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Contributors

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Meet the editor

Mr. Schwartz worked in technical education and publishing for over three decades before his semi-retirement in 2017. He now works as a consultant to Thought Technology Ltd., one of the world's leading biofeedback manufacturers. From 2010 until 2017, he was the director of the BFE "Learn from the Best" and "International Research & Education" programs. Their purpose was to facilitate the design of continuing education, training and certification programs in biofeedback. The Biofeedback Federation of Europe is a non-profit organization located in London, England. Mr. Schwartz is a regular speaker at international and national conferences. In 2011, he edited the In-Tech book, "EMG Methods for Evaluating Muscle and Nerve Function".

Contents

Preface

Mr. Mark Schwartz, the editor, is a private consultant for Thought Technology Ltd., and the Biofeedback Federation of Europe (BFE). He would like to acknowledge the authors who contributed to the volume and the dedication of IntechOpen staff, especially Anita Condic, Author Service Manager, without whose guidance and assistance the project could not have been completed.

The purpose of the book is to introduce the reader to a variety of research on biofeedback. The six chapters form a sample of the range of biofeedback for physical and mental health rehabilitation in the clinic and at home. All six authors describe, in their own way, how objective electrophysiological data provides useful measures for assessment and therapy. They are to be congratulated on their work.

The first chapter, "Biofeedback and neurofeedback in the treatment of migraine", is written by Ph.D. student Zivoder Ivana. The second chapter by Prof. Dumitrascu looks at pelvic floor rehabilitation and is titled "Factors predicting failure in anorectal biofeedback". The third chapter by Dr Liao Da-Vin is titled "Collaborative, social-networked posture training with posturing monitoring and biofeedback". It is a useful and timely description of the role of biofeedback to support rehabilitation therapy at home and describe how objective information of physiotherapy treatments could increase the quality of service and the consistency of treatment outcomes. The fourth chapter by Prof. Silva Hugo is titled "Bridging the clinic-home divide in muscular rehabilitation". It also covers the role of biofeedback to support rehabilitation therapy at home. The fifth chapter is written by Ph.D. student Grin-Yatsenko Vera and is titled "Effect of infra-low frequency neurofeedback on infra-slow-EEG-fluctuations". The sixth and final chapter in the volume, "Control systems of bionic limbs of the new generation and control systems with EMG signals of VR and games, toys" by M.A. Ivaniuk Natallia goes beyond the person and shows how biofeedback can be integrated in the behavior of a bionic hand.

The first chapter describes a case study conducted by a nurse and a medical doctor to demonstrate biofeedback and neurofeedback for a migraine. The case demonstrates how a female patient was taught self-regulation techniques to enhance individual control of pain and reduce migraine-related stress with a review of the literature with a focus on European populations. The author underlines the importance of listening to the details in an interview for possible treatment options.

The second chapter by Prof. Dumitrascu provides a good summary and introduction to anorectal biofeedback as practiced in a tertiary hospital in Romania. The reader will learn of the key factors that influence outcomes and the technique and clinical use of anorectal biofeedback. The study method is clear and supports the results. The discussion and literature review is thorough and provides an interesting comparison with centres in other countries.

The third chapter is by Dr Liao Da-Vin and is titled "Collaborative, social-networked posture training with posturing monitoring and biofeedback". It is a useful and timely description of the role of biofeedback to support rehabilitation therapy at home and describes how objective information of physiotherapy treatments could increase the quality of service and the consistency of treatment outcomes. The experiment is clearly described and the conclusions support the presented research with evidence from the literature. The chapter provokes more thought on how the application of mobile devices and apps need to be adapted for different treatment approaches and for specific conditions and contexts such as client populations of teens, parents, guardians and friends.

The fourth chapter is by Prof. Silva Hugo and is titled "Bridging the clinic-home divide in muscular rehabilitation". It also covers the role of biofeedback to support rehabilitation therapy at home and describes how objective information of physiotherapy treatments could increase the quality of service and the consistency of treatment outcomes..

The fifth chapter, "Effect of infra-low frequency neurofeedback on infra-slow-EEG-fluctuations" places Infra Low Frequency Neurofeedback (ILF NF) within the framework of EEG biofeedback. The review of EEG biofeedback based on frequencies within the conventional EEG spectrum of 0.5 to 40 Hz is useful and clearly distinguishes between the purpose of Infra-Low Frequency (ILF) neurofeedback with references from the literature to support infra-slow potential fluctuations in modulating the level of cortical excitability and thus regulating brain dynamical activity. The difference(s) between "normal" and "balanced" in the interpretation and conclusions regarding modifications in the changes in the amplitude distribution within the ILF spectral range as a reflection of the "normalization" or "balancing" in the metabolic balance in the brain tissue and increasing efficiency of compensatory mechanisms in the stress regulation systems is described.

The sixth and final chapter, "Control systems of bionic limbs of the new generation and control systems with EMG signals of VR and games", provides a useful introduction and overview of the importance of gestures of electromyographic activity based on a neural network and the use of the bracelet bionic hand. The comparison of artificial limbs for cosmetic vs functional purposes touches on hand prosthetics, prosthesis, myoelectric, control, learning, real-time, discriminating, multichannel surface electromyography (SEMG) pattern recognition, video games, myoelectric, control, multi-function, adaptation, reinforcement Artificial Intelligence, virtual reality (VR) and game devices.

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Chapter 1

Biofeedback and Neurofeedback in the Treatment of Migraine

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Ana Vodanovic Kosic

Additional information is available at the end of the chapter

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Abstract

Biofeedback is a noninvasive method of measurement of physiological functions where precise instruments measure the slightest changes in body functions. Many of the studies have shown that using biofeedback can reduce the occurrence of migraine or reduce the strength of the pain. Some results from a study suggest that the use of biofeedback in combination with medication is more successful than medication alone in treating migraines. Also, holistic approach by using behavioral technic is necessary to provide maximal results by methods. To more precisely work with patients who suffer from a migraine, it is also important to know the pathophysiology of a migraine. According to relevant research, we combined biofeedback treatment that consisted of a combination of three forms of biofeedback treatment: neurofeedback, breathing, and vascular biofeedback. Combination of treatments in 25 sessions helped the patient with a long history of a severe migraine. Further research of patients suffering from a migraine with different treatment protocols is needed to establish the method.

Keywords: biofeedback, neurofeedback, migraine treatment, pathophysiology, breathing technique

1. Introduction

Migraine headache is one of the most common headaches in the general population, 15% suffering from the European Union population [1] which with disabling symptoms significantly decreases the quality of life of the patients [2]. According to the International Classification of Headache Disorders [3], a chronic migraine is a type of a primary headache occurring in 15 or more days per month for more than 3 months, in which more than 8 days per month of headache meet the criteria for a migraine with or without aura or respond to specific migraine treatment. Not only in Europe, but also in the world, migraine has today a high incidence. The prevalence of a migraine in Europe is 15%—ranges depending on the individual countries, 12–27.5% [1]. According to data published in 2006, Croatia, with Germany and Denmark, has the highest prevalence of migraine in Europe [1].

Migraine is a disabling neurological condition characterized by episodic attacks of usually unilateral headache, with pulsating character and light and sound intolerance, associated with nausea and vomiting. The tendency to suffer from a migraine has a genetic component, but attacks can be triggered by a series of internal and external factors. Two types of migraine have been described: episodic migraine (EM) (with subtypes migraine with aura and migraine without aura)—in which a typical headache occurs on fewer than 15 days per month—and chronic migraine (CM) with headaches in 15 or more days per month for at least 3 months [3]. It is not rare that an episodic migraine has progression to a chronic migraine. The development of a chronic migraine has been associated with the presence of many risk factors: female sex, older age, low level of education, low-income populations, predisposition for anxiety, depression, sleep apnea or snoring, overweight, history of frequent headache, stressful life events or major life changes, asthma, allergic rhinitis, and caffeine consumption [4]. Because of all these facts about migraines, it is not difficult to think about complexity and longevity of the treatment. Also, many of people who suffer from migraine in their life use more than one treatment to get better results, which is reduced pain and number of migraines. For more than four decades, many different experts have been trying to find the best way to treat a migraine. Because the causes of migraine are not fully clarified as well as the physiology of migraine, so no unique treatment has yet been conceived.

The annual costs of migraine such as diagnosis, treatment, reduced productivity, and absence from work are estimated to be 5 billion euros in the European Union [5]. It follows from the above that a migraine is not only a medical but also a socioeconomic problem. Apart from the economic, the lack of influence of migraine is manifested in the social sphere. This recurrent disease significantly reduces the quality of life of the diseased, as it limits them to perform daily activities. This directly affects both the near and the outer environment and above all the patient's family. Thus, the consequences of a migraine are reflected in all areas of life—family, professional, and social—resulting in dissatisfaction with their own achievements in all these spheres and creating a sense of inefficiency and intolerance, creating a vicious cycle with negative consequences [2]. Therefore, the comprehensive approach to solving this problem is very important, and education, of both the general population and the patients, and raising health care to a higher level, with ongoing support for migraine-sick patients, are indispensable for shaping a healthier society.

The incidence of migraine before puberty is greater in boys than in girls [6]. It grows up to 12 years in both sexes and is the highest in the age range of 30–40 years. After puberty, the ratio changes and increases in favor of women and with 40 is 3.5:1. After 40 years, the strength of the symptoms is reduced (except for women in perimenopause), and the beginning of migraine headaches in the fifties is rare [7]. The prevalence of migraine is higher in the case of white races than in black races and, on the other hand, is proportional to the socioeconomic status [6].

Migraine is a disease with many faces. The most common form is migraine without aura, occurring in about 80% of patients, while migraine with aura occurs in about 20% of the patients [8].

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2. Pathophysiology of migraine

Pathogenesis of a migraine has long been a subject of discussion among scientists. It has been considered that typical headaches are caused by intracranial vasodilation preceded by vasoconstriction causing aura—vascular theory. Today it is known that this is not the case, and although new findings have emerged, the exact mechanism and genetic determinants are not yet fully clarified. The admitted neurovascular theory states that causes of migraine lie in neurogenic processes, followed by secondary changes in brain perfusion [7].

For a long time, it was thought that the cause of the aura, which precedes headaches, is cerebral vasoconstriction. Today, this theory is denied, and the aura is explained by neural dysfunction rather than ischemia due to vasoconstriction. The process of cortical widespread depression, described in 1944 by Brazilian scientist Leão, is now associated with the emergence of visual aura [9]. It is a self-stimulating process that is thought to be due to hyperexcitability of the brain.

There is a release of potassium and neuroexcitatory amino acids of glutamate from neuronal endings, whereby the surrounding tissue depolarizes and then a longer period of neuronal activity is observed. Impulses travel by tissue at a rate of 2–6 mm/min—which is the first feature to retrieve parallel with the rate of appearance, progression, and spread of characteristic visual auric symptoms. During this process, there are also molecular events that cause sterile inflammation and changes in brain perfusion. During the aura seizures, studies using positron emission tomography showed initial hyper-phase, followed by reduced cortical blood flow caused by reduced metabolism due to depolarization and associated decreased neuronal activity. Changing the blood flow in the post-anterior direction is followed by the spread of the impulse through the cortex and is not anatomically linked to the site and during the cerebral blood vessels [10].

During the functional magnetic resonance imaging study, blood oxygenation was found to be initially increased, followed by a decrease in oxidative clearance in the occipital cortex, which ranged at 3–6 mm/min—which may again be related to the appearance of visual symptoms of aura [11]. In addition to being associated with oligemia, corticosteroid depression also influences the trigeminal activation of the trigeminovascular system and changes the permeability of the blood-brain barrier and thus generates migraine headaches [12]. Cortical widespread depression leads to activation of trigeminovascular afferent fibers. Because of this activation, prolonged blood flow increases through the middle meningeal artery and extravasation of plasma proteins in the pituitary mater. There is the opening of the neuronal panicles and the release of proinflammatory cytokines. Consequently, there is a sterile inflammation and pain that affects the brain veins [12].

2.1. Pathogenesis of migraine headaches

When trigeminal ganglion stimulation occurs, neuropeptides are released that are key to the emergence of neurogenic inflammation. The key substances are P and calcitonin gene-related peptide (CGRP) [13, 14]. Substance P is released primarily from thin non-ligated C fibers, while CGRP releases A and C fibers. They, within neurogenic inflammation, cause vasodilation (CGRP), protein extravasation, and dural mast cell activation.

There is the release of ions, cytokines, and other inflammatory mediators in the environment of sensory fibers that inject the brain envelope. Due to the presence of these substances, prolonged activation of peripheral nociceptors occurs, which is eventually perceived as pain. Neurogenic inflammation prolongs and enhances migraine headaches. Because of inflammation, there is also sensitization [13, 14]. Sensitization of neurons and neural fibers indicates an increase in their susceptibility. The threshold is lowered, and the magnitude of irritability and area of the irritable area grow [12]. Because of this, the weaknesses of the stimuli at perhaps atypical sites can be perceived as pain. Spontaneous neuronal activation also occurs. There are two forms—peripheral and central sensitization. In peripheral sensitization, it is about capturing primary afferent neurons, while in central sensitization, it is more susceptible to "higher" neurons—those in the trigeminal nucleus and other parts of the brain stem and hemisphere. Sensitization is believed to be responsible for many of the clinical symptoms of migraine. Pulsating pain, strengthening pain due to physical activity, hyperalgesia, and allodynia are associated with sensitization.

2.2. Genetics of a migraine

The association of genetic factors with the onset of a migraine has been first proven in patients with familial hemiplegic migraine (FHM). This is a migraine subtype where an aura appears to be fully reversible motor deficiency [12]. There are three types of family hemiplegic migraines:

- FHM1 is linked to the mutation of the CACNA1A gene, located on chromosome 19p13.1, and encodes for the $\alpha 1$ subunit of the P/Q calcium channel neurons [15]. The P/Q calcium channel manifests multiple expressions in the central nervous system, regulates serotonin and glutamate release in central and peripheral synapses, and is associated with increased susceptibility to cortical widespread depression [16]. With the mutation of this gene, episodic ataxia type 2, paroxysmal disorder causing cerebellar ataxia, migraine-like symptoms, nystagmus, and cerebellar atrophy [17] are associated.
- FHM2 occurs due to the mutation of the ATP1A2 gene encoding the $\alpha 2$ subunit of Na/K ATPase. This gene is found on the 1q23 chromosome, and the mutation causes reduced ATPase oligodendrocyte activity and decreased affinity for potassium ions, leading to the reduced removal of the same from the extracellular space and reduction of retention of glutamate from the synaptic cracks [18]. The elevated concentration of potassium ions and glutamate in the extracellular space results in hyperexcitability of the brain [16]. Because of the emergence of isolated FHM, it is also possible to combine with cerebellar symptoms, childhood convulsions, and the emergence of mental retardation epilepsy [19].
- The FHM3 mutation affects the SCN1A gene (on the second chromosome), which encodes the Nav1.1 voltage channel. The Nav1.1 voltage channel is key to generating and spreading neuronal action potential, and genetic mutation causes excessive activation of action potentials and can alleviate cortical widespread depression through several mechanisms: high trigger rates can lead to increased extracellular potassium concentrations and further depolarization and increase the release excitatory neurotransmitter glutamate [15]. In addition to being associated with the emergence of family hemiplegic migraine, this gene is also recognized as a cause of generalized convulsion in adult and childhood epilepsy [16], generalized epilepsy with febrile convulsions, and myoclonic epilepsy in early childhood [20].

Discovery of the mutations of these genes explains very few migraine cases, but their detection is very important for a better understanding of pathogenesis [21]. Other forms of migraine are most likely to be complicated genetic disorders, where multiple genes are responsible for the occurrence of migraine and in which the gene base is intertwined with environmental factors [12].

3. Diagnosis of a migraine

Diagnosis of a migraine is based on the clinical picture or diagnostic criteria set by the Headache Classification Committee of the International Headache Society [3]. There are two types of a migraine—migraine without aura and migraine with aura. Headaches that occur 15 or more days a month for more than 3 months and 8 or more days of migraine headache are diagnosed with chronic migraine [3].

Specific diagnostic tests for migraine do not exist, and image methods are in most cases not necessary. According to the American Academy of Neurology, the use of radiographic image methods (MSCT, MR) is recommended only if an abnormal neurological status is found and in patients with an atypical clinical history of headaches or headaches that cannot be classified into either a migraine headache or some other primary headache [15]. Differential diagnosis of a migraine without aura includes primarily tensile headache, whereas the differential diagnosis of migraine with aura also involves transitory ischemic attack and partial epileptic seizure. At the setting of diagnosis of a migraine can help presence of auras (the presence of positive phenomena following negative phenomena), the sequence of their occurrence, progression, duration, and possibly the existence of associated symptoms [12].

Also, at diagnostic, it is very important to take an extensive interview to get detailed information on all spheres of life of the person with migraine (frequency, pain, time of occurrence, association with other events, relationship with some period of time, place of appearance of pain and description of pain, susceptibility to events in their own surroundings—greater expectations of oneself or others—sensitivity to criticism, events that could have caused migraines). Being a good listener to hear all the details of the person with migraine is of crucial importance because it also depends on proposing the possible treatment. After an initial interview where we collect all the necessary information, we shall decide together with the person about how to treat a migraine. For biofeedback as a method of treatment, it is very important to find out how much the person is motivated to invest in and separate the time they will devote to these treatments. At some people, it is still a bigger motive to take some medications that will quickly solve their problem.

4. Treatment of a migraine

Migraine headache therapy according to European Federation of Neurological Societies (EFNS) recommendations' indication for individual drugs was elaborated according to EFNS guidelines at three levels [22]:

- Level A—the drug is effective, ineffective, or harmful, as demonstrated by at least one convincing first-level research (prospective, randomized, double-blind clinical study in a representative population sample or systematic review of prospective, randomized, double-blind clinical studies in a representative sample of populations) or with two consistent, convincing second-level studies (prospective, cohort, double-blind research in a representative sample of populations or randomized, controlled research in a representative population sample).
- Level B—the drug is probably effective, inefficient, or harmful, as proven by at least one persuasive research other levels or superior trials of the three (all other controlled studies in the representative sample of the population where the expected outcome is independent of the treatment of the patient).
- Level C—the drug is probably effective, ineffective, or harmful this is proven by at least two-level three trials.

4.1. Abortive migraine therapy

Abortive migraine therapy involves interrupting the headaches in a short time. The choice of the drug and the way it is administered depend on the clinical picture; the strength of a headache; whether it is associated with additional symptoms, such as nausea and vomiting; and the health of the patient itself—the presence of cardiovascular and/or other illness—and pregnancy. Symptomatic therapy works best if early, immediate headaches are given, with a larger dose being more effective than many smaller ones [23]. In the treatment of weaker to moderate headaches without nausea and vomiting, the nonsteroidal anti-inflammatory drugs (NSAIDs) are prescribed for oral use. If a headache is followed by nausea and vomiting, the NSAID and antiemetics are used parenterally [24]. Moderate to severe headaches without nausea and vomiting are treated with specific drugs—triptans in oral or triptan combinations and NSAIDs (sumatriptan and naproxen) [24]. A moderate to severe headache with nausea and vomiting indicated the use of triptan subcutaneously or intranasally [23].

If the number of headaches varies from attack to attack, the patients are taught and prescribed two or more drugs, either orally or parenterally, which they use as needed [25].

Pregnancy is contraindicated in the use of all medicines used to treat a migraine except paracetamol and aspirin and ibuprofen in the second trimester. Triptans may be used with specialist consensus and if the risk to the child for attack and vomiting is greater than the risk of using triptan [26]. Ibuprofen and paracetamol from the NSAID group, domperidone from the antiemetic group and sumatriptan nasally from the triptan group [26], may be used for childhood treatment and adolescent treatment.

4.2. The prophylactic treatment of migraine

The prophylactic treatment of migraine is prescribed to patients to prevent or reduce the incidence and strength of symptoms. Prophylactic migraine treatment should be initiated if headaches significantly reduce the quality of life (family and professional), headaches occur twice a month or more often, abortive treatment is inadequately effective, and common, long-lasting, and unpleasant aura occurs [26].

It is important to emphasize that the introduction of prophylactic therapy should be discussed with the patient, who should be familiar with the possible adverse effects of therapy and adapt the drug and the dose to each individual patient [26]. The main goals of prophylactic therapy are to reduce the incidence and duration of headaches, improve the quality of life of patients, and prevent progression of transient episodic to chronic migraines. Prophylactic therapy should also be introduced if the patient is suffering from a specific form of migraine that can lead to permanent neurological damage, hemiplegic migraine, basilar migraine, persistent aura without migraine infarction, and migraine infarction [27]. Pregnancy is recommended only for magnesium and metoprolol [28], and flunarizine, propranolol, or topiramate may be used in childhood and adolescence [26]. In the prophylactic treatment of migraine, certain drugs are used such as antihypertensive, antidepressant, antiepileptic, and nonsteroidal anti-inflammatory drugs.

4.3. Non-pharmacological prophylactic treatment of migraine

In addition to drug therapy, preventive procedures include life-changing practices that include sleep hygiene, regular meals, exercise, and avoiding known trigger for reducing migraine frequency. Using techniques such as relaxation exercises, cognitive-behavioral techniques, biofeedback, acupuncture, and transcutaneous electrical stimulation of the nerve (TENS) can also contribute to the prevention of migraine headaches [23].

According to preventive treatment, it is recommended in patients with high frequency of migraine attacks (usually more than 4–5 days per month)—which is always the case in a chronic migraine, but also when attacks are rare, but very severe and disabling (intense pain), or when patients have contraindications or no response to triptans [29]. Relaxation training and biofeedback focus on the perception of pain, biofeedback training focus on the physical response involved in pain persistence, and cognitive-behavioral techniques target the experience of feeling pain. Knowing the factors that produced chronic headaches may allow the patient to modulate the pain. Patients are taught self-regulation techniques to enhance individual control of pain and coping strategies for a chronic headache and reduce migraine-related stress [30]. In the treatment of a migraine, we can certainly combine different methods. Some people can take certain analgesics only in the period of headaches; some take preventive therapy. With the use of nonpharmacological treatments such as biofeedback, according to our experience, the analgesia is gradually diminishing. The use of multiple combinations of treatments always goes on the assumption that a combination of multiple treatments will sooner and faster produce better results.

