions as anxiety and depression.

9.2.2 Physiological Arousal in Primary Insomnia

The "behavioral" model of insomnia suggests that insomnia occurs acutely in association with predisposing and precipitating factors and is chronically maintained by perpetuating factors [5]. Primary insomnia is usually diagnosed when somatized tension and learned sleep-incompatible behaviors play a predominant role in the maintenance of poor sleep [6]. In other words, people with insomnia exhibit an apprehensive over-concern about sleep, while the maladaptive sleep-preventing behaviors perpetuate sleep disturbances. According the "psychophysiological" model of insomnia, conditioned arousal may act as a perpetuating factor [6]. Other perpetuating mechanisms include dysfunctional sleep-related behaviors, learned sleep-preventing associations and other cognitive factors [7].

The delay in sleep onset in individuals with insomnia compared with normal sleepers suggests that insomnia may be associated with inappropriate physiological arousal. Previous findings across a broad range of physiological systems consistently support the concept of physiological arousal in individuals with primary insomnia [7, 8]. Compared with normal/good sleepers, individuals with primary insomnia have increased high-frequency EEG activation, abnormal hormone secretion, increased whole body and brain metabolic activation, and elevated heart rate and sympathetic nervous system activation during sleep [8]. Evidence of a link between physiological arousal and primary insomnia has implications for clinical management.

9.3 Biofeedback Instrumentation

This section introduces the terminology and biofeedback signals relevant to the treatment of insomnia.

9.3.1 Terminology

1. Voltage, also known as electric potential difference, is a measure of the energy of electricity. Electric potential is the energy required to move a unit of electric charge to a particular place in a static electric field. The unit of measurement is the volt.
2. Electric current is a flow of electric charge carried by moving electrons in a conductor such as wire through a medium. The unit for measuring the rate of flow of electric charge is the ampere (amp.), which is charge flowing through some surface at the rate of 1 C/s.
3. Polarity refers to the direction in which electrons flow. Direct current means electricity flowing in a constant direction (constant polarity). Alternating current means that the polarity changes, reversing positive and negative over time.
4. Frequency refers to cycles per second and is measured in hertz (Hz). Muscles generate frequencies in the range of 0–1,000 Hz.
5. A filter is a device designed to attenuate specific ranges of frequencies, while allowing others to pass, and in so doing limit the frequency spectrum of a signal. A passband is the range of frequencies that can pass through a filter without being attenuated.
6. The combination of two active leads and one ground is referred to as bipolar.
7. Signal is defined as the information that the therapist intends to measure. A signal is a discrete part of a communication.
8. Noise is defined as the unwanted information. Any electrical device generates unwanted noise.
9. A differential amplifier rejects electrical artifact.
10. An integrated signal is a signal calculated by the integrator.
11. An electronic signal is a signal generated by electronic means.
12. Smoothing is an example of data enhancement methods that are used to process raw signals in order to improve the quality of the data.
13. Integration is a method of quantifying the EMG signals and refers to measuring the area under a curve over a time period.

9.3.2 Biofeedback Signals

9.3.2.1 Electromyography (EMG)

Surface electromyography (EMG) is a noninvasive method of measuring muscle contraction. Muscle is a force-generating/force-transmitting tissue. Each striated muscle is innervated by a single motor nerve. Muscle fibers do not contract individually; instead, an entire set of muscle fibers, innervated by a single motor neuron, contract simultaneously. This functional physiological unit is called the

motor unit. The EMG monitors the electrical signals emanating from muscles and thus EMG is an electrical correlate of muscle contraction. Electrical signals are generated by *single motor units* and indexed in *microvolts*. In EMG, ionic signals originating from the muscles are converted into electronic signals which are measured by the instrument.

The detection of EMG signals from a localized muscle region requires meticulous attention to noise reduction and grounding, electrode site preparation and placement, as well as appropriate differential pre-amplification and preliminary signal conditioning [9, 10]. Most EMG pre-amplifiers include filters to eliminate noise. However, these filters may not be selective and effective. It is therefore important to minimize noise through appropriate placement and shielding of equipment as well as careful grounding of the participant.

EMG utilizes surface electrodes (sensors) which are directly attached to the skin using adhesives. The sensor consists of an insulated shell in which there is an imbedded metal plate. A conductive gel should be used to bridge the gap between the plate and the skin. Most of the disposable sensors are pre-gelled and have built-in adhesives. Prior to the attachment of the conductive gel and electrodes, the skin surface is usually cleaned to remove dirt and oil and gently abraded to reduce inter-electrode impedance. Each set of EMG sensors constitutes one channel of feedback. An EMG biofeedback electrode channel generally consists of two active electrodes and one inactive (ground or reference) electrode. This is referred to as a bipolar sensor arrangement, now the most commonly used method of recording EMG signals. The amount of EMG recorded is the sum of all action potentials of the contracting muscle fibers between the electrodes.

If the active sensors are placed perpendicular to the muscle fibers, more muscle activity within the general area will be sampled. For a general relaxation placement, the ground sensor can be placed halfway between the two active sensors. If the active sensors are placed parallel to the underlying muscle fibers, then the underlying muscle activity will be picked up and the signals primarily reflect specific muscle activity. The ground sensor should be attached to a bone prominence near the two active leads for a specific muscle site placement.

EMG signals are amplified using differential amplifiers in which the difference signal between two electrodes is amplified and carried through the signal processing chain. As a result, any bioelectrical or extraneous electrical signal that is common to both electrodes is attenuated. An EMG detection passband from 10 to 500 Hz or 1,000 Hz is usually chosen. Selection of an EMG detection passband is based on the consideration of (1) susceptibility to artifact, (2) presence of extraneous electrical noise, (3) need to minimize cross-talk, (4) high-frequency noise internal to the amplifier and (5) the amplitude of the EMG signals to be detected. EMG signals are then conditioned. The raw, filtered EMG signal is a stochastic train of motor unit action potentials. Without conditioning, raw EMG signals are unsuitable for quantification. Usually the signal is rectified and passed to an integrator or smoother for signal conditioning [9].

9.3.2.2 Respiration Monitoring

Respiration sensors include a sensitive and repeatable girth sensor (also known as a strain gauge sensor) using a latex rubber band fixed with a self-adhering belt for monitoring respiration rate, waveform and amplitude. The respiration belt can be worn over the thorax or over the abdomen. When connected to a computer-based system, the strain gauge sensor allows observation of the expansion of the chest or the abdomen during each breath.

9.3.2.3 Photoplethysmography for Pulse Rate Monitoring

Pulse rate is usually recorded using a blood volume pulse (BVP) sensor. The BVP sensor is a blood volume pulse detection sensor (also known as a photoplethysmography sensor) housed in a small finger-worn package to measure heart rate and provide BVP amplitude, BVP waveform, heart rate and heart rate variability (HRV) feedback.

By attaching the BVP sensor to the skin, it is relatively easy to detect the pulsatile component of the cardiac cycle. Each cardiac cycle appears as a peak. With each cardiac cycle the heart pumps blood to the periphery. Even though this pressure pulse is somewhat damped by the time it reaches the skin, it is enough to distend the arteries and arterioles in the subcutaneous tissue. The change in volume caused by the pressure pulse is detected by illuminating the skin with the light from a light emitting diode and then measuring the amount of light either transmitted or reflected to a photodiode. A common sensor placement is the second digit of the right hand. When connected to a computer interface, the BPV sensor allows for measurements of beat-to-beat pulse variations.