5. Biofeedback and neurofeedback in the treatment of migraine

Biofeedback is a noninvasive method of measurement of physiological functions. Precise instruments measure the slightest changes of different body functions—which are then in a clear and understandable manner shown in the form of feedback. The person gets an insight into what is going on inside the body and thus learns to change patterns of behavior to improve health and performance. Any changes that are wanted are rewarded, which leads to learning of the new patterns of behavior [31]. Biofeedback is a common intervention in pain management. For migraine treatment, the most frequently used biofeedback methods have been peripheral skin temperature biofeedback, blood-volume-pulse feedback, and electromyography feedback [31]. Neurofeedback is a method of obtaining feedback on brain processes, that is, a type of training that observes wave activity and is presented to the individual through the screen through video games. It is based on the measurement of specific brain activity patterns that are characteristic of certain cognitive processes or conditions such as attention, concentration, depression, insomnia, anxiety, fears, stress, headache, or migraine. The neurofeedback method functions as a "mirror that you hold in front of the brain." It gives information on how the brain works. That way the brain can train to function better. It is possible to alleviate feelings of anxiety and anger and increase self-esteem, concentration, and organizational skills. According to symptoms and problems that a person could have, neurofeedback could be used to increase self-esteem and concentration and decrease anxiety and anger. Brain activity can be targeted by the brain function that we call neuroplasticity. Neuroplasticity refers to the ability to change brain activity over time and represents one of the fundamental parts of the human evolution process and is found to be the basis of some mental and health disorder acquisition.

Before training the target change activity in the brain, it is necessary to see what the initial activity is. Electrical activity in the brain is recorded with electroencephalograph, or EEG. The program analyzes brain activity through brain waves and uses, as well as feedback data presented through video games (motion of missiles, cars, changing image size, etc.). Brain activity by measuring brain waves is monitored via a computer interface, whereby the neurofeedback trainer follows brain activity and the client looks at his screen where he traces his brain activity in the form of video games and sound signals. If we want to achieve that the brain produces more rapid waves (important for mental functions and attention), when brain activity is increased precisely at those frequencies, the client will get better in the game or gain more points. If activity increases with slow-wave frequencies (those we want to reduce), then the success in the game will be weaker. Gradually, the brain will react more and more to these instructions and learn a new pattern of brain activity. The client does not have to think about the process of controlling activity that occurs at a subconscious level. The client just needs to relax and let the brain use its own ability to self-regulate. Observing brain activity information through real-time senses is what makes neurofeedback unique and successful. While some aspects of neurofeedback are automated using modern computer technology, each brain is unique, and each individual situation is different. It is therefore very important that the trained neurofeedback therapist takes an individual approach to the treatment of each client.

Focus and emotional balance are important to outstanding performance in all areas of our work and activities. By training certain brain wave patterns in certain areas, we can develop the skill of entering the "zone," at those times when it is most important for us to be excellent and regardless of the circumstances in which we are located. We must not forget that one of the most important preconditions for excellence is a quality dream. Stress and anxiety can seriously affect the amount and quality of sleep. Neurofeedback training can reduce anxiety and strengthen the brain activity that will help us sleep again well.

Some studies have shown that using biofeedback can reduce the occurrence of a migraine or reduce the strength of the pain. A German meta-analysis of the efficacy of biofeedback for migraine—account 55 studies—showed medium effect size for all biofeedback interventions and proved stable over an average follow-up phase of 17 months. The frequency of migraine attacks and perceived self-efficacy demonstrated the strongest improvements. Blood-volume-pulse feedback yielded higher effect sizes than peripheral skin temperature feedback and electromyography feedback [32].

Sharff et al. [33] conducted a study to examine the effects of hand-warming biofeedback, as compared to hand-cooling biofeedback and no treatment at all. Sharff et al. found that the children who were in the hand-warming biofeedback group improved more than the comparison groups and sustained this improvement for up to 6 months later.

Results from a study conducted by Grazzi et al. [34] suggest that the use of biofeedback in combination with medication is more successful than medication alone in treating migraines. Results showed a relapse rate of 42.1% (16 of 38) for participants in the medication only group vs. a relapse rate of only 12.5% (2 of 16) for the medication plus biofeedback group at year 3 of follow-up. This study, therefore, suggests that a combination of medication and biofeedback rather than either by itself may perhaps be the best means of treating migraines, specifically transformed migraines.

Vasudeva [35] conducted a study to examine whether migraine sufferers who experienced aura reacted differently to biofeedback/relaxation than those without and if this was accounted for by blood flow velocity. The results have shown the biofeedback group experienced a decline in the severity of their migraine pain and reported about using less medication to treat/control the pain. Furthermore, no association between biofeedback-assisted relaxation and blood flow velocity was found. Therefore, this study provides corroborating evidence for the notion that biofeedback is an effective treatment for migraines. Another migraine study with 62% of participants using neurofeedback reported major or total improvement in their migraines [36]. Per the study, most patients had long histories of migraines and had tried multiple pharmaceutical treatments prior to trying neurofeedback. Most were on medications during the study. Participants took part in an average of 40 sessions over 6 months. For neurofeedback training, they used a different site such as temporal locations (T3, T4), central areas (C3, C4), frontal areas (F3, F4), prefrontal areas (FP1, FP2), and parietal areas (P3, P4) for typically one to two sessions at each location. Seventy percent of the 37 participants showed a 50% or greater reduction in the frequency of their migraines, and only 16% failed to improve at all. Of those who improved, 62% reported major or total improvement in their migraines. The goal of neurofeedback, however, is to reduce, on an ongoing basis, the number and intensity of migraines. Based on these results—and on clinical experience from clinicians around the country—neurofeedback offers the potential for significant relief for anyone still struggling with migraines.

From some studies, in the electrophysiological activities of migraine sufferers, there are certain abnormalities, so it is understandable that interventions using EEG may be beneficial at migraines [37, 38]. For example, a study in children with a migraine, with or without aura, shows an increase in frequency theta compared to the control group [37]. One of the used neurofeedback protocols for a migraine emphasizes the brain activity reward of 12–15 HZ at T3 and T4 sites [37]. Siniatchkin et al., in their research, showed a significant reduction of migraine in 10 young people after 10 sessions of neurofeedback in central frontal and central areas by teaching them control of sporadic cortical potential activity that represents cortical sensitivity and reactivity [39]. Michael Tansey in his work with four people with migraine after neurofeedback training in the central frontal and central area showed a decrease in low frequency that became less dominant and strengthened faster frequency [40]. Also, neurofeedback training includes a newer method called hemoencephalography (HEG) that is used on the frontal lobe with gaining information on heat value and learning to increase the frontal temperature or forehead temperature [41]. The elevation of PIR HEG signals reflects the composite thermal activity generated by vascular supply, vascular return, and brain cell activity. Changes of the heat signal from the underlying prefrontal cortex reflect the degree of engagement and increase of neuronal activity. This method also, according to literature, helped to reduce migraine pain as well as the frequency of their headaches in people with migraine diagnoses [37, 41, 42].

According to relevant research, we started a combined biofeedback treatment as a combination of three forms of biofeedback treatment: neurofeedback, breathing, and vascular biofeedback. After an initial assessment and extensive interview, we decided together with the person to combine multiple treatments at one visit. First, we did neurofeedback treatment, followed by breathing with the diaphragm for 10 min and then vascular training, with the aim of learning to achieve vasoconstriction. Treatments started at the beginning of September 2015 and completed at the end of December 2015. During the treatment, a headache diary was conducted by the person.

Our treatment goals were an improvement of the quality of life and increase in everyday functioning by reducing the symptoms related to the primary diagnoses.

Before we started treatment, we have done an initial assessment which included:

- Analyses of medical documentation (conducted diagnostic and therapeutic procedures).
- Structured interview.
- Measuring of baseline EEG (one channel, Cz).

With neurofeedback as a method, we chose to train a relaxed focus or sensorimotor rhythm (SMR) with maintaining muscular relaxation and reducing the internal anxiety and tensions most commonly occurring in the fast beta activity (high beta amplitude) above 22 Hz and may be associated with stress as well as other psychological events. Given that it was a young person, but also loads with her law study, the idea was to strengthen the relaxed focus with neurofeedback and reduce internal tension. Along with the effectiveness of neurofeedback that we have been able to see in improving performance as well as at some difficulties during our decades of use, we thought that it is a good choice to work with a migraine. After neurofeedback, breathing training with the diaphragm lasted for 10–15 min with the aim of relaxing the body through muscle relaxation and breathing training that would lead to vasodilation and relaxation of the whole body by stimulating the parasympathetic action of the autonomic nervous system. Subsequently, we have been using vasoconstriction-vasodilation training with the aim of enabling a person to learn that vasoconstriction occurs when a migraine occurs. The training is done in such a way that the sensor is set to a. temporalis with a signal that must be at least 10 μV. During the 21-min training sessions, we had 4-min vasoconstriction training and 1-min relaxation training alternate. Choosing all three training sessions at the same time was to prompt positive changes in pain reduction as well as migraine rates.

The reason for choosing that particular way of training (neurofeedback, breathing, vasoconstriction training) was to have one relaxation training between two difficult pieces of training. It is not so easy to work one hour and a half with maximum work of the person. We also could recommend monitoring peripheral temperature as a secondary parameter during vasoconstriction training, but we did not consider it necessary to include it because the effectiveness of the training achieves vasodilation, that is, a certain blood flow, which also increases the peripheral temperature. Of course, it would be useful to put the sensor in peripheral temperature for future research. We did not use EMG biofeedback, it was not necessary in this particular case. HEG would certainly be useful as a method and probably use it to have it in the software. The device we used in training was NEXUS-10 MARK II and software BIOTRACE+, of the Dutch company Mind Media.

The training lasted 4 months during which the person came two to three times a week for complete training; breathing training was used daily. During the 4 months, a headache diary was also conducted. During the training session, there was no migraine, or a headache was on pain scale 3, on the scale of 1–10.

Implementation of neurofeedback was by using protocols that are determined individually according to the initial assessment, and mean duration of each session was 30 min. Electrode position was according to the international 10–20 systems, and frequency bands were inhibited or rewarded. Administered protocols were on Cz, C4, and C3. Neurofeedback was used to increase sensory motor rhythm (SMR) in the sensory-motor area, to decrease high beta activities and to learn to maintain a relaxed state with a clear focus and concentration. Below is a description of the neurofeedback training with a detailed performance about working on individual points according to the international 10–20 systems:

Cz: inhibition of theta waves (4–9 Hz), strengthening of SMR and beta waves (12–15 Hz), and inhibition of high beta (22–30 Hz)—ten sessions.

C4: inhibition of theta waves (4–9 Hz), strengthening of SMR and beta waves (12–15 Hz), and inhibition of high beta (22–30 Hz)—seven sessions.

C3: inhibition of theta waves (4–9 Hz), strengthening of SMR and beta waves (14–18 Hz), and inhibition of high beta (22–30 Hz)—eight sessions.

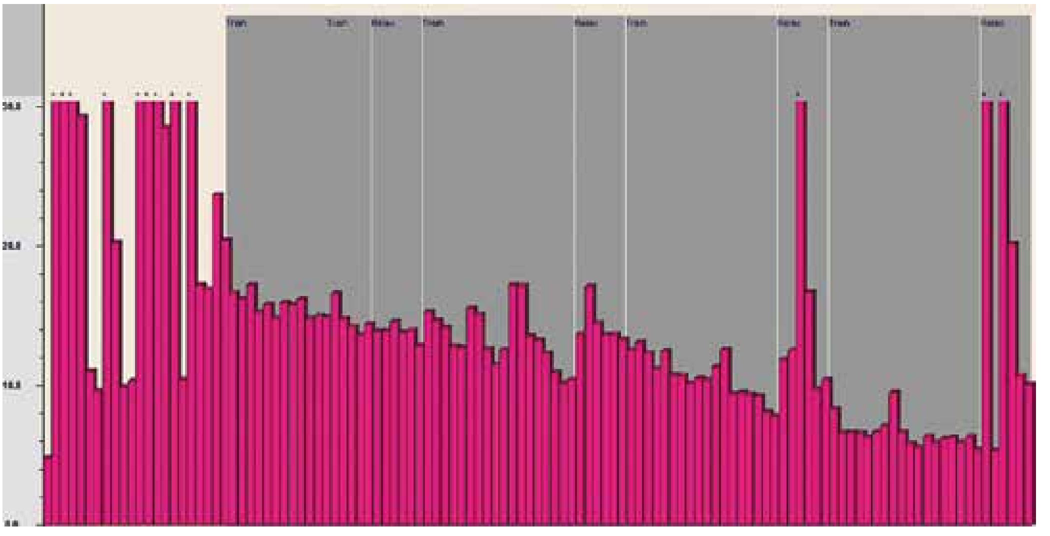

Figure 1. Vascular training with BVP sensor on a. temporalis (session 2).

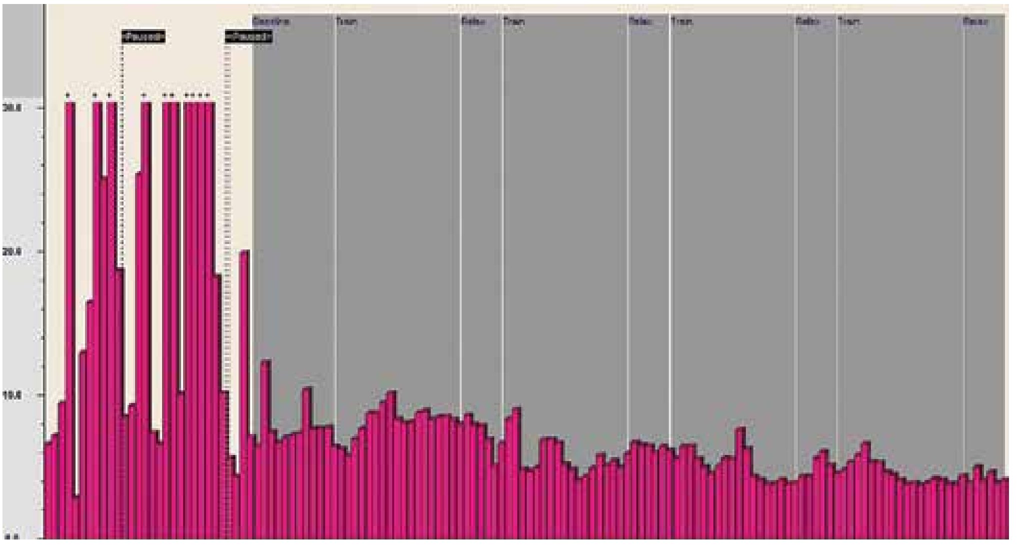

Figure 2. Vascular training with BVP sensor on a. temporalis (after 1 month).

Implementation of biofeedback included vascular training which means 25 sessions of vascular training on a. temporalis, learning the modality of vasoconstriction and vasodilatation. Each training session was 30 min. We used the device that had the vascular training. The goal was to have the amplitude of BVP signal smaller at training phase than relax phase. The results of the few training we shown in **Figures 1–3**.

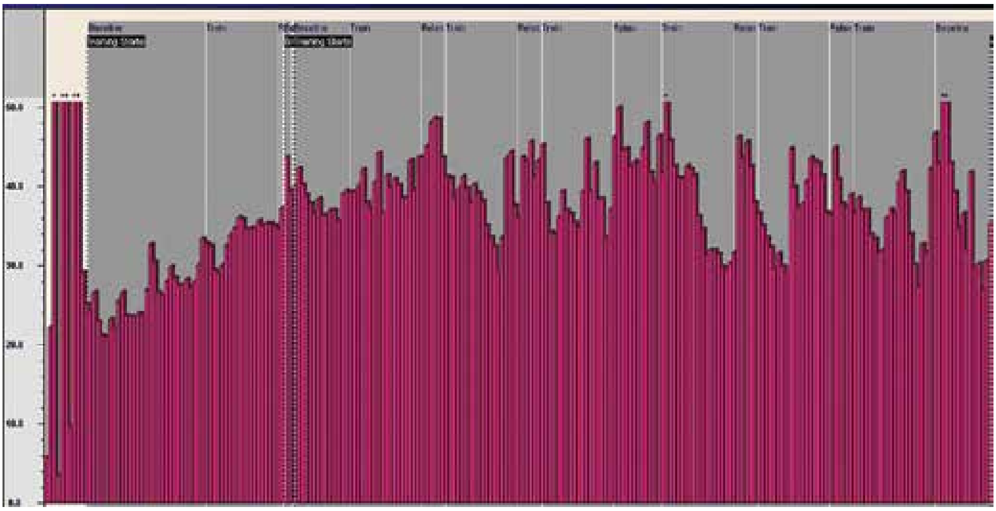

Figure 3. Vascular training with BVP sensor on a. temporalis (after 3 months).

5.1. Breathing technique

Breathing is a willing and reluctant function, which means we can, but we do not have to pay attention to breathing. Breathing is under control of the breathing center located in the extended spinal cord, which means that the breathing takes place without our influence. It is controlled by an autonomic nervous system that manages various functions in the body and is often not recognized or affected by them.

How then to affect the function of breathing? Breathing can be controlled by a conscious mechanism of breathing an attempt to relax the body and slow down the physiological processes. Today, when the challenges—and therefore stressors—in everyday life are very intense, body relaxation for the sake of health is very important. People who use certain breathing techniques feel their benefit. They are more relaxed, they feel happier, and they do not feel in their own body of great pressures of everyday life. To explain why breathing is important and how it affects a person, we need to look at the vascular system that is also affected by the autonomic nervous system. The most frequent changes due to the great pressures in life most people feel in that system. Mostly, it is a disruption of heartburn, accelerated breathing, a sense of losing air, and "kicking in the heart"—all these are symptoms that lead to bad feelings and the inability to function every day.

Common respiratory changes are associated with retardation or acceleration of the bloodstream and are caused by the sympathetic and parasympathetic autonomic nervous system. The first accelerates it, and the other serves to slow down all the functions in the body. The same happens with breathing—in the sympathetic work of the autonomic nervous system, the breathing is faster, shallow, and irregular, while in the parasympathetic effect, breathing is slower, which most commonly occur during rest and sleep without our influence. For the body to function normally, it is necessary to balance both systems.

Figure 4. "Breathe in" with the diaphragm.

Experts engaged in the vascular system of research have found that reducing cardiac variability leads to a greater inclination to the bloodstream disease, and deaths are also more common. Also, biofeedback use aims to increase heart rate variability by using breathing techniques. So, breathing is a tool that we use not only to relax but to influence the well-being of the bloodstream system. The breathing used in the training itself is breathing with the diaphragm (breathing with belly) that breathes the lowest part of the respiratory system—the diaphragm—as we show in **Figure 4**.

Breathing training at a migraine was used by breathing with the diaphragm in the duration of minimum 10 min at one session. The person had instructions to use this breathing also at home at least once a day taking care that the breathing is taking place without the influence of external distractors. Breathing technique is a recommended method for relaxation and to reduce stress which is important for people with a migraine. Breathing with the diaphragm is the healthiest breathing we can use. The aim is to provide the best possible exchange of oxygen and carbon dioxide. The body of the belly breathing curves upward, so that the lower part of the chest is enlarged and the lower part of the lung fills with air, as the belly breathes. With this breathing, we get a full effect: the fullness of the ribs, the bones, the spine, and the scurvy and thus the higher lung capacity.

In people who are often affected by different stressors, the use of breathing techniques is of utmost importance. Breathing encourages the parasympathetic action of the autonomic nervous system that slows down and relaxes our body. Breathing is a mechanism that affects HRV and changes that will lead to optimum functioning of the individual.

The daily use of breathing with the diaphragm for at least 10 min leads to the stimulation of protective mechanisms in our body and the creation of so-called protective "receptors" that protect the body from long-term adverse effects of stress. Below is a detailed description of breathing by using the diaphragm.

5.2. Instruction for breathing training—10 min

1. Take a comfortable position and remove anything that sticks around you.
2. Relax the upper body muscles (face, neck, shoulders, upper back, arms).

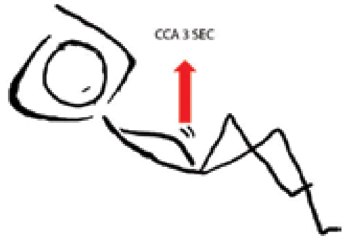

Figure 5. Slowly "breathe in" through your nose about 3 seconds and inflate your belly such as balloon.

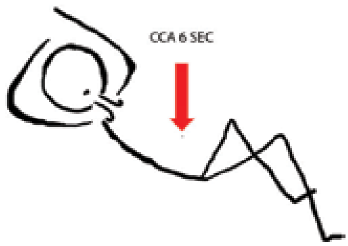

Figure 6. With open mouth slightly, and slowly exhale by counting to six (until you out all the air).

3. If you are feeling comfortable, place your palms on the belly, at the height of the navel.
4. Close your eyes and relax your body.
5. Slowly breathe through your nose counting in yourself by three, inflating your belly as if you were blowing a balloon (**Figure 5**).
6. Try to keep the rest of the body relaxed and not lift it up.
7. It is important that you take as much air as is enough to fill your belly.
8. When you are breathing out, open your mouth slightly, and slowly exhale by counting to six (until you breathe all the air) (**Figure 6**).

Only the body will stimulate your next breath and repeat the cycle. Exercise at least once a day. You can use it several times if you feel the need for relaxation.