9.3.2.4 Electroencephalography (EEG)

Electroencephalography (EEG) provides a noninvasive measurement of brain electrical activity. The electrical activity in the brain recorded from surface electrodes is an alternating current in which the polarity changes (i.e., a current switching between positive and negative directions over time). If the polarity reverses three times per second or less, the range of frequencies is referred to as delta (1–3 Hz). Similarly, if the polarity reverses between four and seven times per second, it is referred to as theta (3.5–8 Hz). Alpha range is between 8 and 13 Hz. Beta range is 14 Hz or higher. Sensorimotor rhythm (SMR) is the activity between 12 and 15 cycles/s which is close to sigma band (12.5–14.5 Hz).

Commercially available surface EEG electrodes consist of hollow metallic discs or cups which are filled with conductive gel before application. Electrodes may be attached to the scalp of the patient singly using adhesive material or as a group using a cap or net. The scalp is usually abraded before placing the electrodes.

9.3.3 Computerized Biofeedback Systems for Professional Use

Computerized biofeedback systems are commercially available for professional use. A list of the systems and manufactures for biofeedback is provided in Appendix 1. Computerized systems specifically designed for neurofeedback are listed in Appendix 2.

9.4 Application of Biofeedback Modalities for Insomnia

According to the Practice Parameters Paper from the American Academy of Sleep Medicine, biofeedback that provides visual or auditory feedback to patients to help them control some physiologic parameters (e.g., muscle tension) in order to seek reduction in physiologic arousal is effective and recommended therapy in the treatment of chronic insomnia [11]. This section introduces the application of biofeedback modalities for the treatment of insomnia. The rationale and treatment protocol are provided. The treatment efficacy is also discussed.

9.4.1 Frontalis Electromyography Biofeedback

9.4.1.1 Rationale and Protocol

Frontalis EMG biofeedback has been widely used in the clinical setting to treat sleep-onset insomnia. The rationale for employing frontalis EMG biofeedback to treat insomnia is that it may induce the relaxation response and reduce physiological arousal. The EMG instrument records electrical signals generated during muscle action. Surface EMG measures electrical signals carried by motor units and thus serves as an electrical correlate of muscle contraction. EMG recorded on the frontalis muscle on the forehead correlates well with generalized muscle tension [12] and can be a good indicator of general arousal. When employing frontalis EMG biofeedback, participants are provided with feedback signals concerning the level of muscle tension in their forehead. In practice, two active electrodes are placed on the frontalis muscle of the forehead, one inch above the eyebrows and directly over the eyes. The reference electrode is placed on the center of the forehead equidistant from the other two active electrodes. The feedback signals provided to the patient can be visual, auditory, or a combination of both. During the EMG biofeedback session, the patient usually lies on a reclining chair and is instructed to concentrate on bringing the feedback signals down to a desired level that is below a predetermined level (threshold). Alternatively, the muscle activity is transformed into a tone where the

frequency of the sound varies with the amount of the muscle tension. The participant is instructed to decrease the frequency of the sound and thereby learn to decrease tension of his/her muscle.

9.4.1.2 Treatment Efficacy

EMG biofeedback is a popular relaxation therapy. However, the efficacy of EMG biofeedback as a treatment modality for sleep-onset insomnia remains somewhat equivocal. In previous studies, a typical treatment protocol was composed of 10–12 sessions, each 15 or 35–45 min in length [13, 14]. One study employed 6 weeks of twice weekly EMG biofeedback sessions plus daily home practice [13]. The EMG activity was transformed into a tone (click) with frequency varying with the amount of muscle tension, in other words, the frequency of the tone increased as muscle tension increased. The subject was then provided with the auditory feedback and was instructed to decrease the frequency of the sound and therefore decrease muscle tension.

It has been shown that frontalis EMG biofeedback is as effective as progressive muscle relaxation (PMR) [15, 16] or pseudofeedback [14] but has not demonstrated superiority in reducing sleep onset latency (SOL) for individuals with sleep-onset insomnia. A summary of the findings from previous studies on the efficacy of EMG biofeedback for sleep improvement is shown in Table 9.1. These studies did not provide conclusive evidence to support the efficacy of EMG biofeedback for sleep improvement due to the small sample size used and questionable rigor of the study design (e.g., no random group assignment).

A review commissioned by the Standards of Practice Committee of the American Academy of Sleep Medicine rated EMG biofeedback as a 'probably efficacious' treatment of insomnia based on the Empirically Supported Treatment (EST) grading system from the American Psychological Association (APA) [17]. Accordingly, criteria for 'probably efficacious' treatments include: (1) two experiments showing the treatment is (statistically significantly) superior to a waiting-list control group, (2) one between-group design experiment with clear specification of group, use of manuals, and demonstrating efficacy, or (3) a small series of single case design experiments ($n > 3$) with clear specification of groups, use of manuals, good experimental designs, and compared the intervention to pill or psychological placebo or to another treatment [18].

9.4.2 Respiratory Sinus Arrhythmia Biofeedback

9.4.2.1 Rationale and Protocol

Respiratory sinus arrhythmia (RSA) is a naturally occurring variation in heart rate that occurs during a breathing cycle and is characterized by a shortening of heart

Table 9.1 Summary of findings on the efficacy of electromyography biofeedback for sleep improvement

Author/year	Design	Number of participants	EMG treatment dosage	Control conditions	Sleep outcome
Coursey/1980	Non-randomized controlled study	22	35–45 min/session, twice/week, 12 sessions	1. Autogenic training 2. Non-relaxation treatment	50% of the EMG and 33.3% of the autogenic participants achieved meaningful improvement in sleep (a global subjective assessment of marked improvement in SOL, a 33% reduction in SOL from baseline and less than 35 min in daily sleep log, and a 25% reduction in SOL from baseline and less than 30 min in EEG.) None of the non-relaxation participants produced meaningful improvement.
Freedman/1976	Non-randomized controlled study	18	30 min/session, 6 sessions	1. PMR 2. Placebo	Both the EMG and PMR groups improved significantly more than the control group in SOL. The EMG and PMR groups were not significantly different in the improvement of SOL.
Nicassio/1982	Non-randomized controlled study	40	30 min/session, twice/week, 10 sessions	1. PMR 2. Placebo 3. No-treatment	Both the EMG and PMR groups improved significantly in SOL compared with the placebo and no-treatment groups. The EMG and PMR groups were not significantly different in the improvement of SOL.
VanderPlate/1983	Non-randomized controlled study	24	15 min/session, 10 sessions	1. Pseudo-Biofeedback 2. Self-monitoring 3. Waiting-list	Both the EMG and pseudo-biofeedback groups showed significantly greater improvement in SOL than the waiting-list group. No significant difference in the improvement in SOL was found between the EMG and the pseudo-biofeedback groups.

EEG electroencephalography, *EMG* electromyography, *PMR* progressive muscle relaxation, *SOL* sleep onset latency

periods (increasing heart rate) with inspiration and a lengthening of heart periods (decreasing heart rate) with expiration in a phase relationship [19]. RSA has been utilized as an index of vagal control of the heart in psychophysiolological research. It is sensitive to behavioral or cognitive states. In humans, the magnitude of the RSA increases with self-induced, relaxed breathing. RSA biofeedback training involves pacing breath rhythm at approximately 6 breaths/min. Lehrer and colleagues [20] proposed that the participant should breathe at his/her resonance frequency so that a resonance between respiratory and baroreflex rhythm can occur to increase the overall HRV amplitude. The resonant HRV frequency is in the vicinity of 0.1 Hz (i.e. 6 cycles/min). At this frequency, HR and respiration oscillate in phase with each other, with inhalation coinciding with HR accelerations and exhalation with decelerations. When participants breathe at their resonant frequency, respiratory effects on HRV stimulate baroreflex effects and produce large increases in both HRV and baroreflex gain [21].