6. Results and discussion

According to the treatment of the person with a migraine, we have done a total of 25 treatments. Three modalities were used at each treatment: neurofeedback, vascular training, and breathing techniques. Duration of one treatment was 1 h and 30 min. The training sessions were done 2–3 times per week. The results were a reduction in the frequency of migraine attacks, as well as a reduction in pain severity during the attacks. The reduction in the frequency of migraine attacks and in the strength of pain was gradual. In September, the person had nine migraines, with pain ranges between 8 and 9. In October, the person had six migraine attacks (3 less), pain strengths from 5 to 8. In November there were five migraine attacks, with a pain score from 2 to 7. In December the number of migraine attacks was four, which is a reduction in frequency by more than 50% since the beginning of the training in September. The pain strength was from 3 to 5, which is also a reduction of more than 40% from September. The person learned to apply the vasoconstriction method when she was experiencing migraine, which reduced the strength of the pain. Also, breathing technique became normal training used daily. The efficacy of biofeedback is evident in the application of the method, for the reduction of a migraine as well as pain relief. Within 4 months of treatment, the person had fewer migraine attacks, and the pain was reduced to such extent that it did not require the use of analgesics. Our experience has shown that it is important to take a good initial assessment and know all relevant information of a migraine as well as to the person itself and to agree with the person on possible treatment goals as well as the incidence of arrivals. The emphasis is on the motivation of the person as well as encouraging motivation, which is always it happens as the frequency and strength of headaches are reduced.

7. Conclusion

Our case study has shown the good curative potential of biofeedback and neurofeedback treatments at a migraine. We confirmed earlier research results that different types of biofeedback methods could have some benefits to people with migraine. Also, we gave some our way of training. Combination of treatments (neurofeedback, breathing, and vascular training) in 25 sessions helped the female patient with a long history of a severe migraine. Further research of patients suffering from migraine with different treatment protocols is needed to establish the method. Therefore, a comprehensive approach to solving this problem is very important, and education, to both the general population and the patients, and the raising of health care to a higher level, with ongoing support for patients suffering from a migraine, are indispensable for the formation of a healthier society. Combination of pharmacologic and behavioral treatments such as relaxation training and cognitive behavior therapy can lead to faster and better results with people who suffer from migraine [43, 44]. Empirically validated behavioral treatments include biofeedback training; relaxation training, combinations of the two, stress management training, and cognitive behavioral therapy could be helpful for people with migraine headache. According to earlier research and our case, we could have recommended a different type of biofeedback methods such as temperature, vascular training, neurofeedback, HEG, and EMG biofeedback. The choice is depending on therapist and client with migraine. Migraines as a disease with many faces need the multidisciplinary and combined approach which provides the possibility of faster achievement of the goals of a therapist and a person with a migraine, which are a reduction pain and the number of migraines. By achieving these goals, we enable a person to have a good and quality life.

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Chapter 2

Factors Predicting Failure in Anorectal Biofeedback

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Dan Lucian Dumitrascu and Dinu Iuliu Dumitrascu

Additional information is available at the end of the chapter

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Abstract

Anorectal biofeedback is a method used by specialists in gastrointestinal motility to treat disorders of defecation. In the case of the anorectal biofeedback, unlike in biofeedback applications in other medical fields, the signal is represented by the pressure in the anorectal canal. The pressure is assessed by anorectal manometry. Patients are trained to become aware of this signal in an attempt to reeducate them for a correct defecation. Following the variation of the signals, patients can learn how to modulate the anal sphincter pressure and to improve their defecation disorders. Anorectal biofeedback is therefore used for fecal incontinence and for chronic terminal constipation. Despite its potential, the method is not intensively used and many patients ignore it. The specialists' evaluation of the method is controversial: from enthusiastic to deceiving results, different data are available. The aim of this presentation is to analyze factors of success and of failure in the use of anorectal biofeedback in a single center specialized in anorectal manometry and to compare our data with results described by other authors.

Keywords: anorectum, biofeedback, constipation, defecation, feces, incontinence, manometry, stool, therapy

1. Introduction

Biofeedback has its application in gastroenterology as well. According to the definition of biofeedback indicated by Webster Dictionary," *the technique of making unconscious or involuntary bodily processes (such as heartbeats or brain waves) perceptible to the senses (as by the use of an oscilloscope) in order to manipulate them by conscious mental control,*" few people would expect the application of feedback in the gastrointestinal tract. If you look to the well-known French dictionary Larousse, one cannot easily understand the use of biofeedback by gastroenterologists:" *Méthode de rééducation utilisant l'action du système nerveux sur les réactions physiologiques "(Method for reducation using the action of the nervous system on physiological recations).* To our disappointment, the explicatory dictionary of our tongue mother, Romanian, simply ignores the word biofeedback, maximum it offers is only "feedback." According to these definitions, nonspecialists could believe that biofeedback is something for the patients with disorders of the nervous system. However, the gastrointestinal tract has its own nervous system as well, thus biofeedback should work also for the gastrointestinal system.

Which is the segment of the gastrointestinal tract best suitable for the application of biofeedback? This is the anorectal segment, having important innervation and requiring a perfect correlation between the contraction and relaxation of its different components during defecation [1]. Defecation is a complex function and its deterioration may have very important impact on the quality of life of any patient with defecation disorders [2]. The application of the biofeedback for the correction of defecation disorders caused by the impairment of the anorectal segment of the digestive tract is called anorectal biofeedback.

The physiological signal triggering the biofeedback activity is represented by the pressure of the anorectum in relaxation and contraction. Thus, anorectal biofeedback relies on anorectal manometry. One can claim that anorectal biofeedback represents the field where anorectal manometry evolves from the diagnostic role to the therapeutic role [3]. The clinical conditions where anorectal biofeedback based on anorectal manometry is useful are represented by defecation disorders: anal incontinence and terminal constipation. Both may become severe conditions deteriorating the quality of life [4–7].

The anatomical and physiological background of the normal defecation relies on the integrity of the anorectal structure and function, and these may be influenced by general or systemic conditions or by local changes [8]. The retentions of the fecal bolus are a complex mechanism that involves the two anal sphincters as well as the 90° anorectal flexure. During defecation, the external anal sphincter is relaxing, the puborectal muscle is relaxing as well, and this leads to changes of the anorectal angle to 140°; meanwhile, the abdominal wall muscles contract to increase the intraabdominal pressure. The anal canal is situated in the thickness of the perineum. Posterior to the anus are found in the levator ani muscles and laterally the ischioanal fossa is found. The anatomical relations of the anterior aspect of the anus are different in women and men. In woman, we found the vagina and in men the prostate.

The internal structure of the anal canal is covered by a mucosa formed from simple epithelium. At this level are present the vertical folds that form the anal columns. The inferior third of anal canal is covered by a stratified squamous epithelium that is continuous with the perineal skin. The external anal sphincter is formed from three circular striated muscles the surround the anal canal. The internal anal sphincter lies directly superiorly to the external sphincter. While the control of the external sphincter is voluntary, the internal one is controlled entirely involuntary. The innervations of the sphincter apparatus are realized through fibers from the lumbosacral plexus.

2. Technique of anorectal biofeedback

The performance of anorectal biofeedback requires the availability of a manometry laboratory [1, 9]. **Figure 1** displays a room for gastrointestinal manometry which is useful also for anorectal anometry and biofeedback. The equipment needed for biofeedback is any good system of standard anorectal manometry or of high-resolution manometry (HRM).

We started the procedure with water-perfused systems, using balloons. The balloons were inflated during the procedure and following anorectal manometry, asking the patient to expel the balloon. The patients were also looking to the screen to observe the pressure variations on the screen. **Figure 2** shows the catheter and the balloon used for biofeedback. More recently, after finishing the investigations described here, we started working with a solid-state high-resolution device.

The investigation of the anorectal function in patients with defecation disorders should be carried out in a dedicated room of the laboratory for gastrointestinal motility studies in conditions of

Figure 1. Laboratory for anorectal manometry and biofeedback.

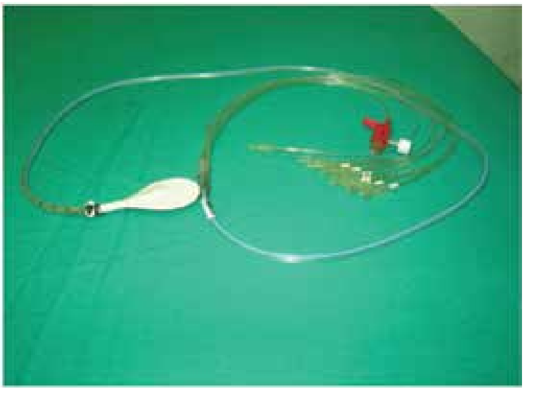

Figure 2. Balloon used for anorectal biofeedback.

comfort (termic and social) respecting patients intimacy. It is advisable to do not accept many trainees during the investigation, as patients could feel stressed and unable to relax the external anal sphincter when asked to do so. One should begin by assessing the anorectal pressures in order to have a correct manometric diagnosis (either incontinence or terminal constipation). During the investigation, the patient is able to look to its own curves of pressure in the anorectal canal, in relaxed condition or in contraction state. Thus, the patient receives the signal offered by the recording of the pressure either by standard manometry or by HRM. The patient becomes aware of the functional deficit of his/her anorectal disorder. The pressure recordings represent in continuation the starting baseline for the exercises to correct these functional disorders [9, 10]. The investigation is carried out by a specialist (can be medical doctor, fellow or technician/nurse), but the biofeedback session should be performed by a very dedicated person, preferably a technician or nurse. The staff should have experience, empathy, patience and tolerance with the patient.

Of course, the patient requires a preliminary preparation for every biofeedback session. This is the same as for anorectal manometric investigation: empty rectum (easy in incontinence, difficult in terminal constipation), emesis should be required at least 60 min before the intervention. All these prerequisites make very much necessary a good collaboration between patient and investigator.

3. Clinical use of anorectal biofeedback

3.1. Anorectal biofeedback in terminal constipation

Chronic constipation is defined as the evacuation of stools from the bowel less frequently than once every 3 days [11]. It also corresponds to the types 1 and 2 of the Bristol Stool Form Scale [12]. Two main factors may cause chronic constipation: slow transportation or difficult evacuation [13]. Therefore, we may encounter two types of constipation: transportation constipation and terminal constipation or dyskesia. Sometimes both factors are contributing to constipation. In this case, we speak of mixed constipation. The indication to use biofeedback in terminal constipation relies first on the identification of this kind of constipation. The diagnosis of terminal constipation is assessed by the measurement of colonic transit time with radiopaque markers [14]. This is a simple method allowing the estimation of total colonic transit time, as well as of segmental transit times for proximal colon, distal colon and rectosigmoid. A normal transit time of the colon rules out the transportation constipation. It is not uncommon to observe a difference between patients' symptoms and real transit time when assessed by radiopaque markers. This difference might be explained either by over reporting of anxious constipated patients or by variability of transit from day to day in same subject.

Terminal constipation has to be confirmed by anorectal manometry. Anorectal manometry is able to diagnose terminal constipation when rest anal pressures are high or when the anal sphincter does not relax after the dilation of an intrarectal balloon. This is caused by the lack of the inhibitory recto-anal reflex. In some cases, the fecal bolus is not perceived because of altered visceral sensitivity or of the enlargement of the rectal ampulla.

If the terminal constipation cannot be managed with normal dietary and pharmacological measures, one should proceed to anorectal biofeedback. The first session starts with the routine anorectal manometry just to identify the pathogenic background and to explain it to the patient. This investigation represents the baseline for consecutive measurements during next sessions. The patient has the possibility to look to the screen of the manometric device and to find out pressure and relaxation alterations.

The sessions are grouped in four steps [15]. During the first step, the patient learns how to try to expel the fecal bolus; during these exercises, the patient tries to relax the anal sphincter to allow to the stool to pass through out. Simultaneously the patient learns how to increase the abdominal pressure. These exercises should be repeated after at least 1 min, several times, for 30 min. If fatigue occurs, the rhythm of exercises should be diminished. During this exercise, one shows to the patient how the correct modality to expel the stool is and is encouraged to continue practicing. In the second step, the patient is helped to become aware of the independence of abdominal and anal contractions. The patient has to contract the anal sphincter without contracting the abdominal muscles and later to contract the abdominal muscles without contracting the anal sphincter. During the third step, the anal relaxation is practiced. After few exercises with the anorectal balloon, the patient is instructed to perform the Valsalva maneuver. The fourth and last step is the forced push to correctly expel the balloon. This movement starts with a diaphragmatic aspiration followed by a respiratory blocking; pushing the balloon has to be energic, progressive and direct. The abdomen of the patient has to become convex. The aim of this maneuver is to obtain three steps elimination of the rectal content: balloon during feedback exercises, feces in real life. The three steps are: anal sphincter relaxation, aspiration of the diaphragm and apnea, correct pushing maintaining the sphincter in relaxed state.

These sessions of anorectal biofeedback should be repeated weekly. Patients can perform also at home these exercises, either without computer, or with transportable biofeedback devices. The length of the therapy is at least 3 months of weekly sessions followed by monthly sessions for another interval of 3–6 months.

3.2. Anorectal biofeedback in fecal incontinence

The fecal incontinence called also anal incontinence is a serious medical condition about which neither doctors nor patients like to discuss [1, 16]. Of organic or functional etiology, this condition is impairing the quality of life very much. Most people do not like to complain of this; therefore, the diagnosis is largely underestimated.

The biofeedback in fecal incontinence is recommended for incontinence caused by the dysfunction of the anal sphincter. In functional incontinence, the results are superior to the organic incontinence; therefore, it should be indicated in functional incontinence, while other conditions present only a relative indication. Incontinence following medullar section, like after traffic accidents, has almost no success at all [3, 17].

The principle of the intervention is to practice a kind of gymnastics for the anal sphincter in order to develop its capacity to retain the fecal material in the rectum. The procedure starts like for constipation by anorectal manometry. This can be carried out by the traditional standard anorectal manometry or better now by HRM. The investigation allows to estimate the degree of sphincter dysfunction and to measure the baseline values of the anal sphincter. In continuation, the patient is trained to be able produce voluntary contractions and to follow on the screen the change in anal pressure in resting and during these exercises. A therapeutic session may last up to 45 min and should be repeated weekly. Every new session should start by the baseline measurement of the anal sphincter pressure. The recordings of these values may encourage the patient and reinforce him/her. One can also estimate the value of this management for the improvement of symptoms. The patient is asked to perform similar exercises at home daily. There are 6–10 sessions recommended. If no answer is obtained, one should stop this therapeutic approach.

The strategy of approach in anorectal biofeedback for incontinence has three phases. The first step aims to develop the capacity to increase the amplitude of voluntary contractions. The patient follows on the screen his/her own contraction and contractile force. The contractions are repeated at 10 s and should be as strong as possible. Between contractions, pauses of 20 s are necessary. The second phase looks for the progressive extension of perineal muscle contractions. The contraction should be as long as possible, with rest pauses twice as long as the length of the contractions [3]. A third phase may be necessary: the proprioceptive reeducation. This phase means to let the patient progressively eliminate small amounts of air, with the aim to develop contraction reflexes at small volumes. To achieve this aim, the balloon is filled with about 60 ml air and the patient is asked to perform anal contractions when he/she feels distension in the rectum. Next steps are the exercises with decreasing air volumes in the intrarectal balloon, to increase the capacity of discrimination and retention [18]. There are good results with biofeedback, but relapse after the end of therapy is possible. We further describe a single center study to look for success and failure factors in anorectal biofeedback.

4. Original study

Anorectal biofeedback is an established method for the therapy of defecation disorders. However, contradictory data are reported with respect to results and sustainability of the results [18–20]. Given the possibility to work in the busiest center of gastrointestinal motility in our country, we aimed to evaluate the value of the anorectal biofeedback. Impressed by the fact that many patients included in our biofeedback program dropped out, we wanted to look for reasons of failure. Therefore, we analyzed cases of patients submitted to anorectal biofeedback, stratified on presentation and etiology of the medical condition and recorded success or failure, as well as reasons for these outcomes.

4.1. Methods

This was a prospective study conducted in a tertiary medical center with interest in functional and motility disorders; it is the single center in this country performing the anorectal biofeedback.

As subjects, we included in this study 20 patients. Eight of them presented with anal incontinence (2 males, 6 females, aged 46–71 years, median 55 years) and twelve patients with terminal constipation (6 males, 6 females, aged 58–78 years, median 67 years). All constipated patients presented only terminal constipation and not transportation constipation. The patients with anal incontinence were functional: 6 cases, or organic: 6 cases (2 after vaginal delivery, 1 after medullar trauma, 2 because of neuropathy). All these patients expressed their informed consent. The study was carried out according to the ethical criteria respected in any human research. They were included after anorectal manometry because conventional therapy was not helpful. Exclusion criteria were represented by the refuse to participate and contraindication to biofeedback. The biofeedback procedure was according to the description of the abovementioned methods. The constipated patients have previously been investigated for colonic transit with radiopaque pellets, and the results were normal in every case. Biofeedback sessions were scheduled twice per week for 2–3 months followed by monthly sessions for another 3–6 months. This rhythm is different from the rhythm described above, but we wanted to have more rapid results and to test the role of such intensive procedure. Patients were advised to repeat daily at home the exercises even in the absence of equipment for biofeedback. Following parameters were investigated (**Table 1**).

All these parameters were evaluated by a qualitative method based on interviews with the patients and using a structured interview appropriate for their understanding.

Descriptive statistics were used according to a commercial package.

4.2. Results

In anal incontinence, the results were favorable in 5/8 cases (60%). Patients were able to better retain the feces and were happy with the quality of life. The rest of three described no improvement. All had organic etiology. In terminal constipation, the outcome was as follows: 5/12 (42%) cases reported positive outcome: normalization or amelioration of bowel movement frequency, while in 7/12 (58%) patients the results were not good.

The patients with incontinence who could follow the biofeedback program till the end had a significant reduction of the number of stools in average from 5 stools/day to 2 stools /day. The result is explained by the reeducation of the anal sphincter. The cases with terminal constipation showed also a change in the bowel movements after the end of the program. Thus, subjects who finished the program and reported improvement showed in average 3 stools per

Adherence to the therapeutic program
Factors with positive or negative role in preserving adherence
Duration of intervention
Evolution of symptoms
Quality of life

Table 1. The parameters investigated.

week, while the patients who did not report any improvement after biofeedback remained with one stool per week.

The adherence to the therapy was also analyzed. It was assessed by recording the presence of the patient to the periodical biofeedback sessions and by interviewing the patients. Thus, it has been observed that among the 10 patients with positive results (5 with terminal constipation, 5 with incontinence), 8 had a perfect adherence, while 2 withdraw with 2, respectively 3 sessions before finishing the program. Those with negative results, in total 10 (7 with constipation, 3 with incontinence) had less subjects who finished the full program. The non-adherent patients presented in three cases terminal constipation and none incontinence. These data show that the adherence to a program of biofeedback in such a sensitive aspect as the defecation is very important for its success. The lack of rapid response may represent the cause of the drop out in several cases.

4.3. Factors influencing the results

We asked the 10 patients who presented favorable outcome on factors who influenced their adherence to therapy and can be determining the success of the biofeedback All mentioned that adherence was considered by them as an important success factor and that they were motivated to attend the biofeedback program. Factors positively associated with adherence to biofeedback therapy and thus with success are displayed in **Table 2**.

Patients who withdraw before the end were less susceptible to indicate positive results. Factors that negatively influenced the success and the adherence to therapy by biofeedback are displayed in **Table 3**.

Motivation to adhere to therapy
Higher education
Lack of invasiveness
Length of the biofeedback program
Lack of organic lesions

Table 2. Factors positively influencing the outcome of anorectal biofeedback.

Local pain caused by frequent catheterization of the anal orifice
Lack of obvious progress during the biofeedback sessions
Distance from the laboratory making the attendance difficult
Attempts to find out alternative therapies

Table 3. Factors negatively influencing the outcome of anorectal biofeedback.

4.4. Symptom evolution

The most embarrassing symptoms, that is, the incapacity to defecate, respectively to maintain feces, have been ameliorated after the biofeedback interventions. One can therefore conclude that the anorectal biofeedback is a useful method for treating defection disorders. Our study was a pilot study, including only a limited number of cases. The reason for this is the low frequency of cases accepting anorectal biofeedback and the reduced number of cases with severe conditions resistant to conventional therapy. This represents a limitation for our conclusions. The health-related quality of life has also been investigated, not by specific questionnaires but by qualitative interview. Addressing questions like these: are you happy with this therapy? Did biofeedback help you? Are your family members happy with this method? All 10 subjects with positive outcome answered to these questions in a positive way, emphasizing that positive outcome is associated with better quality of life.

5. Discussions and literature review

The main limit of our study is the reduced number of patients who accepted the program of anorectal biofeedback. On the other hand, we have to accept that the study was performed in the single center of this country performing this kind of management of defecation disorders. The indications for biofeedback are relatively scarce, and for some patients, there are no obvious early results, thus discouraging patients to continue next sessions. A success factor is the motivation of the patient, leading to increased adherence, and not all of possible patients are indeed motivated. Other patients refuse because they would have to travel long distance to the biofeedback laboratory. Our center is also very busy with usual manometric investigations; therefore, time left for biofeedback is reduced also from our side. But even in these conditions, our center is one of the few in East Europe working on anorectal biofeedback. Therapeutic results are important for the patients mainly in functional anal incontinence, but also for terminal constipation. The maintenance of the outcome in terminal constipation after the finishing of the biofeedback sessions is modest, and relapses have been described after the end of the interventions [19].

Better results are observed in the functional anal incontinence and almost nil in organic anal incontinence. About 70% of cases positively respond to biofeedback but there are not predictive criteria to predict well the outcome of anorectal biofeedback in incontinence. Nor in functional incontinence are the results perfect, even if carried out in supervised laboratories. At the end of therapy, relapse can occur in up of one quarter of cases with fecal incontinence. The relationship between the operator and the patient is very important for success of failure, given the very intimate character of this procedure. Lack of appropriate behavior or of empathy will lead to failure. Lack of adherence is another failure factor. Female patients respond better than males, also possibly because the nurses/technicians working in the biofeedback laboratories are of the same gender [20–23]. The complexity of the physiological phenomena involved in defecation renders the therapeutic approach by biofeedback a difficult task. We consider that not all executor muscles can be involved in exercises. As severe the motor alterations are, as difficult is to expect a favorable outcome.

5.1. The experience of other centers on anorectal biofeedback

In recent years, a number of useful papers have been published on this field, increasing the evidence on the use of anorectal biofeedback for anal incontinence and for terminal constipation. These titles complete the corpus of references accumulated in the last 30 years. A PubMed search using keywords anorectal biofeedback renders more than 400 titles. This shows the interest of the investigators on this topic.