When applying RSA biofeedback, feedback is usually given in the form of a visual display of variations in heart rate in a phase relationship with inspiration and expiration. In practice, a respiration strain gauge sensor is applied over the abdomen and a BPV photoplethysmography sensor is attached to the second finger of the right hand. The participant is instructed to breathe approximately in phase with heart rate changes. A beat-to-beat cardiotachometer, superimposed in phase with heart rate changes is a typical form of feedback display.

The participant can also directly received HRV biofeedback. HRV represents beat to beat changes in the inter-beat interval and is generally considered to be a measure of autonomic tone. Decreased HRV is generally an outcome of autonomic nervous system imbalance, specifically excessive sympathetic activation and deficient parasympathetic activity [22]. Biofeedback training can teach patients to increase the percentage of total HRV in specific frequency ranges. HRV biofeedback training is aimed at teaching people to decrease physiological arousal by increasing HRV amplitude [20]. The monitoring of HRV activity is detected through ECG or through photoplethysmography as previously described. Respiration measures are usually incorporated into HRV biofeedback to facilitate the learning of diaphragmatic breathing.

RSA treatment is usually delivered in multiple sessions. A suggested RSA treatment protocol has been outlined by Lehrer et al. [20]. According Lehrer's manual, the participants receive 5–6 sessions, each 30–50 min, with one session per week. During the initial session, the objective is to determine the participant's resonant frequency. This is accomplished by having the participant breathe at different frequencies ranging between 4 and 7 breaths/min and finding the frequency (resonant frequency) that yields the highest amplitude of heart rate oscillations. A pacing stimulus is presented on a computer display screen, instructing the participant when to inhale and exhale. Then, in the subsequent sessions, the participant is instructed to breathe abdominally at his/her resonant frequency to produce the maximal increases in the amplitude of HRV.

9.4.2.2 Treatment Efficacy

RSA or HRV biofeedback is usually applied to clinical situations where a reduction in physiological arousal is desired. Empirical data on the effect of RSA biofeedback for improving insomnia is lacking. In a study testing the effect of RSA biofeedback for anxiety disorders, RSA biofeedback, using a home training device (StressEraser), significantly improved total sleep time but not overall sleep quality [23]. In another study, RSA biofeedback using the StressEraser reduced the score of the Insomnia Severity Index in individuals with posttraumatic stress disorder, however the effect was not superior to PMR [24]. In both studies, the participants were instructed to practice breathing with the StressEraser device 20 min daily for 3–4 weeks. Home training of RSA has the advantages of being cost-efficient and convenient. Future studies will continue to monitor the effectiveness of home-based RSA training programs on sleep improvement.

9.4.3 Neurofeedback

Neurofeedback, also known as EEG biofeedback, refers to learned self-regulation of specific EEG frequency components.

9.4.3.1 Rationale and Protocol

Sensory motor rhythm (SMR) is an oscillatory idle rhythm of synchronized electromagnetic brain activity. For most individuals, frequency of the SMR is in the range of 12–15 Hz. Barry Sterman's groundbreaking research showed the connection between SMR EEG activity and epilepsy. When cats sit quietly, they show an episodic 12–14 cycles/s rhythm over the sensorimotor cortex. Sterman et al. [25] trained cats to produce increased levels of this rhythm by operant conditioning during wakefulness. These cats subsequently showed more 12–14 Hz waves during sleep and produced longer epochs of undisturbed sleep than control cats. The first evidence of clinical EEG and sleep EEG changes with SMR training in humans was reported by Sterman and Shouse in [26].

In a typical SMR training protocol, the EEG is recorded from C3 or C4 with a reference electrode placed on one ear. Audiovisual reward is given for production of brief bursts of 12–14 Hz activity [27, 28]. The goal is to increase the production of 12–14 Hz activity, while suppressing 4–7 Hz activity [29]. The recorded EEG signals are displayed on a computer screen in the form of analog/digital signals or transformed into a tone. In order to achieve the training goal, participants are given instructions on how to produce the desired or targeted signals on the computer screen and/or to produce a reward tone while suppressing an unwanted tone through trial and error.

Theta waves define stage I sleep, the transition phase between full wakefulness and sleep. Theta feedback has been employed to facilitate sleep for those who suffer from sleep-onset insomnia. When an individual learns to voluntarily generate enhanced levels of theta activity, sleep onset is more rapid. In practice, EEG is recorded from Oz or C4 with a reference electrode placed on the ear or forehead. For individuals with anxiety disorders, theta enhancement protocols train the participant to produce 3.5–7.5 Hz activity while suppressing 8–12 Hz activity [29, 30]. The feedback modality is given primarily in the form of auditory feedback with eyes closed. Participants strengthen their self-regulation of EEG waves by means of producing a desirable tone and/or suppressing an undesirable (e.g. annoying) tone.

9.4.3.2 Treatment Efficacy

A summary of the findings on the efficacy of neurofeedback for sleep improvement is shown in Table 9.2. Both SMR and theta feedback significantly improved self-reported sleep parameters in individuals with insomnia [31], however the effect of neurofeedback was not superior to the control condition [32]. Interestingly, individuals with insomnia responded well to SMR feedback if they were relaxed at baseline whereas those who were initially tense and anxious benefited from theta training [31]. SMR feedback also showed a dose-dependent treatment effect, as the number of feedback sessions positively correlated with sleep improvement [32]. A recent study showed that instrumental conditioning of SMR (12–15 Hz) shortens sleep latency and increases the number of sleep spindles as well as declarative learning in healthy participants [27]. In summary, the effect of SMR conditioning on sleep spindle bursts has been demonstrated in healthy individuals, however its sleep improvement effect on individuals with insomnia warrant further investigations. Theta feedback-assisted relaxation training may help reduce tension and improve sleep, but its efficacy as a treatment for sleep improvement in individuals with insomnia remains to be examined.

9.5 Conclusions and Future Directions

Insomnia is now been described as a “disorder of hyperarousal”. Stressful life events, appraisal of stressors, and associated coping skills are possible precipitating and/or perpetuating factors that chronically maintain poor sleep. Managing chronic insomnia must involve a change in an individual’s lifestyle. As the goal of biofeedback is to teach the participant to learn voluntarily control over his/her physiological processes and to institute a behavior change, it has great potential to be used as a stand-alone treatment for insomnia or as an adjuvant to pharmacological and cognitive psychotherapy. Unfortunately, there has been a lack of well-conducted randomized-controlled trials examining the efficacy of various biofeedback modalities on sleep improvement in individuals with insomnia. Definitive conclusions

Table 9.2 Summary of findings on the efficacy of neurofeedback for sleep improvement

Author/year	Design	Number of participants	Neurofeedback; protocol	Control conditions	Sleep outcome
Hauri/1981	Randomized controlled trial	48	1. SMR 2. Theta plus EMG 1–2 h/session, 2–4 times/week, 15–62 sessions	3. EMG biofeedback 4. No-treatment	Changes in sleep parameters in the three biofeedback groups were not significantly different from those of the control group.
Hauri/1982	Randomized controlled trial	16	1. SMR 2. Theta 2–3 times/week, 26 sessions		Both the SMR and theta feedback groups showed significant pre-test to post-test improvements in TST, SOL and number of awakenings per night as assessed by daily sleep logs. There were no significant pre-test to post-test changes in any sleep variable when assessed by PSG.
Hoedlmoser/2008	Randomized controlled trial	27	SMR 1 h/session, daily, 10 sessions	Randomized frequency conditioning	The SMR group showed a significant improvement in SOL and sleep spindle number from pre-test to post-test as determined by PSG, compared with the control group.