A major paper recently published is the French consensus on therapy of chronic constipation, written by the National Coloproctology Society of France [24]. This working group arrived to a consensus stating that anorectal biofeedback should represent the gold standard for the therapy of anorectal dyssynergia, but only if no response to medical treatment can be observed. This consensus emphasized thus the role of biofeedback treatment of anorectal disorders, situation it as a second line intervention, given the ponderous characteristics of this procedure. In the author's recent review, the shortcoming of HRM in the diagnosis of anorectal disorders is described, while anorectal biofeedback is perceived as a useful tool for terminal constipation caused by dyssynergia. The effect of biofeedback training is explained by central effects. However, baseline manometric data do not predict yet the outcome of biofeedback therapy [25]. Unlike in our study, the author did not consider the role of logistical difficulty cause by distance from the venue of the biofeedback and manometry laboratory.

Another recent work coming from the very active and expert group around Satish Rao [26] evaluated the factors associated with response to biofeedback in anorectal dyssynergia. On a much larger group than our group, containing more than 120 subjects in a post-hoc analysis, the authors showed that anorectal biofeedback improved in more than 60% of the cases the terminal constipation and three quarters of them presented a correction of the dyssynergia. However, there were few predictive factors for success or failure, as either demographic characteristics of the patients or the severity of constipation and manometric baseline data did not differ between the successful and failure cases. Single differences were recorded in respect to satisfaction: lower scores in those who improved and in the used of digital expulsion, maneuver which predicted success. It means that expectancy and difficulty of expulsion are associated with better effect of the biofeedback therapy [26]. Anorectal biofeedback may be performed according to different strategic steps, depending on the experience of each center. But we still need comparative studies to decide which technique is more performing. An attempt to find out which technique is superior was undertaken in a recent study [27]. In St. Marks Hospital, a randomized trial in four groups of anal incontinence was organized. Two groups of patients with incontinence were created according to the living area: urban or rural; each group was further subdivided into two subgroups: one included face-to-face interaction, while the other included telephonic interaction. The therapy lasted 4 months and showed improvement by biofeedback of incontinence, of psychological factors: that is, anxiety and depression, of quality of life, and of manometric data. This study carried out on 350 subjects showed that adding to the procedure of biofeedback an interaction either by face-to-face or by telephone intervention, there is no additional effect on incontinence but patients' satisfaction is higher. Unlike in our area, where living on country side is associated with withdrawing from the biofeedback program because of logistic issues, in this UK study it seems that living in rural area does not influence the outcome of biofeedback. This study is continuing an attempt which was published more than 10 years earlier [28]. In this older study, an attempt to evaluate and validate the interaction with the patient beside the technical procedure only was made. Biofeedback is an effective treatment for patients with fecal incontinence, yet little is known about how it works or the minimum regime necessary to provide clinical benefit. This study compares the effectiveness of a novel protocol of telephone-assisted biofeedback treatment for patients living in rural and remote areas with the standard face-to-face protocol for patients with fecal incontinence. The authors have created a strategy based on the offer of an initial face-to-face assessment before the standard anorectal biofeedback procedure; telephone interview to guide distance living subjects with biofeedback was also used. This strategy was compared with the standard intervention based on manometry, using an ultrasonographic signal for biofeedback. The study included more than 200 participants. More than 70% of them completed the treatment. From these, in more than 50% of cases, the patient rated themselves an improvement; the observers rated in more than three quarters of cases positive results in respect to fecal incontinence and quality of life. Nor in this case was the use of telephone superior to the standard intervention.

All these studies underline the long way from the beginning of the use of biofeedback for fecal incontinence and terminal constipation (dyssynergia). Not more than 10 years ago, systematic reviews of the methods were not able to find relevant and well conducted studies nor definitive conclusions. Thus, the Cochrane Review of 2006 looked for biofeedback interventions on fecal incontinence [29]. The collaborative group was only able to find out 11 eligible studies, including only over 550 subjects. Most trials presented methodological shortcomings, thus having conclusions that could not be accepted without reserves. In no paper could be reported any major improvement of outcome between any biofeedback procedure versus the standard non-biofeedback therapy. The Cochrane group considered the anorectal biofeedback superior to vaginal biofeedback in females with obstetrical history predisposing to incontinence. Thus, the authors concluded that the number of studies (at that time) was insufficient and the quality of most of them not good enough to warrant the use of biofeedback for incontinence. One year later, a British showed a similar reservation versus the biofeedback [30]. In 2012, another Cochrane report [31] dedicated to therapy of fecal incontinence was able to bring much better evidence. This time, the Cochrane collaborative group found 21 eligible studies including more than 1500 subjects. The quality of the studies was better. Some small studies showed the advantage to add exercises or electrostimulation of the sphincter to biofeedback. This time the newer method of sacral nerve stimulation was considered superior to conservative and biofeedback management. The authors were not very happy with the number of studies found, although its number was increased. The effect of biofeedback was inferior to nerve stimulation [31]. Of course, the outcome depends very much on the etiology of incontinence [1].

Anorectal biofeedback has its application also in pediatric patients. There are several papers reporting its effect on children [32–37]. From older studies with less enthusiastic data [33], now we have enough evidence on the benefits of anorectal biofeedback in children with fecal incontinence or encopresis, or respectively with anismus. The problem of the pediatric investigation is the reduced collaboration with small children. On the other hand, there are devices allowing to perform biofeedback at home.

The role of biofeedback in different applications has been recently emphasized by the fourth edition of the textbook of Schwartz and Andrasik [38].

6. Conclusions

Anorectal biofeedback is a useful method to reeducate the defecation and which is applied in incontinence and terminal constipation. Anorectal biofeedback has positive results in functional anal incontinence and moderate results in terminal chronic constipation. Motivation and high degree of education are factors positively influencing the outcome of anorectal biofeedback. Among failure factors, we should consider the difficulty of some patients to travel long distance to the biofeedback laboratory and unpleasant repeated manipulation of the catheters in the anal canal.

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Chapter 3

Collaborative, Social-Networked Posture Training with Posturing Monitoring and Biofeedback

Da-Yin Liao

Additional information is available at the end of the chapter

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Abstract

This chapter presents an application of biofeedback techniques to train people to be aware of their bad posture to timely improve the posture. We design and develop a collaborative, social-networked posture training (CSPT) tool, which is composed of a sophisticated wearable posture training headset, a training belt, a social network App and cloud storage and computing services. The wearable posture training headset is equipped with real-time sensors to monitor head and neck posture. The training belt is used with a smartphone to monitor the lumbar-spine and low back posture. Biofeedbacks of sound, voice and vibration in the smartphone are sent to people to remind their poor posture. In the CSPT App, people can glance over their friends' posture performance to encourage good posture. Experiment results show that the proposed approach is very effective in increasing people's good posture percentage of time. Social support and peer influences are important and effective to encourage the people in maintaining good posture and in being willing to spend longer time in wearing the posture training tool.

Keywords: biofeedback, posture training, head and neck posture, lumbar and low-back posture, collaborative training, social network, peer-influenced learning

1. Introduction

This chapter aims to develop a biofeedback tool to train people, especially K-12 students, to maintain good posture while sitting. The rapid rise of poor posture in students—the curse of modern era has drawn more public attention recently due to their long-lasting use of smartphones, tablets and computers in head forward flexion postures. The phrase *text neck* [1] is invented to describe the repeated stress injury to the body caused by poor posture and brought on largely by overuse of all digital devices. Chiropractors and spinal specialists worldwide have seen an increase in the number of young patients experiencing text neck. Text neck and its syndrome are threatening to turn today's children into a generation of hunchbacks.

Poor posture not only causes structural and spinal problems to people, but it can also lead to cognitive problems that may incur anxiety and depression [2, 3], especially to those emotional and sensitive people like teenagers. Poor posture of moving the head forward and bending down in a hunched position for typing or gaming imposes high pressure in the spine. The pressure increases drastically with every degree of head/neck flexing. Digitally savvy teens are likely the most affected because they use smartphones, tablets and computers the most. For head position of bending 45 degrees, the head exerts 22.5 kg, comparing with 5.5 kg in its normal position [4]. Keeping a good posture with the body aligned in a neutral position is the key to avoid straining the body. Posture awareness and timely improvement are important to stretch and relax the tense muscles. In practice, it is not easy to aware poor posture, not to say to timely correct the poor posture.

Based on biomechanical measurements and measurements of the physiological systems of the body, biofeedback is the technique providing biological information to patients in real time that would otherwise be unknown [5]. The idea is to provide individuals with increased information about what is going on inside their bodies and brains. A close field called *cybernetics* [6] deals most directly with information processing and feedback, which makes learning possible. From a cybernetic perspective, individuals receive clear and direct biofeedback about their physiology which helps them learn to control the corresponding functions. Applications of biofeedback techniques can be traced back to the late 1950s, in the United States with the convergence of many disciplines [7]. Biofeedback methods have been used for more than six decades in rehabilitation to facilitate gait retraining [8]. The growth of biofeedback has been evolving with the development of new, more refined techniques for providing individuals with feedback for specific physiological processes.

Biofeedback devices have been used successfully in improving head control and balancing in children with cerebral palsy [9]. The investigation results on the effects of biofeedback on the sitting posture of a 14-year-old girl with cerebral palsy indicate a significant improvement in posture [10]. Breen et al. [11] develop a biofeedback system for real-time correction of neck posture in computer users. All the six subjects have a significant decrease in the percentage of time spent in bad posture when using biofeedback. Mirelman et al. [12] use an audio-biofeedback training system with headphones and successfully improve patients with Parkinson's disease from dysrhythmic and disturbed gait, impaired balance and decreased postural responses. Franco et al. [13] develop a smartphone-based system to monitor the trunk angular evolution during bipedal stance and help the user to improve balance through a configurable and integrated auditory-biofeedback loop.

Prolonged poor posture could cause permanent pains in neck and shoulder, especially for older people. However, for kids and adolescents, the severity can be reduced through proper exercise of neck and shoulder. Taking frequent breaks at work with neck and shoulder stretches can boost our productivity and also help improve blood flow and relieve tension.

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To avoid neck and shoulder straining, it is important to be aware of and timely improve the posture to keep the body aligned in a neutral position, that is, a good posture.

Furthermore, to know is one thing and to do is another thing. For children on the brink of adolescence, posture awareness and maintaining a good posture is more difficult to achieve. Texting and gaming are very interesting to teens. The effects caused by poor posture are neither obvious nor immediate to people. Their sequelae of annoying neck and shoulder pains can only appear over a long period of time. Parents and teachers can frequently remind kids to sit and stand up straight. However, they are unable to stay aside with children all the time, and most young people do not like so. Adolescents are most influenced by their friends and classmates. As the first generation of the twenty-first century, current teenagers were born into an entirely digital world. They grew up with Internet connection and have been surrounded with new technologies—mobile phones and social network software all days long. No matter good or bad, collaborative social networks have become an integral part of their lives and open up a new way with peers and improve engagement as well as effectiveness to their activities.

In the childhood, kids learn a lot from their parents and other significant adults. But their influences become less as children grow up. Peers become most influenced to adolescents who adopt or mimic many behaviors of their peers in some social settings in order to be accepted by their peers. Teenagers urge encouragement and recognition from their peers. Several factors like what characteristics of the individuals are, how responsible the group members are, and so on, may have positive or negative influences on teens' imitation to their peers. The influences whether they are strong or weak are heavily relied on teens' trust to each other and their competition among the peers of the group [14, 15].

The twenty-first century born teens, the "*i-Generation*," are digital natives. Their learning and social networking are all with the Internet, mobile phones and social network apps. While technologies and software websites may rise and fade, social network software still plays an important role in the *i-Generation* for their identity formation, status negation and peer-to-peer sociality [16].

In both ethnographic and empirical studies, it is commonly observed that the behavior of individuals is affected by that of their peers [17]. Group interactions are an important influence on individual decisions. In education, the returns to programs such as athletics and art cannot be measured simply by their direct effects on grade points. The participation and group interactions among students are also important earnings. With harmonious social relations, academic achievement may be easy to attain, even in schools in the most disadvantaged neighborhoods.

Some researchers have conducted experiments in which subjects receive information about others' choices [18, 19]. In these experiments, a subject's choice depends on both subject's preference as well as others' choices. Brechwald and Prinstein [20] review empirical and theoretical contributions to a multidisciplinary understanding of peer influence processes in adolescence over the past decade. They identify five themes of peer influence research, including behaviors relevant to peer influence, peer influence mechanisms, peer influence moderators, integration of behavioral genetics, neuroscience and peer influence research. While most previous research emphasize on the dynamic, reciprocal associations between selection and socialization in adolescent peer relations, their review focuses predominantly on their socialization processes as the mechanisms in the past decade have continued to vary considerably due to new mobile and social network technologies.

It is difficult to detect and measure peer effects precisely. Peer effects are the average intra-group external effects which are identical on all the members of a given group. Due to the disaggregation and availability of data, the group boundaries for such peer effects are often random and varying. Calvó-Armengol et al. [21] propose a peer-effect model to relate analytically equilibrium behavior to network location. Their results show that the outcome of each individual embedded in a network is proportional to her Katz-Bonacich centrality measure [22, 23] at the Nash equilibrium. For each individual, the Katz-Bonacich centrality measure considers both her direct and indirect friends but puts less weight to her distant friends.

The term *social network* refers to the web of social relationships that surround individuals [24, 25]. Social networks are a social structure of nodes that represent individuals and the relationships between them within a certain domain. This research adopts social networks as the linkages between students. The closeness of students is embedded in an informal group where group members can provide social functions like informational, instrumental, emotional and appraisal supports to individuals. Social supports and collaboration can be very constructive to physical, mental and social health of individuals. The wide use of smartphones and social networking apps offer opportunities for the development of innovative interventions to promote physical activity. Ayubi et al. [26] develop a persuasive and social mHealth application designed to monitor and motivate users to walk more every day. Collaborative social networks open up new ways to work with peers and improve engagement and effectiveness to activities [27].

Publics, where norms are set and reinforced, play a crucial role in the development of individuals. However, society's norms and rules only provide the collectively imagined boundaries. People, especially teenagers, learn through action, not just theory. They are also tasked with deciding how they want to fit into the structures that society provides. Their social identity is partially defined by themselves and partially defined by others. The answer to why students joined social network sites is usually simple: "That's where my friends are." The rapid adoption of social network sites by teenagers in the United States and in many other countries around the world has drawn much research attention [28]. Centola [29] studied the spread of health behaviors through artificially structured online communities and the effects of network structure on diffusion. His research reveals that when participants receive social reinforcement from multiple neighbors in the social network, individual adoption is much more likely.

Social presence is shown to have an effect in different virtual learning environments [30]. Liccardi et al. demonstrated the social dimensions of a collaborative learning network, its formation, its presence and its influence on different social networks in education [31]. They found that group composition may affect how efficiently a group achieves its set goals. It is optimal that there are both goal-oriented group members and socially oriented people within the same network. Both are needed in order for a group to achieve its goals as well as experiencing the group as socially rewarding.

This chapter presents the research that uses biofeedback techniques to train people to be aware of their bad posture to timely improve the posture. We develop a collaborative, social-networked posture training tool which is composed of a wearable posture training headset, a posture training belt, a social network App and cloud storage and computing services. The wearable training headset is equipped with real-time sensors to monitor head and neck posture. The training belt is used with a smartphone to monitor the lumbar-spine and low back posture. The App provides biofeedbacks of sound, voice and vibration to remind students of their poor posture. In the App, students can glance over their friends' posture performance to encourage good posture.

This chapter is organized as follows. Section 1 describes the motivation and identifies the importance and challenges of this research. In Section 2, we present the techniques of posture training with biofeedback. Section 3 proposes the collaborative, social-networked posture training (CSPT) approach. Section 4 details the systematic design and integration of the developed posture training system. Section 5 presents the design of experiments to validate the effectiveness of collaborative, social-networked posture training. Experiment results are analyzed in Section 6. Finally, in Section 7, the concluding remarks are made with some future research directions.

2. Posture training with biofeedback

2.1. Biofeedback

Biofeedback is an autonomic feedback mechanism that gains awareness of physiological functions from the information measured by instruments [32]. Biofeedback monitors and uses physiologic information (e.g., hearing, vision, feeling) to teach people to change specific physiologic functions (e.g., posture) accordingly. A biofeedback mechanism involves measuring biomedical variables and relaying them to the user using either direct feedback regarding the measured variables with a numerical value displayed, or transformed feedback where the measured variables are transformed into an adaptive auditory signal, visual display or tactile feedback method. The majority of biofeedback therapy has focused on the treatment of upper limb and lower limb motor deficits in neurological disorders.

Figure 1 depicts the biofeedback posture training loop, where head, neck and lower back posture is monitored and biofeedback to the human sensory nervous system with sound, light and vibration in order to notify the people to improve her head, neck and lower back posture accordingly. In the biofeedback process, posture signals are first measured by sensory and filtering devices where filtered sensor data are generated and sent to posture estimator to construct the corresponding posture angles. The posture angles are used by fuzzy logic trainer to diagnose the posture and determine what alters (sound, light, or vibration) to biofeedback to the human sensor nervous system.

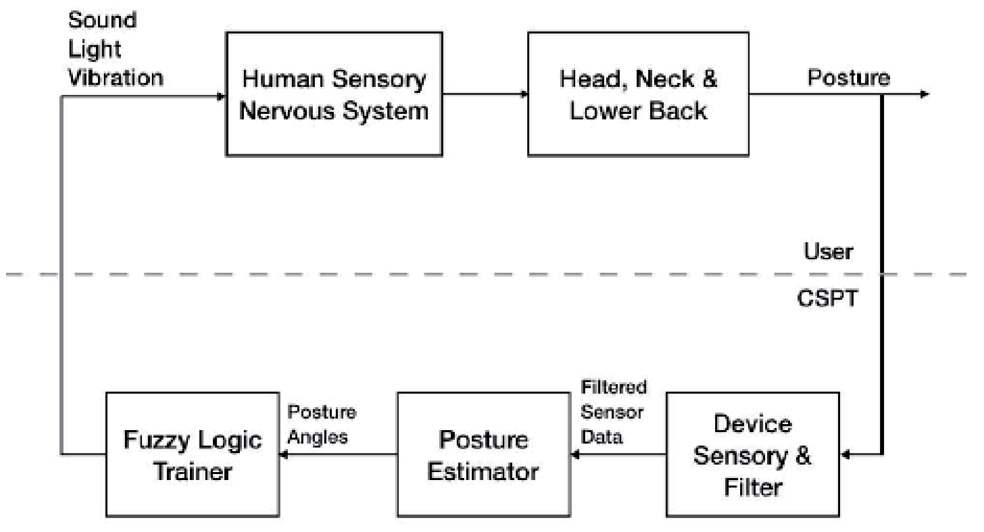

Figure 1. The CSPT biofeedback posture training loop.

Biofeedback is one of the popular clinical therapy approaches in healthcare. It aims at helping people take responsibility for the cognitive, emotional and behavioral changes needed to affect healthy physiologic change. Biofeedback is a learning process where many instruments are used to monitor the physiologic processes, measure and transform the measurement data into auditory, visual, or vibrating signals in a simple, direct and immediate way. In the biofeedback process, physiologic information is monitored and fed back through the biofeedback instruments. Biofeedback guided by the information provided by the biofeedback instruments is to enable and change the physiologic process of the people.

A well-designed biofeedback mechanism should consider the following conditions:

- whether the individual is capable of responding;
- how the individual is inspired to learn;
- how the individual is encouraged to learn; and
- whether the individual is given correct information about the results of the learning effort.

In this chapter, we adopt sounds, music, flashing light and vibration functions of smartphones in design of our biofeedback mechanism so that teens can receive timely notations when their bad posture is detected.

2.2. Posture monitoring

The purpose of posture training is to keep the body at its *neural* position. Several attempts have been made to define neutral of the head/neck and lumbar/low-back regions [33–42].

Many physiological landmarks such as tragus, canthus, eye socket, nation, or infraorbital notch have been used in measuring head/neck posture. Sitting is a common aggravating factor in neck, shoulder and low-back pains. Head/neck posture and cervical flexion are a complicated mechanism involving the skull and eight joints of C1 through T1 vertebrae. The head/neck angle often referred to as the degree of forward or peering head posture, or neck protraction is typically defined as the angle between vertical and a line connecting C7, T1, or the acromion to various skull landmarks. The C6-C7 vertebrae are important because they support and stabilize the head during its movement. When people sit in a good posture, the line of gravity should pass through the C6-C7 vertebrae. The C7-tragus angle, also known as the cranial-vertebral angle, is the angle between a vertical line passing through C7 and the line from C7 to the tragus. The lumbar angle (T10-L3 and L3-S2) [38] is typically defined to measure the ability to reliably position people into a neutral lumbar spine sitting posture.

In a study comfortable head and neck posture at computer workstations, Ankrum and Nemeth [43] suggested that the mean observed head tilt (Ear-Eye Line 7.7° above horizontal) and head/neck posture of 43.7° in C7-tragus against vertical are more flexed. Breen et al. [11] measure head and neck angle by placing an accelerometer device at the C7 vertebrae directly, as measuring the cranial-vertebral angle.

As the state of head/neck posture is unobservable, in this research, we adopt the C7-tragus and L3-S2 angle, as the metrics to measure head-and-neck and lumbar postures, respectively, as depicted in **Figure 2**. A comfortable head-and-neck angle is about 30° in a normal sitting posture and about 40° in using computer. A posture below 25° or beyond 50° is considered poor and need-to-be-corrected. A comfortable lumbar angle is about 5° in normal sitting posture. A posture below 0° or beyond 15° is considered bad.