EMG electromyography, *PSG* polysomnography, *SMR* sensorimotor rhythm, *SOL* sleep onset latency, *TST* total sleep time

regarding the effectiveness of biofeedback modalities for the treatment of insomnia has yet to be determined. Future research should employ larger sample sizes with adequate statistical power and use a randomized controlled design to examine the effectiveness of each biofeedback modality for improving sleep in individuals with insomnia. The mechanisms underlying the sleep improvement effect of biofeedback, if any, should also be explored.

Appendix 1: Computerized Biofeedback Systems

System	Manufacturer	Contact information
ProComp (Infiniti) BioGraph EEG, EMG, GSR, Temp, HR, Resp System	Thought Technology, Ltd.	20 Gateway Drive, Plattsburgh, New York 12901 Tel: 1-800-361-3651 or (514) 489-8251 Fax: (514) 489-8255
ProComp2 (Infiniti) 2 Simultaneous Channel EEG, EMG, GSR, Temp, HR, Resp System	Thought Technology, Ltd.	Web: http://www.thoughttechnology.com/index.html
ProComp5 (Infiniti) 5 Simultaneous Channel EEG, EMG, SC, Temp, HR, Resp System	Thought Technology, Ltd.	Web: http://www.thoughttechnology.com/index.html
Cardiopro Biofeedback Module (RSA) for the ProComp + Infiniti EEG, EMG, SC, Temp, HR, Resp System	Thought Technology, Ltd.	Web: http://www.thoughttechnology.com/index.html
Myotrac Dual EMG Clinical System System	Thought Technology, Ltd.	Web: http://www.thoughttechnology.com/index.html
Computerized EEG, EMG, SC, Temp, HR, Resp Systems	BrainMaster Technologies, Inc.	195 Willis Street, Bedford, OH 44146 Phone: (440) 232-7300 Web: http://www.brainmaster.com
Windows based systems EEG, EMG, SC, Temp, HR, Pneumograph Systems	J&J Engineering	22797 Holgar Ct. NE, Poulsbo, WA 98370 Web: http://www.jjengineering.com/index.htm
Bio Integrator Biofeedback & Neurofeedback System (2 EEG Channels, 2 EMG Channels, 1 Temp Channel, 1 SC Channel, 1 HR Channel,1 Resp Channel)	Bio-Medical Instruments Inc.	2387 East 8 Mile Rd., Warren, MI 48091-2486, USA

EEG electroencephalography, *EMG* electromyography, *HR* heart rate, *Resp* respiration, *RSA* respiratory sinus arrhythmia, *SC* skin conductance, *Temp* temperature

Appendix 2: Computerized Biofeedback Systems (Neurofeedback Only)

System	Manufacturer	Contact information
ProComp (Infiniti) BioGraph Multichannel EEG (up to 8 channels)	Thought Technology, Ltd.	20 Gateway Drive, Plattsburgh, New York 12901 Tel: 1-800-361-3651 or (514) 489-8251 Fax: (514) 489-8255
ProComp2 (Infiniti) 2 Simultaneous Channel EEG, (or 2nd channel -EMG, SC, Temp, HR, Resp) System	Thought Technology, Ltd.	Web: http://www.thoughttechnology.com/index.html
Bio Integrator Dual EEG (Synchrony)	Bio-Medical Instruments Inc	2387 East 8 Mile Rd., Warren, MI 48091-2486, USA
2E channel EEG Biofeedback System	BrainMaster Technologies, Inc.	195 Willis Street, Bedford, OH 44146 Phone: (440) 232-7300 Web: http://www.brainmaster.com
Windows based systems EEG Systems	J&J Engineering	22797 Holgar Ct. NE, Poulsbo, WA 98370 Web: http://www.jjengineering.com/index.htm

EEG electroencephalography, *EMG* electromyography, *HR* heart rate, *Resp* respiration, *SC* skin conductance, *Temp* temperature

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