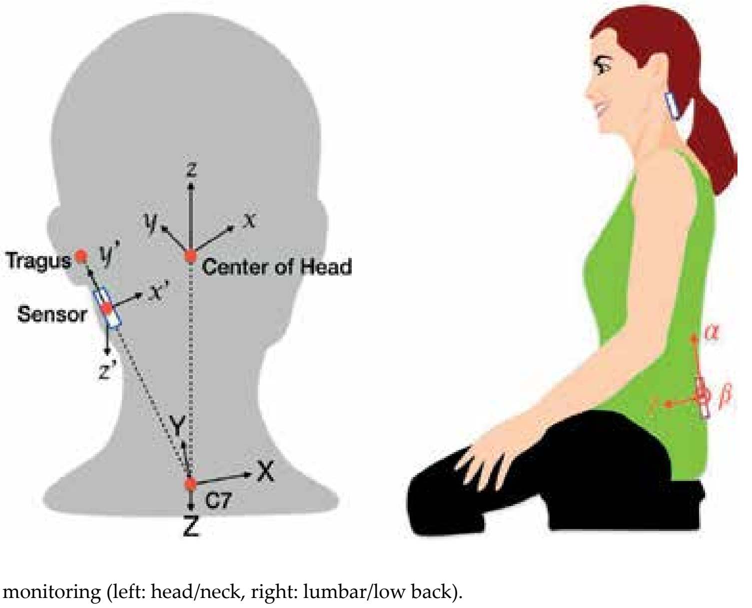

Figure 2. Posture monitoring (left: head/neck, right: lumbar/low back).

Figure 3. Posture training devices (left: head/neck training headset, right: lumbar training belt).

Let $G = \left[G_{x'} G_{y'} G_{z'}\right]^T$ be an acceleration vector, where $G_{x'}$, $G_{y'}$ and $G_{z'}$ represent the acceleration in x'-, y'- and z'-axis, respectively, and $G_{x'} G_{y'} G_{z'} \neq 0$. The tilt angle along the z'-axis, ρ, can be calculated by the following equation:

$$\rho = \cos^{-1}\left(\frac{G_{z'}}{\sqrt{G_{x'}^2 + G_{y'}^2 + G_{z'}^2}}\right) \tag{1}$$

With the accelerations measured and provided by the accelerometer, Eq. (1) can calculate the tilt angle of the sensor with respect to the earth.

The calculated tilt angle needs to be further transformed into the coordinate system (x, y, z) of the head, with its origin at the center of the head in **Figure 1**. The sensor tilt angle is then converted into the head/neck posture angle. The lumbar angle can be determined along similar calculations. The stream of the posture angles forms a set of time-series data, which are processed by the meta-heuristic based on Kalman filter and fuzzy logics algorithms [44]. Rather than placing an accelerometer in the C7 vertebral only such as in [11], our innovative design puts the posture angle sensor along with the C7-tragus line. The posture angle sensor is fixed with a fine plastic enclosure that is attached to a lanyard and connects to a creatively designed earhook in both sides of the ears. **Figure 3** shows the wearable training headset.

3. Collaborative, social-networked posture training

This research adopts the direct biofeedback learning mechanism that the individual gains control of the head and neck posture after receiving the biofeedback. Our biofeedback sensing and

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filtering device monitors real-time head/neck and lumbar posture and determines head craning forward or hanging downward as well as the forward low back. Using the biofeedback process with sound, light, or vibration, people receive alert and warning when their head/neck or lumbar posture is determined as bad. The biofeedback mechanism guides the people to identify, change and correct the head/neck or lumbar posture to right positions.

Operation scenarios of the collaborative, social-networked posture training (CSPT) system are summarized into the following five stages: *Preparation*, *Measuring*, *Posture Control*, *Analysis* and *Sharing*, whose details are described as follows:

Stage 1. *Preparation*.

A subject wears the posture training headset and the lumbar belt, invokes the CSPT App and places the smartphone in the lumbar belt.

Stage 2. *Measuring.*

The posture monitoring sensors start to monitor the posture status and send streaming data of posture angles to the receiving CSPT App or gadgets.

Stage 3. *Posture Control.*

The App or gadgets biofeedback to the subject with sound, music, vibration, or flashing light, when poor posture is determined. The subject responds and corrects the head/neck or lower back postures to the good positions timely.

Stage 4. *Analysis.*

Posture data are compiled, transferred and stored in the cloud for further analysis. The subject can query and review their own historical behaviors and analytic information in their smartphone or smartwatch.

Stage 5. *Sharing.*

Notifications of posture alerts and analytic data can be shared to subject's parents, guardian, or friends. Without violating privacy and security considerations, the data and analytics stored in the cloud can be shared to doctors, researchers, or public health workers to improve healthcare and welfare.

The collaborative, social-networked posture training (CSPT) framework is designed and based on three fundamental technologies of (1) real-time posture measuring, (2) biofeedback control and (3) social networks and collaboration. Monitoring and measuring of head/neck and lower back postures require techniques of sensing the movement and measuring the displacement of head/neck and lumbar positions in real time, with respect to their neural positions. Transformation among many coordinate systems is needed to reflect head/neck and lower back postures.

There have been some researches attempting to define the normal and correct posture of head, neck and shoulder, from various different points of view [45–47]. The idea along the neutral spine position—ears aligned with the shoulders and the shoulder blades retracted—is mostly used by many researchers and practitioners. This research defines the head/neck posture by the head-and-neck angle—the angle between true vertical (or horizontal) and a line connecting C7 vertebra and tragus (the cartilaginous protrusion in front of the ear hole). This research also defines the lumbar posture by the lumbar angle—the angle between true vertical and a line connecting L3, the middle of the five lumbar vertebrae and S2 at the level of posterior superior lilac spine. Both the head-and-neck and lumbar angles are measurable (or *observable* in the control theory context). We use both the head-and-neck angle and the lumbar angle to model the upper-body posture. The determination of a good posture depends on a series of sophisticated transformation and computation with the fuzzy logic combination of head-and-neck and lumbar angles. When a bad posture is detected and lasts for a short period of time, the biofeedback mechanism starts to send alerts and notifications to the wearing kid to adjust and restore to a good posture.

Biofeedback technology is based on the idea that people can get more control over those normally involuntary functions by harnessing the power of the mind and becoming aware of what is going on inside the body. Biofeedback facilitates relaxation. It can help relieve several mental and physical conditions that are related to stress. The posture training CSPT App provides biofeedbacks via sound, music, voice and vibration to remind teenagers of their poor posture.

Social connections—both quantity and quality—are crucial to mental and physical health. The reasons that we adopt social networks and collaboration technology to encourage posture training of teens have three folds: first, Internet users, especially *i-Generation*, are now spending several hours per day with their peers on social media platforms. Second, information sharing has become an indispensable part and is more dynamic and more connected in social media revolution. Social networks platforms make it easy for teens to share their experience and performance of their maintaining good posture to their peers. Third, teens interact with their peers and receive appraisals and encouragement from their friends through social networks so that positive social support and competition are timely and reinforced. Posture training and collaboration among the teens is thus achieved.

As depicted in **Figure 4**, the CSPT framework consists of four building modules—posture monitoring wearables of posture training headset and lumbar belt, a smartphone, a social network CSPT App and CSPT cloud services. A posture monitoring device implemented with an embedded posture-sensing system is devised to monitor the neck-and-head posture in real time. A smartphone is used to provide interface to the device. A special-design lumbar belt is used to hold the smartphone so that the low back posture can be properly measured. While the subject wears the posture monitoring wearables, the corresponding posture data are filtered, streamed and sent to the CSPT App for posture estimation and determination. Once a bad posture is determined, the CSPT App sends biofeedback signals of sound, music, flashing light, or vibrations to notify the wearing kids to adjust and improve their posture timely. User's posture data are sent to the CSPT cloud for storage and further processing. The statistics and analytics of posture behaviors by individuals and groups are provided by CSPT cloud computing. Teens as well as their parents, teachers and friends can overview these posture behaviors in the CSPT App, including peers' appraisals and encouragements. Strong and interesting engagement to posture training activities can be established and continue via good peer support and positive peer competition.

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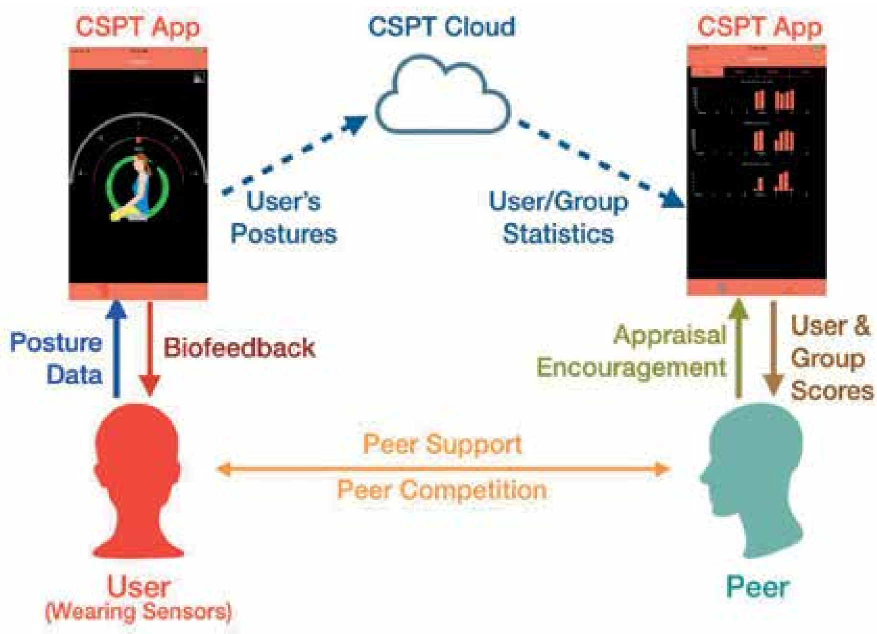

Figure 4. The CSPT framework.

4. CSPT system design

The CSPT system consists of three subsystems: wearable posture training headset, social-networked posture training App and cloud services subsystems. Each subsystem is described as follows:

4.1. Wearable posture training subsystem

The wearable posture training headset subsystem is a sophisticatedly designed, earhook headset that is equipped with a real-time sensory system to monitor head and neck posture. The sensory system is an embedded system with dedicated hardware of accelerometer functions to detect and transmit the three-axis acceleration values of the device continuously. We adopt a 32-bit ARM Cortex M0 microprocessor [48] as the core of the embedded system. The microprocessor operates at CPU frequencies of 30 MHz and equips with 16kB of flash memory and 4kB of SRAM with AES 128-bit encryption.

A three-axis accelerometer is used in the embedded system to detect the attitude of the posture monitoring hardware, that is, its pitch, roll and yaw. The accelerometer is featured by its ultra-low power, high performance, micro-electro mechanical system (MEMS) motion sensor for lightweight and long-lasting applications and wearable devices. The accelerometer is used to measure the accelerations of three axes of pitch, roll and yaw and generate 16-bit data streams with output rates in hundreds Hertz. The analog readings measured by the accelerometer are first digitalized and then sent to the 32-bit microprocessor through serial communication interfaces of I2C (Inter-Integrated Circuit) or SPI (Serial Peripheral Interface). The received signals are then filtered and calculated to generate the tilt angles of the posture monitoring hardware with Eq. (1).

4.2. Social-networked posture training CSPT App subsystem

The social-networked posture training CSPT App subsystem is the main interface to posture training users and their peers. The CSPT App provides a number of functions including gateway of sensor data, posture data processing, fuzzy logics and posture determination, biofeedback initiating, data feeder to the cloud and presentation or rendering the historical and analytic posture information. The CSPT App is also a social networking graphical user interface (GUI) for posture training and information sharing among individuals and their peers.

As the key element in the CSPT system, the CSPT App executes and manages many tasks, including signal processing, posture determination, biofeedback and data management to cloud computing. It receives, processes and further transmits posture angles. It determines the good posture and decides to notify when biofeedback is needed. The CSPT App renders the analytic data streams from the cloud, manages identity and access control and does encryption/decryption of the data and user ID, as the platform for chatting, messaging and file sharing of social network functions.

The CSPT App is also a notifier for people to receive alerts or warnings so that they can correct the poor posture immediately. When a biofeedback is enabled, the CSPT App plays default or customized sound or music and makes the smartphone vibrate for a short period of time to notify the users to change their bad posture. The smart feature of the CSPT App enables the intelligent detection of wearable devices so that no sound, music or vibration is made when the wearable devices are not attached or out of their operating space like being left on the desk. To avoid annoying, the notification period increases when the bad posture continues.

The friendly GUI of the CSPT App is the core to people. The CSPT App renders the analytic data streams from the CSPT Cloud. People can watch and be aware of the real-time status of their postures and realize how good or poor their head/neck and low back postures are. People can also glance over their peers' posture training performance. Based on the historical data from the cloud, people can explore their analytics, including the percentages of maintaining good postures, total wearing times and average response times. The resolution of time scales spreads from day, week, month, to year. **Figure 5** depicts two screenshots of the CSPT App GUIs for the analytic report in the day (right) and for poor posture (left), respectively.

The light speed advance of mobile technologies always makes the smartphone markets and products dazzling. Backward compatibility is a non-negligible issue in developing smartphone apps, especially to the Android platform. Not every smartphone is fresh new and up-to-date. For young kids and teens, some of them may use cheap-but-obsolete styles or their parents' used smartphones. These legacy smartphones usually use old operating system (OS) and supporting interfaces that are even unable to upgrade. In order to maximize the compatibility to most existing smartphones, the development of the CSPT App subsystem has to consider various and many smartphone models from different manufacturers with different OS and software versions. As compared to the development of other subsystems, it is so tedious and challenging.

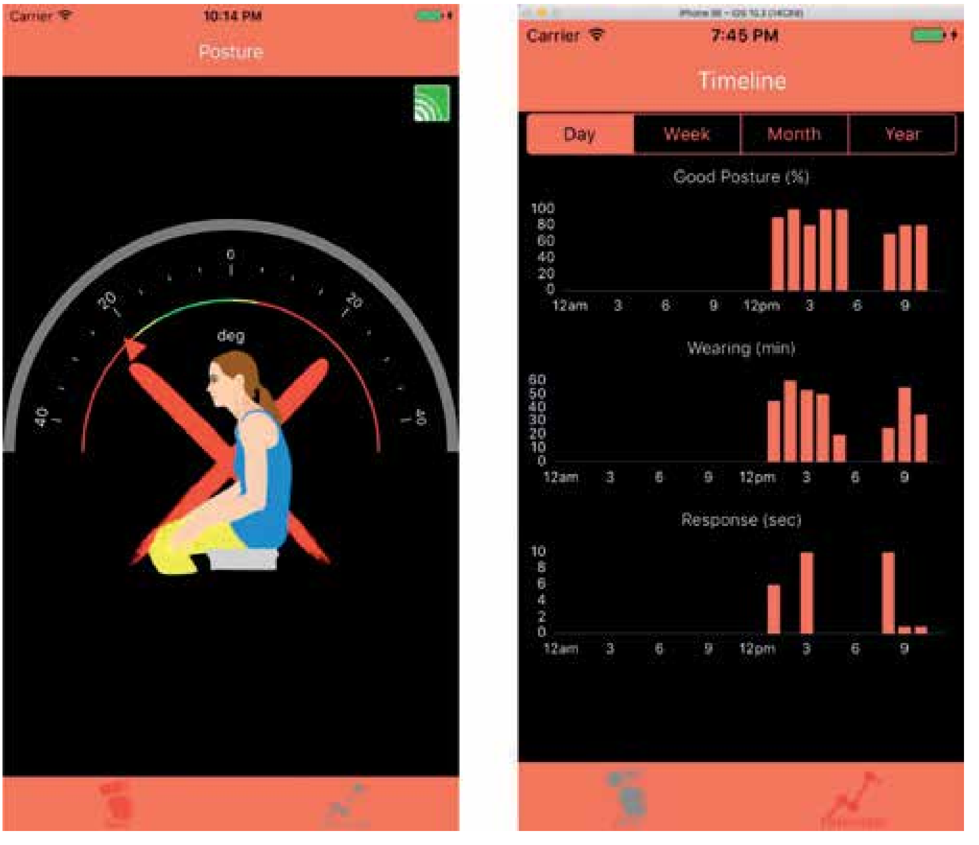

Figure 5. Screenshots of CSPT App (left: poor posture, right: analytics).

4.3. CSPT Cloud Services subsystem

The CSPT Cloud Services subsystem manages user data, generates the analytics and provides social network services for posture training. Web services with the on-demand computing platform operating from 12 geographical regions across the world are adopted to provide the CSPT cloud services. NoSQL databases are built to manage user data, posture angles and analytics.

5. Experiment design

To validate the effectiveness of the proposed CSPT posture training framework, we design several experiments considering a group of six teens in a middle school in San Jose, California, USA, whose families are similar in their race of Asian Americans, socioeconomic status, occupational status, family size, housing, geographic location, ethics and morals. The six teens denoted as "C," "E," "GC," "GW," "H" and "L," by the first letter(s) of their names, respectively, are all 8th graders in the school and friends to each other. They study, play and chat in very close proximity to each other of the group.

5.1. Experiment method

Our design of experiments has four objectives as follows:

- to validate the effectiveness of the developed posture monitoring wearables;
- to validate the effectiveness of the proposed CSPT posture training framework;
- to study the effects of peer influences on posture training; and
- to study the effects of biofeedback on posture training.

The following three scenarios are designed for the experiments as follows:

Scenario S1: Both the biofeedback and social network functions are DISABLED.

Scenario S2: Biofeedback is ENABLED but social network function is DISABLED.

Scenario S3: Both the biofeedback and social network functions are ENABLED.

We conducted the experiments in each student's home with the guidance of students' parents. Each student was equipped with a wearable training headset, a training lumbar belt and the posture training CSPT App. They were asked to wear the training headset and lumbar belt for at least 60 min a day. The experiments were carried out from October 17th to 21st and from October 24th to 28th, 2016, detailed as follows:

Scenario S1 was conducted first on October 17th and 18th. Scenario S2 was followed and conducted on October 19th, 20th and 21st. Scenarios S3 was conducted from October 24th to 28th. Before each experiment, all the teens do not know about any details of the three scenarios. For the first 2 days (October 17th and 18th), each teen was asked to wear the headset and belt without knowing anything about biofeedback and social network functions. They were told and became aware of the biofeedback music, voice and vibration in Day 3 (October 19th). On October 24th, the teens were asked to download App's social network function where they can glance at their friends' training scores. During the experiments, all the teens knew who of their peers are participating in the experiments. Teens can share their observations and knowledge to each other during the entire experiment period.

5.2. Experiment data collection

The experiment data of time-series posture data are generated by the wearable devices, collected by the CSPT App and sent to the CSPT Cloud. The experiment data are transferred through a RESTful [49] protocol-based application programming interface (API) to the Cloud. We utilize Node.js [50], featured by its fast, scalable and easy implementation for API, mobile, web and Internet of Things (IoT), in implementing the mobile API to access the data and services.

6. Experiment results

The effectiveness of the posture training tool and the proposed CSPT framework is deliberately reviewed and validated throughout the experiments. **Table 1** shows the experiment

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Date	Good posture (%)						Wearing time (min)						Scenario
	C	E	GC	GW	H	L	C	E	GC	GW	H	L	
Oct. 17	65	85	80	78	74	87	60	61	60	63	61	74	S1
Oct. 18	68	88	82	76	77	85	61	64	60	62	61	77	
Oct. 19	89	95	96	95	90	98	60	72	62	62	62	75	S2
Oct. 20	90	92	95	92	95	99	61	68	68	61	64	82	
Oct. 21	85	95	90	93	92	98	61	69	65	60	61	86	
Oct. 24	92	100	98	100	98	100	62	113	85	96	89	127	S3
Oct. 25	95	100	99	100	99	100	87	151	90	111	120	149	
Oct. 26	94	100	100	99	100	100	102	155	121	160	158	156	
Oct. 27	99	100	100	100	100	100	115	169	162	176	159	180	
Oct. 28	99	100	99	100	100	100	152	192	170	179	167	190	

Table 1. Experimental results.

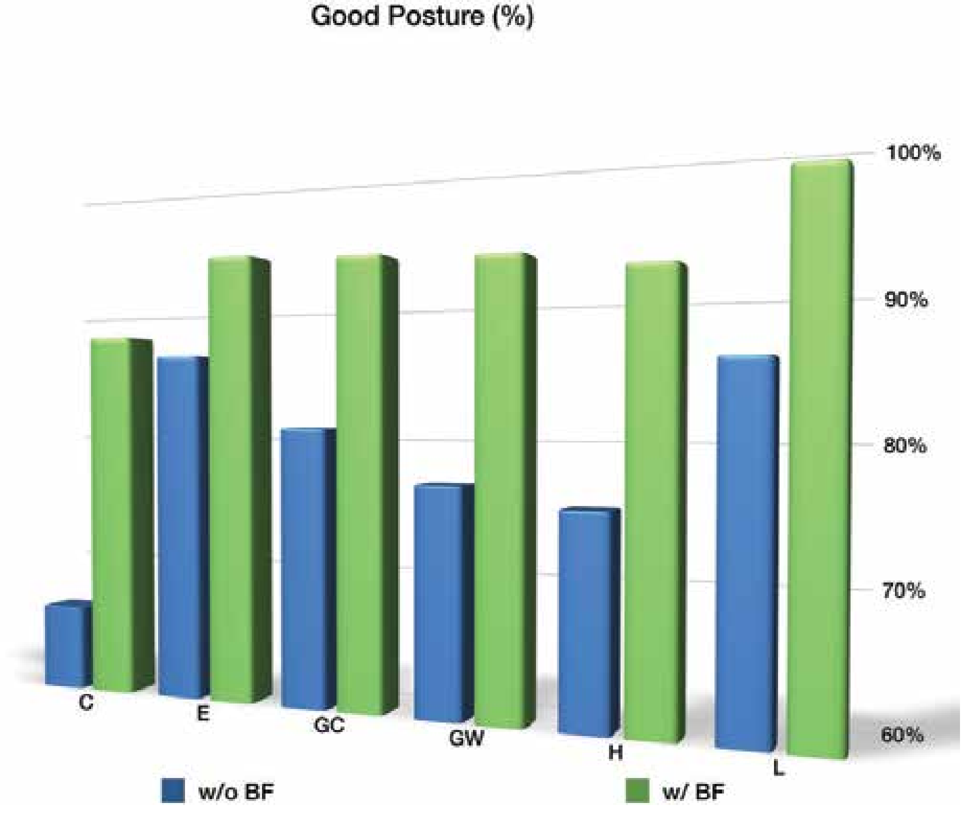

Figure 6. Comparison of results without and with biofeedback.

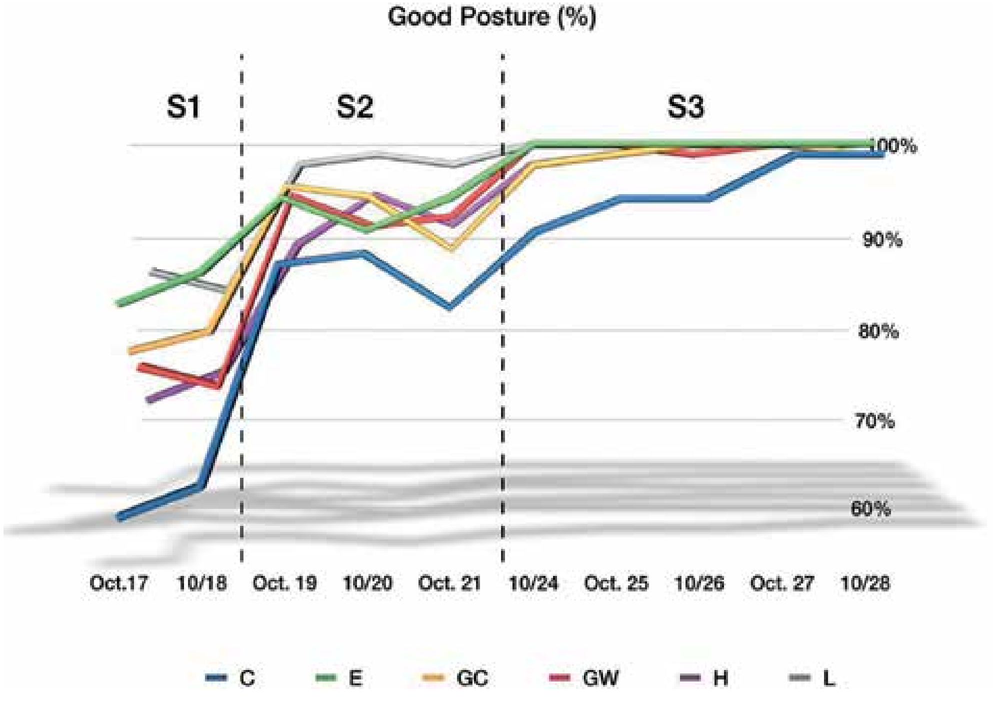

Figure 7. Results of good posture percentages of time (%).

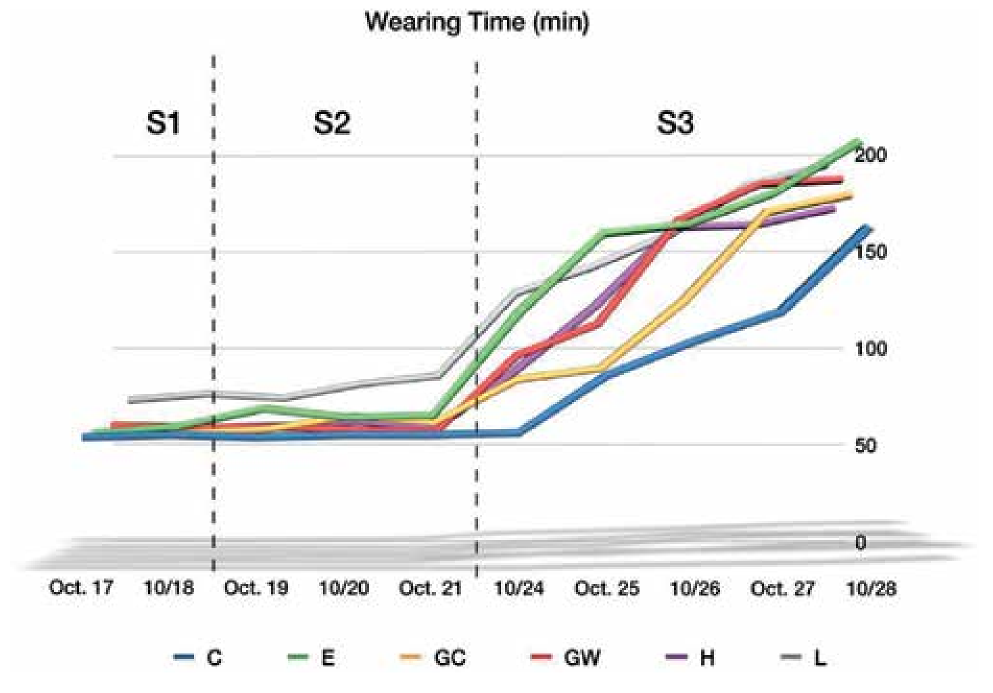

Figure 8. Results of wearing time (minutes).

results of percentages of good posture (%) and the total wearing times (min) of the six students. Comparison of average good posture percentages between Scenarios S1 (without biofeedback) and S2 (with biofeedback) is depicted in **Figure 6**. Note that biofeedback does facilitate the increase of percentages of good posture for all the teens significantly. Similar results on the effectiveness of biofeedback on forward head posture improvements have been observed and reported in the literature [11, 45].

Figure 7 demonstrates the results of percentage (%) of time in good posture of each teen in Scenarios S1, S2 and S3. Obviously, teens are encouraged by peer influences from their social network and social support in maintaining good posture. Results of wearing times of each teen in Scenarios S1, S2 and S3, as depicted in **Figure 8**, comply with the same observations. As compared to teens' wearing times in Scenarios S1 and S2, peer competition and encouragement do promote longer wearing times in Scenario S3, respectively. The proposed collaborative, social-networked approach is effective for teens of peer influences to be supported, encouraged and collaborative to achieve the goals of maintaining good posture.

7. Conclusion

This chapter develops a posture training tool to invoke people' awareness of their bad posture so that they can timely improve their poor posture and maintain good posture while sitting. A collaborative, social-networked posture training (CSPT) approach is used in the design of the posture training tool. Three technologies of real-time posture monitoring, biofeedback and collaborative social networks are adopted in the CSPT framework, which is composed of a sophisticated posture monitoring headset, a training lumbar belt, a smartphone, a social-network CSPT App and cloud services. Experiments are conducted to validate the effectiveness of the proposed CSPT framework with a group of six middle-school teenagers. We design three testing scenarios to explore the effects of biofeedback and social networking. Our experiment results indicate that the proposed CSPT framework with posture monitoring and biofeedbacks are effective in increasing the percentage of time in good posture for each teen in the group. Experiment results also show that peer influences and social support are crucial and effective to encourage the teens in maintaining good posture and being willing to wearing the posture training tool for longer time.

Some mHealth apps like iOS Health [51] and Google Fit [52] and other mobile wearable fitness devices [53] are available in the market. To our best knowledge, none of them implement social networks or social media functions. Future research may develop an integrated social networks platform to provide health services or bio-sensing functions of heartbeats, blood glucose and electrocardiogram (EKG). Although the motivation of this research is preliminarily for posture training while sitting, the applications of the proposed CSPT framework and the devices are not limited to sitting posture only. They can be applied to other workplace environments, sports and performance psychology. Further research directions may also extend the developed biofeedback techniques to applications like driver sleepiness detection, core stability training, therapeutic, fitness and so on.

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Chapter 4

Bridging the Clinic-Home Divide in Muscular Rehabilitation

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Hugo Humberto Plácido da Silva

Additional information is available at the end of the chapter

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Abstract

Musculoskeletal disorders (MSDs) are a major worldwide problem that regularly affects up to a third of the general population. In the US alone, the market for physical therapy was valued at ~32 B USD in 2015, recently growing at ~6% YoY. Besides the direct impact in the quality of life and cost of treatment, MSDs accounted for one-third of days lost due to work-related ill health and injury in countries such as the US, UK and Finland, with ~20% of leaves of absence due to MSD injuries being above a 1-month period. To help mitigate these issues, in this chapter, we describe a novel biofeedback system designed to support part of the rehabilitation processes at home, further extending the state of the art with an app-driven and cloud-based approach. This approach enables the therapists to remotely monitor the progress of the patients and near instant adjustment of the training program from the clinic. The system consists of low-cost wearable devices for electromyography (EMG), a set of user-friendly smartphone apps, and a cloud-based service that allows the patient to have a remote evaluation of his/her performance, handled by the clinical therapist that prescribed the treatment.

Keywords: physiotherapy, biofeedback, telemedicine, serious games, cloud computing

1. Introduction

1.1. Musculoskeletal disorders today

Musculoskeletal disorders, known as MSDs, are injuries or pain in the body joints, ligaments, muscles, nerves, tendons, and structures that support limbs, neck, and back. MSD pain is a global challenge, since it affects up to three-quarters of the overall population [1]. It is the most common cause of severe long-term pain and disability in Europe with a tremendous social and economic impact, as evidenced by the following:

1. people with musculoskeletal pain are frequent visitors to primary health care centres, hospitals, and paramedical institutions;
2. within the EU, MSDs represent 15–20% of consultations in primary care [2];
3. MSDs are the major cause of work absence or productivity loss, disability pensions, early retirement, and increasing need for social support;
4. the estimated losses resulting from a decreased productivity due to MSD injuries represented 2.9% of the GDP in the US from 2004 to 2006 [3];
5. back, shoulder, and neck pain affect nearly 40% of adults reporting MSD pain worldwide.

For these reasons, MSDs are recognized as a priority by the EU Member States and European Social partners, according to European Agency for Safety and Health at Work [4]. Physiotherapy is the main non-pharmacological clinical MSD treatment. However, a host of common problems plague physiotherapy treatment today, namely.

1. inconsistent outcomes;
2. time to recovery (i.e. treatments take too many sessions);
3. patients spend considerable amounts of time visiting the clinics to receive treatment, often during working hours.

For these reasons, the majority of patients abandon or must repeat treatment within a year. The low success rate and inconsistency of treatments for MSD pain lead to increased financial costs, both for the patient and for health reimbursement systems.

1.2. Treatment methodologies

According to the National Health Service (NHS) in England, physiotherapy practice to address MSDs can include a variety of different treatment and preventive approaches, depending on the specific condition. On a first session, the physiotherapist will assess and determine together with the diagnostic provided by the doctor (if the patients visited a doctor before) as to what kind of intervention the patient may need.

The main approaches generally used by physiotherapists are (1) education and advise (i.e. providing general and specific guidance on ways to improve well-being, by taking regular exercise or to reduce risk of pain or injury during daily life activities); (2) manual therapy (e.g. mobilization, massage, and manipulation of body tissues and structures to relieve pain and stiffness, improve blood circulation and promote relaxation, and improve movement); (3) electrotherapy (e.g. transcutaneous electrical nerve stimulation—TENS, ultrasound, iontophoresis, and treatments alike); (4) movement and exercise (e.g. specific training activities to help improve mobility, function, and decrease pain levels).

Within the later approach, exercises are often tailored to a specific anatomic region, and in many cases to patients even, aiming to prevent a specific injury or to treat localized symptoms by improving movement and strength. In addition, exercises usually need to be performed with specific objectives and repeated regularly for a certain period of time. The need to automate these processes and provide extra input to guide the patient while performing the exercises, allowing an accurate and correct performance, motivated the introduction of biofeedback techniques.

A common type of biofeedback rehabilitation is surface electromyography (sEMG), in which one or more muscles are assessed to show (e.g.) graphics and/or play sounds in real time, providing information to both patient and physiotherapist as to whether the correct muscle groups are active or relaxed and the precise levels of activation. This approach accelerates the learning process for a new mobility task, helping also to avoid re-occurrence by making sure the patient effectively learned the new pattern [5–7]. While re-education by means of biofeedback has been mostly adopted at the clinical level, novel paradigms are enabling its extension to patients' homes, as described throughout the next chapters.

2. Re-education via biofeedback

2.1. At the clinic

Biofeedback is a general concept that involves every external input given to the patient in order to enable him/her to learn how to change physiological activity, to facilitate his/her performance, and improve health and performance, where sEMG is also included [8]. For the case of MSDs, this technique is particularly useful to give the correct perception about the dynamics of the muscle groups that are being exercised. As a result of the conditionings introduced by the disorders, very often patients perform a specific task or movement full of compensations,[1] with a low participation of the muscle groups needed to correctly converge to a full recovery scenario with mobility patterns that can be considered clinically normal.

It is common to see patients alone in the physiotherapy gym, performing the exercises in a highly distorted way (e.g. as fast as they can), which often contributes to worsen their condition. Using sEMG biofeedback equipment helps to prevent this kind of situations, ensuring that patients have specific indications to follow and get motivated by visual and acoustic aids, while knowing that in the end the physiotherapist will have access to all that was done when the patient is alone. This puts the patient in charge and also increases his/her responsibility regarding the recovery process (**Figure 1**).

At a clinical level, sEMG biofeedback is first used as an assessment tool, allowing an objective analysis of movement patterns (e.g. activation sequences and timings), levels of electrical

[1]Compensation occurs when the muscles responsible for a specific movement are not working (due to pain, neurologic reasons, or simply by altered movement patterns related with specific sport gestures or daily activities), and other surrounding muscles replace their activity, in order to allow functionality.

activity and muscles participation in different movements. This gives the first information, combined with other tests performed, to define an exercise plan and specific exercises to help decrease symptoms. After this initial step, we get to the main purpose of the tool, which is to guide exercise execution in real time. Specific targets can be defined to challenge the patient and to make him/her climb to the next step in the recovery process. Recorded data from assessment and training can be compiled into a final report so that progress in-between rehabilitation sessions at the clinic is objectively tracked.

The use of sEMG biofeedback equipment is associated to a 50% faster recovery time in conditions such as shoulder impingement and scapular instability (average of seven sessions), and in a reduction of the recurrence of 75% after 2 years follow-up (9% recurrence) [5].

2.2. At home

The hiatus introduced by the spacing between rehabilitation sessions is a known limitation to a faster and more effective recovery, leading to the recommendation by therapists of specific exercises to be performed as homework. These work as an extension of the training performed at the clinic and can also be adequate after clinic sessions are completed, as a way to manage pain in the long term or as prevention. Carrying the biofeedback approach to home training is a great advantage for recovery success, reinforcing the goals achieved at the clinic and working as a contribution to get results faster. It is also a more convenient approach to allow busy patients to get treated, decreasing the needed visits to the clinic, as the therapist can access all training results remotely and also adjust the exercise plan if needed.

Home training exercises can be aided by tools as simple as paper guides (e.g.), or more sophisticated like mobile applications and purpose-built sensors. Regardless of the tools, the goal is to complement the rehabilitation process while being away from the clinic. However, many times people easily drop out of the home training programs or change the programs themselves (e.g. thinking that more repetitions are better), without the therapist having a way of assessing neither the compliance nor the quality of the performed exercises.

2.3. The clinic-home divide

Typically, home training is a simple extension of the clinic session, based on printed images and parameters that constitute fairly monotonous procedures, which allied with the complexity of the motor learning process makes patients give up most of the times. Patients easily feel that they are not performing the exercises correctly, do not have professional guidance to help and give feedback, and it is easier not to compromise with homework exercise. Fortunately, technology walks side by side with progress in medicine, and new solutions appear every day. One solution for the above problem is the development of sEMG sensors that collect muscular electrical activity and, in conjunction with mobile apps, for example, allow patients to monitor their muscle behaviour in real time. Nowadays,

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technology can be made very friendly and easy to use; however, until recently, the devices were too cumbersome, complex and not so adaptable to the independent use by the patients. Furthermore, it was difficult to access the home sessions remotely and be aware of what was done at home by the patient.

In the following sections, we describe how home training is no longer isolated and unsupported. Patients can exercise at home with the confidence that the way they are mobilizing their muscles is correct and not potentially harmful. Home exercises are described as effective in accelerating the rehabilitation process [9]. In our approach, the process starts from a face-to-face session, where all sEMG assessments are performed by the physiotherapist, a treatment plan is designed, initial exercises are performed and a home plan is defined in order to continue what was started at the clinic. Once at home, the patient logs in his/her mobile app, checks where to apply the EMG sensors guided by visual cues on the app, reviews the list of exercises through example videos and executes all defined exercises supported by real-time biofeedback. In the end, a direct message can be sent to the physiotherapist via the application, to express how easy/hard was the session, how is the patient feeling, and so on, so the therapist can make sure the patient performs the exercises correctly and in an adequate quantity and change the prescribed plan if needed. Regular visits to the clinic must be scheduled, according to patient-specific needs and progress.

This is an important paradigm shift to the way physiotherapy can be seen and approached. As presented next, a modern infrastructure has been designed especially to support home rehabilitation sessions in an integrative way, by means of (1) wearable and user-friendly miniaturized sEMG sensors; (2) intuitive mobile apps prepared to easily guide the patients on the execution of the pre-configured exercises prescribed by their physiotherapist (in a serious game approach); (3) objective reports shared with the physiotherapist with the possibility to send messages about the session by the patient, which promotes a fluid communication between patient and physiotherapist; (4) online dashboards to access the home training results and make changes to the prescription, so that the next time the patient logs in the

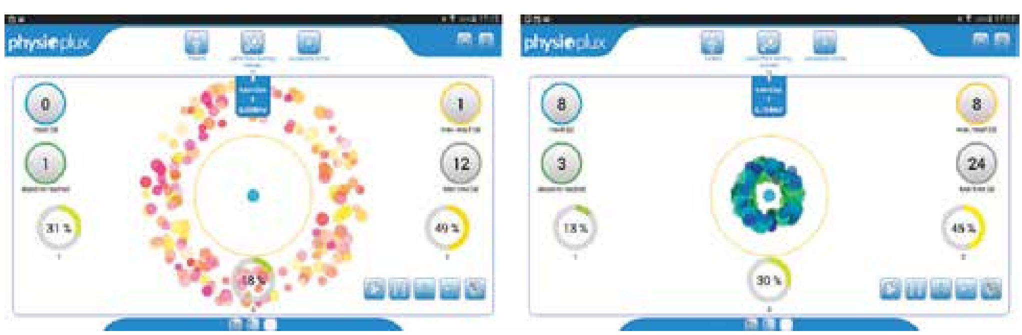

Figure 1. Electromyographic (EMG) biofeedback software with a concentric circle graphic relative to one muscle, to guide the patient to execute the exercise correctly and within the needed time. The goal is to contract the muscle in order to put the red dots inside the circle, making them green. The opposite, to help the muscle to relax, is also possible.

home training app, changes will appear, adjusting the app to patients' exercise needs. With these solutions, the link between clinic and home training is straight and the knowledge regarding the activities performed by patients at home is direct, facilitating the configuration of follow-up physical therapy sessions and reducing the number of visits to the clinic whenever possible.

3. Enriching the clinic-home loop

3.1. Wearable sensor nodes

There are several wearable sensors available off the shelve, as a preference, small wireless sensors are more adequate, to simplify placement and allow free range of movements with no restrictions. To communicate with the mobile apps, Bluetooth is commonly used, so no wires at all are needed.

We can also see devices that not only have EMG sensors for biofeedback, but also have accelerometers and other sensors to provide positioning feedback and correction, which, although do not tell the whole story in terms of what's happening internally, can be a much simpler usage scenario for the patients (**Figures 2** and **3**) (**Table 1**).

3.2. Serious gaming

The serious gaming concept is a good description of what is modern biofeedback. Appealing and intuitive graphics are available to facilitate the knowledge about the intended movement or muscular contraction. The idea is to captivate the patient's attention and motivate them to keep doing the exercise with dedication and in higher levels of demand than normal. It is like a game against the self, where the patient wants to cross over his/her limits and comfort zone. This principle is part of the sEMG biofeedback tools used in the clinic and at home, where the objective is always to achieve the goals defined by the physiotherapist for each specific exercise, creating a more engaging experience [10].

Nevertheless, considering that excessive exercise can be harmful, there is a real need for defining the exact parameters at which home training should be aimed for. Indeed, a home application enables autonomous training in a controlled manner, not only allowing patients to train at the right intensity and in a guided way but also providing them with the confidence and motivation required to adhere to and finish the plan. In our approach, the display includes a straightforward image showing where to place the sEMG sensors, as well as a bar chart, asking to push or relax the monitored muscles; at the same time, the counter counts down on the time for each repetition and on the number of series. This process will be repeated for each exercise prescribed, and, in the end, a final report shows a score based on the repetitions concluded, also aiming to motivate the patient. In addition, it is of utmost importance to give the user a number of tools to aid the exercise execution. Such is the case of an option that dynamically adjusts the exercise goals on the fly, taking into consideration the values that are

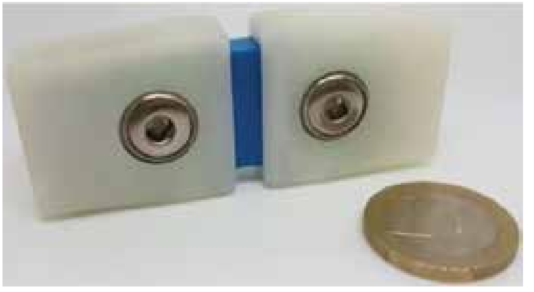

Figure 2. Example of a possible form factor.

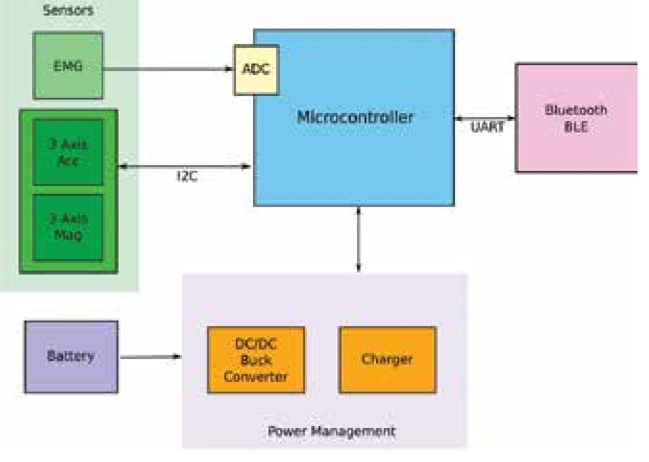

Figure 3. Block diagram of the wearable sEMG sensor.

Communication	Bluetooth classic or Bluetooth low energy
Range	Up to ~10 m
Sensors:	
EMG	12-bit resolution with a 3-μV signal noise
ACC	14-bit resolution
MAG	16-bit resolution
Battery	155 mA of 3.7 LiPo rechargeable (8-h battery life)
Size	28 × 70 × 12 mm
Weight	25 g

Table 1. Sensor characteristics.

being monitored during the execution. Other possibilities include sending a written message to the physiotherapist through a field on the final report, which will be received in real time. The physiotherapist can then change the prescription remotely, adapting the exercises to the current patient state and needs.

Figure 4 depicts an example as to what an exercise would look like, with clear, achievable goals. The patient can visually grasp on the video what movements he/she needs to perform, what is expected from him/her in terms of sets and repetitions and whether he/she is contracting/relaxing the right muscles.

In **Figure 5**, an example of a simplified report can be seen. The idea is that the patient can get an immediate gratification by seeing a very simple number that should depict how well he/she was able to achieve goals (there is a scale between 0 and 100 inside the star). There is also information below, as to how each exercise has contributed to the final score.

The HIT TARGET represents the time the patient was able to keep up with the goals within the exercise, and the COMPLETE how many repetitions he/she was able to complete. Using a ponderation between these values, and all of the executed exercises, a final score can be shown.

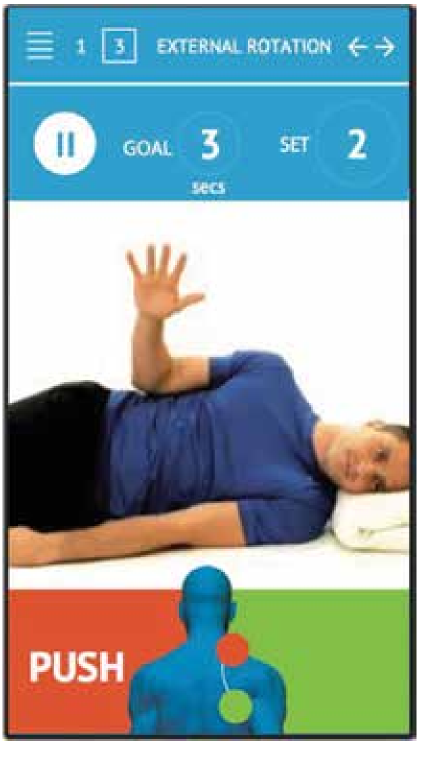

Figure 4. Example of instructional video.

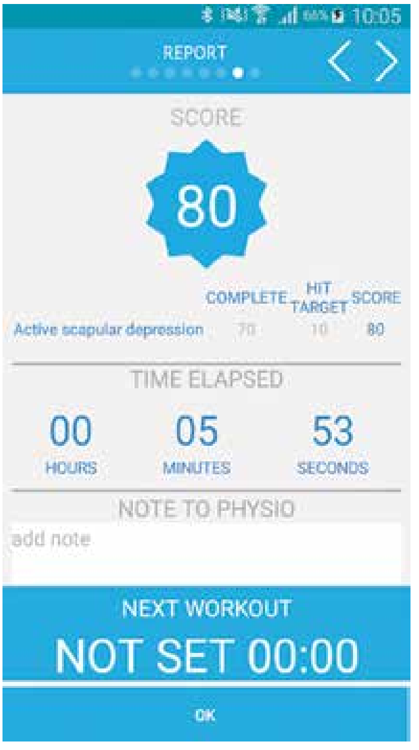

Figure 5. Final report.

3.3. Monitoring dashboard

The access to a monitoring dashboard is crucial in this clinic-home process. It is the way to establish a permanent contact with the patient even if several weeks pass since the last visit to the clinic, allowing access to all the home training data and to perform changes on the prescription to go towards the patient's needs

In **Figure 6**, we can see an overview of all the patients assigned to a given physiotherapist, and what their status are, with regard to their homework compliance. The traffic light colour code assists the physiotherapist to quickly check whom to address:

1. Green—user is active and has been executing the exercises on time;
2. Yellow—user is active, but is lagging behind on the exercise execution, so he/she may not be able to execute them during the prescribed period;
3. Red—it is impossible for the user to execute the remaining exercises during the time available.

This not only allows the physiotherapist to have the next session more tailored to the needs of the patient but also tweaks the exercises that the patient needs to execute during the next home session, as depicted in **Figure 7**.

Figure 6. Dashboard overview.

The most important parameters that can be used to adjust the difficulty of the rehabilitation process are as follows:

1. Variance—this allows the mobile app to adjust the difficulty of the exercise, depending on how capable the patient is feeling that day. The 'easier' the Variance, the more leeway there is;

2. Frequency—the frequency parameters allow the physiotherapist to define how often the patient executes the exercises, and how they are structured within the sessions. Tweaking these values can increase the recovery speed, but need to be treaded carefully, as it can lead to injuries or lack of motivation;

3. Exercise type—if the patient is more and more comfortable with the type of exercises he/she has been given, it is a good idea to vary them, so that the muscle memory does not only work with a given, very specific, motion.

3.4. Cloud-based infrastructure

Such a system is rooted in a distributed infrastructure that supports this plethora of equipment, the data being collected, and different user roles management (**Figure 8**). This infrastructure needs to be reliable, secure, scalable, and high performance.

These needs come from the fact that having patients at home using these systems needs to be much more scalable than having single systems on the clinics being shared among the several professionals, as the quality of service will be under heavier scrutiny by a broader audience.

To answer these needs, a cloud-based infrastructure with easily scalable and deployable services needs to be used. With this in mind, in case there are higher surges of access, the system can easily deploy new instances, or throttle their capacity up, without impacting the system's availability, enabling continuous delivery.

There are currently several commercial offers to build this kind of robust architectures that do not rely on single servers (either physically or on a single geographical location). For the sake of this discussion, Amazons' AWS system is depicted, as an example or suggestion as to how such an architecture can be deployed. As it can be seen, it relies on distributed static assets throughout the globe, and load balanced requests to readily available, and scalable application servers (depicted earlier as Amazon Elasticbeanstalk).

In this day and age, there have been several regulatory concerns about the patient's privacy, first with the US Health Insurance Portability and Accountability Act (HIPAA) from 1996, and with the General Data Protection Regulation (GDPR) from 2018. For these systems to work, some unique patient information is usually required to be stored on a database, such as their name, email, age, or a password so that they can access their own information (right of access).

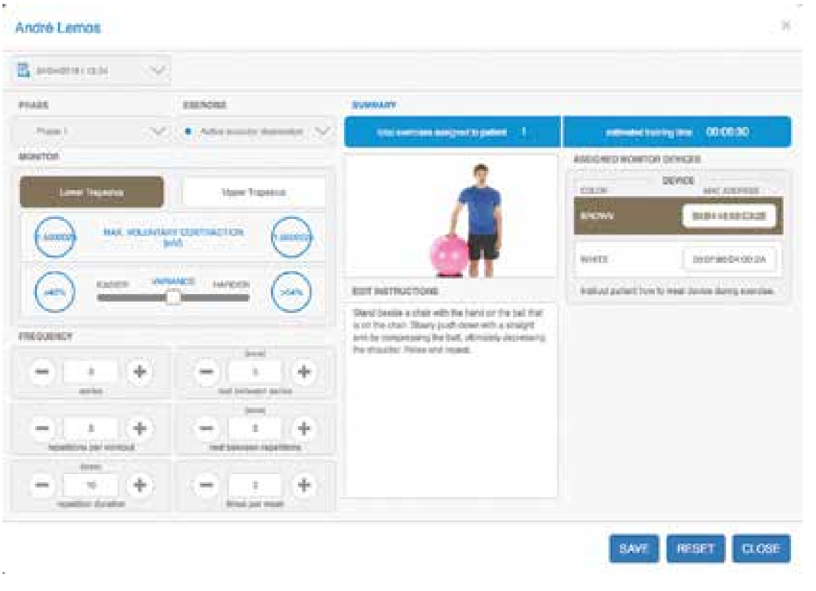

Figure 7. Homework configuration.

Since these systems can collect huge amounts of clinical data, it is also advisable that in case there is a data breach, there is a pseudonymization of the most relevant information as this reduces the risks to associate the data with the subjects [11]. This process is depicted in **Figure 9**,

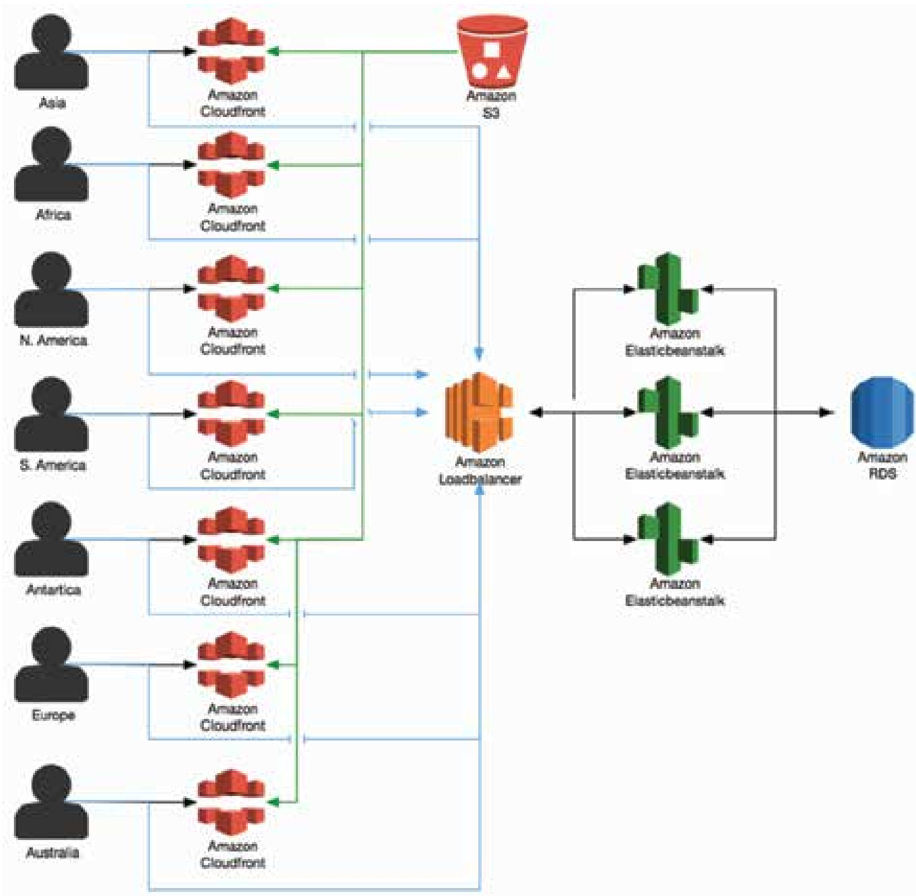

Figure 8. Cloud-based architecture.

where the data stored on the repository use a pseudonymization to refer back to the data on the database.

This kind of mitigation should be used not only for the storage of sensitive data but also in the way the data are exchanged between the several systems that these micro-services, cloud-based systems require, so that man in the middle attacks are thwarted, by using tokenization (**Figure 10**), which is a way to substitute sensitive data, such as an email and password pair with a token that has no meaning or representation outside of the system.

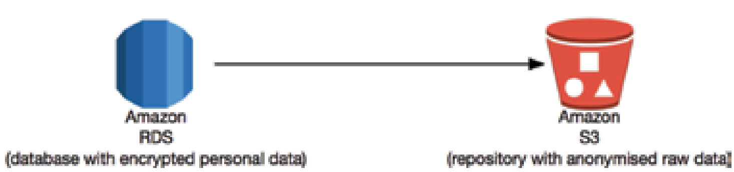

Figure 9. Physical separation of sensitive data.

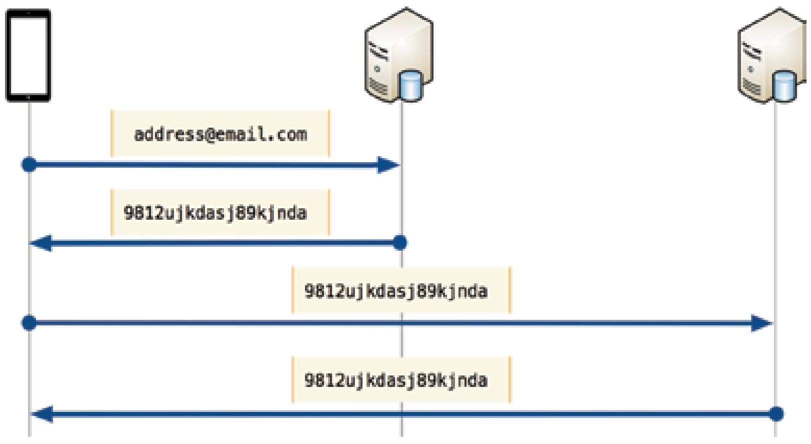

Figure 10. Example of a tokenization process.

4. Conclusions

High recurrence rates and high dropout rates lead to high economic and social costs in the treatment of musculoskeletal disorders (MSDs). Different reimbursement systems for the physical therapy treatments can be found within different countries in Europe, where private insurance or state health systems cover the cost and inefficiency of MSD treatments. In the US, the cost burden is shared between patient and insurers, where patient's co-pay at an average 50% per session. In other countries, as China, there are almost no physiotherapists; treatments of MSD are directed towards general practitioners who are overwhelmed with a large number of patients and tend to treat the pain and not address the root cause. Inefficiency and difficulty to assess the quality of treatments for MSD pain is a concern to the insurers and health-care systems, which are searching for more consistent diagnostic and treatment approaches, along with new models for reimbursement, in which reduced costs and objective outcomes of treatments can be demonstrated.

When discussing with insurers such as Achmea in Holland, they recognize that while physiotherapy represents around 7% of their cost expenditures, quality physiotherapy care ranks as the number one reason a patient will select an insurance plan or change providers. Therefore, insurers are acutely aware of the need to increase patients' actual or perceived physical therapy care and motivation to resolve underlying pains. With no objective information of physiotherapy treatments, the quality of the service and the consistency of treatment outcomes are difficult to assess. Moreover, unscrupulous practitioners can bill unnecessary treatments, leading to high costs and a strong effort from the insurances to fight fraud. This problem was stated in the front page of NY Times: 'Physical therapy has become a Medicare gold mine. Medicare paid physical therapists working in offices $1.8 billion in 2012 alone, the 10th-highest field among 74 specialties' [12]. In this context, a huge insurance reform is coming where the capitation of reimbursement will be done in the model 'pay per treatment outcome' instead of 'pay per session'. Physiotherapy clinics are then going to be pressed to lower overall costs of treatments and improve overall quality and consistency. Thus, there is a pressing need within physical therapy practice for a validated method to improve the consistency of the outcomes of MSD treatment, and increase patients' satisfaction and quantification of treatment quality and efficiency. In this chapter, we present a novel biofeedback system designed to support part of the rehabilitation processes at home, further contributing to help mitigate the known issues associated with conventional approaches.

Acknowledgements

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Conflict of interest

There is no conflict of interest.

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Chapter 5

Effect of Infra-Low Frequency Neurofeedback on Infra-Slow EEG Fluctuations

Vera A. Grin-Yatsenko, Valery A. Ponomarev, Olga Kara, Bernhard Wandernoth, Mark Gregory, Valentina A. Ilyukhina and Juri D. Kropotov

Additional information is available at the end of the chapter

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Abstract

Infra-low frequency neurofeedback (ILF NF) has been proposed as an alternative or complementary treatment method. Previous studies have reported a good effect of ILF training on the subjective perception of positive psychological changes after training. Here we study whether the objective physiological parameters reflecting the brain function also change under the influence of ILF NF. Eight participants 21–50 years of age with no history of neurological or psychiatric diseases, but reporting about some physiological or psychological complaints, performed 20 sessions of infra-low frequency neurofeedback training. EEG in visual Go/NoGo test was recorded before the course of Neurofeedback and after its completion. The spectral power of slow EEG oscillations in the post-training recording was compared with the pretraining baseline. Along with remission of the clinical complaints, significant increase of spectral power in 0–0.5 Hz frequency band was observed in all eight participants in the post-training EEG patterns compared to the pre-training EEG, which may be linked to the improvement in the metabolic balance in the brain tissue and increasing efficiency of compensatory mechanisms in the stress regulation systems.

Keywords: neurofeedback, post-training effects, infra-low frequency, slow EEG oscillations, stress regulation

1. Introduction

The utilization of adjunctive, alternative or complementary treatment methods (CAM) has been growing in recent decades, driven by demand. Based on the report published by the

National Institute of Mental Health (NIMH), there is a problem of burgeoning "off-label" medication prescription [1] and overrated effectiveness of pharmacological treatment for some conditions. Additionally, it has been found that best outcomes often depend on a combination of treatment strategies, including psychotherapy [2–6].

According to the definition proposed by the National Institute of Health (NIH), complementary medicine (CAM) constitutes a broad domain of healing resources that lie outside those intrinsic to the politically dominant health care system of a society [7]. Inevitably, CAM will include technologies that are in the preliminary stages of mainstream acceptance. Such a technology is neurofeedback, which typically utilizes specific frequencies of the EEG in feedback configuration in order to promote cerebral self-regulatory competence. Despite its origins in well-grounded animal research in the 1960s [8], and subsequent studies in application to epilepsy and attention deficit hyperactivity disorder (ADHD) in the 1970s and 1980s [9, 10], neurofeedback was not adopted into standard medical practice at the time.

Originally discovered in 1956 by Kamiya, what came to be called EEG biofeedback found its first clinical application to anxiety [11], but that finding was not welcomed by the mental health disciplines either. Nevertheless, neurofeedback has matured as a type of CAM over the last several decades, with some 2700 citations in PubMed for neurofeedback, EEG biofeedback, and neurotherapy. With refinements derived on the basis of "practice-based evidence," neurofeedback is now belatedly entering the mainstream.

Neurofeedback belongs in the class of brain computer interface technologies, in that it allows the user to react to his own brain electrophysiological signals in real time [12]. These are registered from surface electrodes, subjected to frequency-selective signal processing, and rendered observable in the form of visual, auditory and tactile feedback. In its dominant realization, the feedback is based on frequencies within the conventional EEG spectrum of 0.5–40 Hz.

In infra-low frequency (ILF) neurofeedback, the modulation target is the brain rhythmic activity that lies below 0.5 Hz [13, 14]. Despite a multidecadal history of research, the organization and functional role of this low-frequency rhythmic activity remains unspecified, and this topic is currently garnering renewed research interest after a considerable hiatus.

The term ILF was introduced by a Soviet Union neurophysiologist Aladjalova in 1956 in her paper "Infra-slow rhythmic changes of the brain electrical potential" [15]. In this paper, she described brain oscillations in the ILF region and suggested a possible physiological basis for these phenomena. Since that time, a vast amount of empirical knowledge has been obtained in studies by Russian scientists in animal research and in studies on human subjects, through reliance on nonpolarizable electrodes to achieve low drift characteristics [16, 17]. The authors found two types of infra-slow oscillations with periods of 10s and 30–90s, respectively. In the United States, similar work was pursued by Kamiya et al. [18]. The ILF domain has also been studied in Austria and Germany [19–24].

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Spontaneous and evoked local field potentials were observed in various cortical and subcortical regions of patients in whom cortical and subcortical electrodes had been implanted for purposes of characterization, diagnosis, deep brain stimulation, or lesioning [25]. The cortical electrical potentials were found to be correlated with infra-slow metabolic oscillations such as fluctuations of local oxygen levels. It was also demonstrated that spectral characteristics of infra-slow oscillations of the human brain remained stable over days and weeks [25, 26]. Recently, ILF potentials have found increased interest in the international scientific community, especially with the growing scientific evidence for a significant role of infra-slow potential fluctuations in modulating the level of cortical excitability and thus regulating brain dynamical activity [27–32].

Infra-low frequency training, developed by Susan and Siegfried Othmer, extended the conventional frequency-based training to the lower frequency range. Feedback is then a matter of observing the slowly undulating signal. The technique has been described in a paper titled Clinical Neurofeedback: Training Brain Behavior [33]. The first reported clinical application was to Post-Traumatic Stress Disorder among military veterans [34]. The second dealt with cases of epilepsy [13]. The method came to be applied broadly to mental health concerns, with a range of application that was even larger than that of EEG-based training. The method has demonstrated dramatically positive outcomes for a variety of mental conditions, including different forms of anxiety, depression, sleep disturbances, ADHD, the autism spectrum, developmental trauma, migraines and other headaches, and traumatic brain injury [35, 36].

A surprising observation with respect to ILF training is the rapidity with which results are sometimes achieved even with challenging clinical presentations. The tonic slow cortical potential appears to be an exquisite reflection of the dynamics of cortical excitability. When the signal is derived in bipolar montage, network relations are revealed, and thus the training impinges on functional connectivity. By operating in the ILF regime, the training preferentially accesses the functional connectivity of the intrinsic connectivity networks that were originally identified with fMRI [29]. These low frequencies also give preferential access to the glial role in the regulation of the glial-neuronal system [37].

In consequence, the ILF training impinges on the ultradian cyclic fluctuation of physiological arousal and related autonomic nervous system regulation [26, 38]. For example, in anxiety disorders, the disruption of autonomic stress regulation system results in a range of symptoms [39]. Indeed, the data of Smith and colleagues support the hypothesis that ILF training preferentially influences autonomic nervous system regulation and thus improves the emotional equilibrium of patients, which in turn positively influences attention and working memory [36]. Further evidence along those lines was recently documented in a large-scale compilation of pre-post continuous performance test data on a clinical population [40]. Improvement in performance was consistently observed, irrespective of the conditions being targeted in the training.

The previous studies showed that ILF patterns of both electrical and nonelectrical phenomena remained quite stable over time. The goal of the present study is to demonstrate that the ILF training procedure induces persistent changes in the amplitude distribution within the ILF spectral range.

2. Material and methods

2.1. Participants

Eight individuals (mean age 33.1; range 21–50) participated in our study: five males (mean age 36.2; range 23–50) and three females (mean age 28.0; range 21–35). All of them had normal mental and physical development, no history of head injury, convulsions or neurological diseases, and were not currently taking any medication or drugs. Despite the absence of any medical diagnosis, participants still reported physical or mental complaints. Some of them experienced fatigue, depressed mood, symptoms of anxiety or mood swings; others had headaches and sleep problems. Most subjects were not satisfied with their concentration and memory function, or with their high reactivity to stress factors. The investigation was carried out in accordance with the Declaration of Helsinki. All subjects gave informed consent after the procedures had been fully explained to them.

2.2. EEG investigation

EEG was recorded using a Mitsar 21 channel EEG system (Mitsar, Ltd). Nineteen silver-chloride electrodes were applied according to the International 10–20 system. The input signals referenced to linked ears were filtered between 0 and 50 Hz and digitized at a rate of 250 Hz. The ground electrode was placed on the forehead. All electrode impedances were kept below 5kOhm. EEG was recorded during performance of the visual cued GO/NOGO task that uses pictures of 20 different animals, 20 different plants, and 20 different humans (together with a distracting beep tone) as stimuli [41].

One trial consisted of the sequential presentation of two pictures (prime and target), presented for 100 ms each, with an ISI of 1000 ms (SOA = 1100 ms). Trials were separated by 1500 ms. Patients were instructed to press the left button of the computer mouse as quickly as possible when an animal was followed by an animal (Go-condition) and not to respond when an animal was followed by a plant (NoGo-condition), or when a plant was followed by a plant or a human (distractor condition). The response interval lasted from 100 to 1000 ms.

The task consisted of 100 Go-trials, 100 NoGo trials, and 200 distractor trials. Trials were presented pseudo-randomly with equal probability. All trials were presented to the subject on a computer screen 1.5 m in front of them using the Psytask software (Mitsar Ltd.). The centrally presented stimuli subtended an approximate visual angle of 3°. Trials with omission and commission errors were excluded from analysis. Quantitative data were obtained using the WinEEG software.

The baseline investigation consisted of quantitative electroencephalogram (qEEG) in Visual Go/NoGo test, which took place 1–7 days before undertaking the course of NF training sessions. qEEG parameters were compared with the Human Brain Institute (HBI) normative Database. All the tests were repeated after 20 sessions in 1–7 days after the last session. The results of the second testing were compared with the pretreatment baseline.

The epochs with excessive amplitude of nonfiltered EEG and/or excessive high and slow frequency activity were automatically marked and excluded from further analysis. Eye blink artifacts were corrected by zeroing the activation curves corresponding to eye blinks. The method is similar to the one described in Vigario [42] and in Jung et al. [43].

Continuous artifact-free EEG epochs were selected manually for analysis. The duration of these epochs varied among the subjects from 550 to 1100 s.

The average spectral density in the 0–0.5 Hz frequency band was estimated for each electrode, each subject and each condition separately using the Thomson's multitaper method, and logarithmically transformed for normalization before further statistical analysis.

2.3. Neurofeedback

The instrument used for the clinical neurofeedback was the Cygnet system (bee Medic), consisting of the NeuroAmp II and Cygnet software, integrated with Somatic Vision video feedback and run on a Windows 7 operating system using a standard personal computer (PC) with a high-resolution monitor.

The Othmer Method utilizes evidence-based and well-established neurofeedback protocols, the implementation of which has been refined through empirical optimization procedures and A-B testing over a large number of neurofeedback clients referred for a variety of conditions. The method is protocol-based and is further characterized by the following essential features:

- It is a symptom-guided approach in which the symptom presentation from anamnesis is used to identify one of several basic patterns of dysregulation that are then targeted in a protocol-based manner;
- The training is process-oriented, involving the ongoing optimization of feedback parameters according to observed symptom changes during sessions and from session to session;
- The method utilizes bipolar EEG montages exclusively, and as such is oriented toward training the functional relationships between key cortical sites;
- The method involves continuous waveform-following for the low-frequency aspect of the training in combination with conventional discrete reinforcements for inhibit-based training;
- The inhibit-based training is triggered on transient anomalies observable within the conventional EEG spectrum;
- The method utilizes mainly audio-visual real-time animations in order to deliver the ILF feedback signal beneath conscious awareness.

The two parameters selectable by the clinician are:

a. position of the electrodes, according to symptom profile and symptom changes;

b. adjustment of the reward frequency according to patient feedback.

Until 2006, the signal processing was very similar to the classical beta-SMR scheme [44]. However, the reward frequency setting of a 3 Hz wide variable bandpass-filter was user-adjustable over the entire conventional EEG spectrum from 1.5 to 40 Hz in center frequency. For that purpose, a horizontal slider was implemented in the graphical user interface. The inhibits were comprised 10 separate filter blocks in fixed frequency steps in the range between 1 and 40 Hz. For both the reward and inhibit scheme, threshold setting was auto-corrected to maintain a chosen level of difficulty, the "percent success."

Specific design parameters in the signal-processing chain between initial EEG acquisition and ultimate feedback animation have always been assessed and optimized by means of an empirical approach based on qualitative evidence criteria. (A useful analogy to this process is the optimization of the suspension system of a car, where human factors come prominently into play.)

By expanding the underlying model of neurofeedback to incorporate the current understanding of the brain as a self-organizing dynamical system that interacts with itself by means of neurofeedback, improved approaches to signal processing and coupling to the feedback animations have been sought. This process got underway in 2001. In that regard, also slow cortical potentials were investigated. With the availability of greater computer power for additional signal processing as well as advanced signal acquisition technologies, it was found that the addition of such slow potentials appears to offer the brain a more direct and effective feedback interaction. It turned out that also with this scheme, tailoring of the parameter setting to the individual patient is beneficial or even necessary, just as was previously found for frequency-band training in the conventional EEG spectrum [45].

In contrast to the classical concept of a rewarding experience that is controlled by the amplitude of the EEG in a given frequency band, the goal here is to present the brain with the most relevant representation of its slow cortical potential. For that purpose, derivations from the measured signal control various features in the feedback animation in a way that optimizes the brain's opportunity to engage with them.

For the purpose of continuity of the clinician's experience with the earlier era, the terminology of "reward frequency" was retained, as the rules for settings and for the optimization procedure carried over into the ILF region. However, the absence of discrete rewards in the ILF training meant that the traditional terminology of reward had lost its meaning. The unfolding of the continuous ILF signal allowed for no external reinforcers. Additionally, the slider that controlled the target frequency within the EEG regime was retained in the new design, but its function in the ILF regime must be understood differently. With the adopted

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signal-processing scheme, the slider influences the natural frequency of the control loop that the brain forms with the feedback system during neurofeedback on a continuous signal. It functions effectively as a kind of gain control.

Training was performed with bipolar placement of silver/silver chloride scalp electrodes applied using Ten20 conductive electrode paste at one or both of two initial placements, T4-P4 and T4-T3 (according to the standard 10–20 system). These are relied upon to characterize the response of the trainee and to guide further optimization. Subsequently, T4-Fp2 and T3-Fp1 are added to the protocol as needed. The "ground" electrode was placed at Fpz.

Each trainee received 20 separate 30–45 min neurofeedback sessions over 7–8 weeks. For each subject, the target frequency in the infra-low frequency region was optimized with each of the standard placements. The placement of electrodes was the standard one developed by Othmer [46] and adopted in the Othmer Method.

2.4. Statistical analysis

Two-way repeated measures ANOVA with factors condition (before-after) and location (19 electrode positions) was used to estimate the statistical significance of the training effect on the slow EEG oscillations. The Greenhouse-Geisser procedure was used to compensate for deviations from sphericity or circularity.

3. Results

After completion of 20 NFB sessions, all participants indicated improvement of their state. Most of them noticed a decrease of inner tension and reactivity to stressful factors. Further, they reported on stability of mood, improved body and space awareness, increase of energy level and of cognitive performance.

The post-training EEG patterns in all eight subjects revealed significant enhancement of spectral power in 0–0.5 Hz frequency band compared to the pre-training EEG. The locations of the most prominent changes were different: in some subjects, the dramatic ILF power increase was observed over the frontal-central region, in other cases over the posterior brain areas.

Figure 1 presents the EEG recordings before and after ILF NF course in one of the participants of our study.

Figure 2 demonstrates the increase of the level of infra-slow activity in 0.03–0.05 Hz range in the post-training EEG in this participant. This increase is most prominent over frontal region.

Two-way ANOVA revealed a significant main effect of the factor "Condition" for the slow activity in 0–0.5 Hz frequency band $F[1,7] = 18.4$, $p < 0.01$. This effect is illustrated in **Figure 3**.

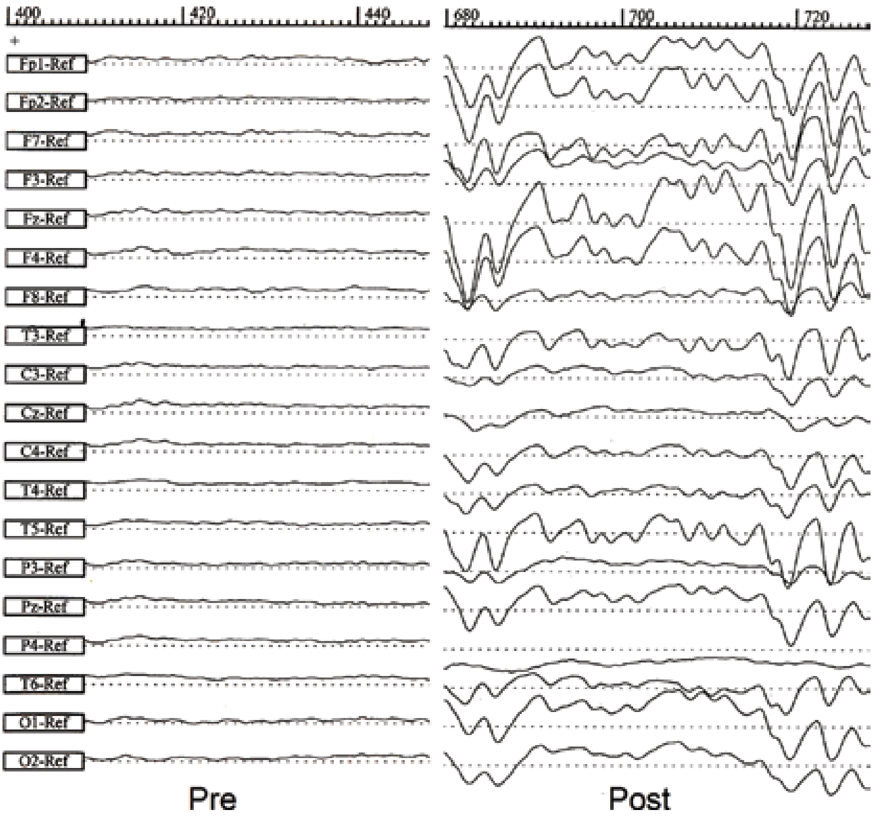

Figure 1. Pre-training (on the left) and post-training (on the right) EEG in the 43-year-old male subject. EEG recorded in the linked ear montage/reference during VCPT performance. Scale: 200uV/cm, speed–1.875 mm/s, time constant–10.0 s (0.016 Hz), low frequency filter–0.5 Hz.

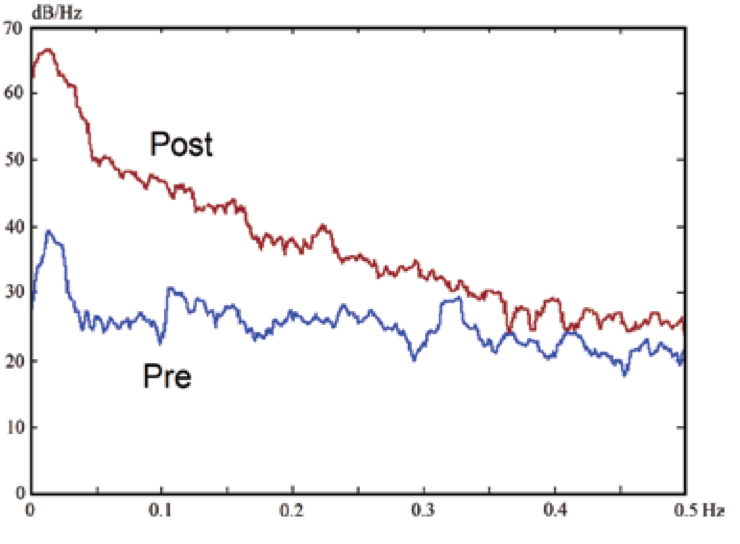

Figure 2. EEG power spectra at Fz in the 43-year-old male subject before and after training**.** Pre-training–Lower curve, post-training–Upper curve, X-axis–Frequency and Y-axis–Spectral power in logarithmic scale.

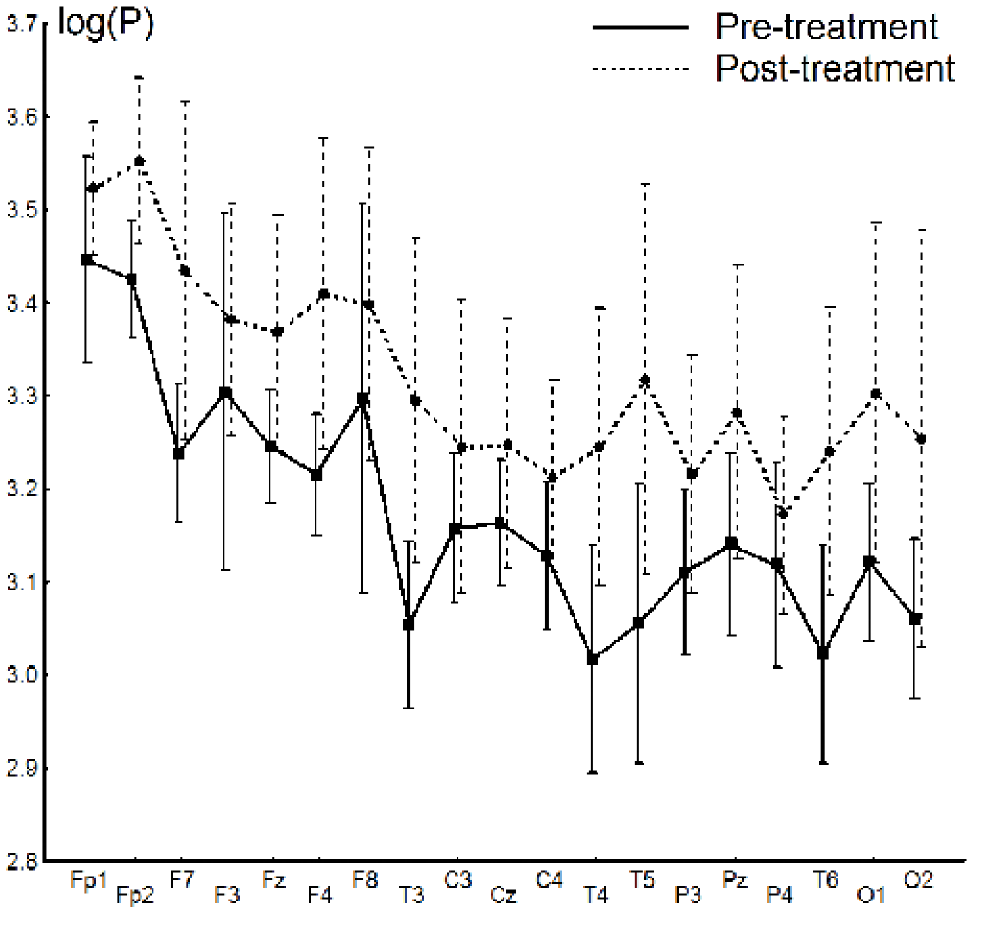

Figure 3. Influence of the ILF NF on the power of EEG activity in 0–0.5 Hz frequency band. X-axis–Electrodes localizations; Y-axis–Logarithmic scale of ILF (0–0.5 Hz) power. Whiskers represent a 95% confidence interval.

An increase of the logarithmical power averaged in eight subjects in 0–0.5 Hz band is seen in all 19 electrodes localizations.

4. Discussion

All participants had normal mental and physical development and had no history of any neurological abnormalities. However, most of them reported some form of self-perceived psychological and physiological issues such as fatigue, depressed mood, symptoms of inner tension, mood swings, headache, and sleep problems. These were accompanied by cognitive concerns such as diminished attention or poor working memory.

After 20 sessions of ILF training, the pattern of ILF activity at rest changed dramatically. The main difference was an increase in the amplitude of the ILF activity up to 0.3–1.0 mV in all recording sites.

These results indicate that ILF training modified the baseline brain state in each case. It is important to add here that the changes in brain dynamics were associated with improvement in subjective perception of stress, fatigue, mood disturbances, and sleep problems after completion of 20 sessions of ILF training. Decreases in inner tension and in stress reactivity were reported. The psychological evaluation also reflects positive changes, including improved stability of mood, better body and space awareness, increase in energy level, and improved concentration and cognitive performance (e.g., working memory).

The effect of ILF training on the subjective perception of positive psychological changes was previously reported by a number of researchers and practitioners that utilize ILF training in their practice [35, 47]. Our analysis has both supported previous observations and established a link between the observed improvement in participants' condition with objective changes in physiological parameters that reflect the dynamics of the brain functional organization.

The previous studies have shown stability of the individual spectral characteristics of ILF brain potentials recorded both from scalp as well from intra-cortical and deep-brain electrodes [25, 26].

Consequently, the increase in the amplitude of the ILF activity found in the present study can be discussed in accordance with the mechanisms of the individual compensatory-adaptive brain-body regulation in response to stress factors [48]. In the present research, we assume that our participants had initial constraints in compensatory-adaptive brain reactions, which lead to the reduced brain tissue metabolic regulation followed by energy deficient state. The present study shows that ILF training outcomes are associated with an increase in amplitude of ILF. The increase in amplitude and regularity of ILF was previously described and discussed as a sign of improved tissue metabolic activity [48–50]. Therefore, the positive trend in ILF characteristics observed in our study may be linked to the increased compensatory mechanisms in the stress regulation systems.

It is important to mention that post-training enhancement of spectral power in the 0–0.5 Hz frequency band were the most prominent over the frontal-central and the posterior brain areas. The distribution of increased activity at infra low frequency is correlated with the principal hubs of the default mode network (DMN), located frontally and parietally on the midline. The DMN is by far the most dominant among our intrinsic connectivity networks (ICNs), typically accounting for more than 95% of the ambient activity of cortex. Among the ICNs, it bears the principal responsibility for the management of the tonic state of the brain. As such it can be thought of as setting the context for more specific functions such as cognitive and emotional control [51].

Previously published results discussed the possible involvement of ILF in the modulation of the internal organization of the DMN, which is associated with the brain homeostatic balance and is involved in the autonomic regulation [35, 36, 51]. These results support the hypothesis of the metabolic stress regulatory mechanisms [48] and raise the question on the role of DMN network in homeostatic balance and metabolic compensation in stress response.

At the same time, the disrupted connectivity within DMN was found in a number of diseases, especially related to faults in the stress-regulation system such as post-traumatic stress disorder [52], general anxiety disorder [53], major depressive disorder [54], and traumatic brain injuries [55].

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Therefore, the positive effects of ILF feedback on the "renormalization of functional connectivity of resting-state networks" proposed by Othmer and colleagues can be linked with the normalization in the metabolic balance in the brain tissue as a specific effect of the ILF training [35].

The present research can be considered as the first step in uncovering the physiological basis of ILF training as the method that targets the balance within brain systems involved in metabolic regulation of brain and body. The role of ILF training on the DMN network regulation is a subject of future research, where the specific physiological effect of this practice in different brain diseases will be disclosed.

5. Conclusions

Our study has shown the changes in the amplitude distribution within the ILF spectral range in all participants that seems to be induced by the ILF training. In other words, the ILF training leads to the changes of the functional state of the brain. We suggest that the modification of the baseline ILF EEG pattern may reflect the normalization in the metabolic balance in the brain tissue and increasing efficiency of compensatory mechanisms in the stress regulation systems.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author contributions

VAG-Y recruited subjects, participated in experimental design, data acquisition, interpretation, and drafting of the manuscript. VAP performed statistical analysis and interpreted the data. BW developed the ILF NF technology. OK was involved in drafting of the manuscript. MG analyzed data. VAI participated in interpretation of data. JDK supervised the study and was involved in study design, interpretation of data and critical review of the manuscript.

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Chapter 6

Control Systems of Bionic Limbs of the New Generation and Control Systems with EMG Signals of VR and Games and Toys

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Vladimir Karimov and Valentsin Shepanskiy

Additional information is available at the end of the chapter

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Abstract

The LLC Bionic Natali company is a startup and has been engaging in creation of bionic artificial limbs of hands for more than 2 years, and the LLC Bi-oN EMG was created one year ago on base of LLC Bionic Natali. From the first steps, projects had been directed on the solution of a problem of development of the domestic bionic functional artificial limb of the hand based on neural network and others algorithms. In projects, it had been created the functional system of management, system of tactile feedback which has increased controllability of a functional artificial limb is already realized and integrated, and also the functional bionic artificial limb of the hand. Based on this work it had been done the general representations and practical application of machine training, neural network and others algorithms. The technology of recognition of gestures of electromyographic activity based on neural network or an analog of network is the cornerstone. The bracelet is put on a hand (in case of disabled people, a stump), further noninvasive electrodes remove potential difference of neuromuscular activity; by means of an electric circuit there is data handling and their transmission to the processor where by means of a neural network there is a recognition of a gripper, further data are transferred for control of a bionic hand. This technology has also found so far mostly theoretical management, but undergoes testing practical, for control of the knee module of a bionic artificial limb of the lower limb. The technology of bracelet became the product of LLC Bi-oN EMG for virtual reality, games and rehabilitation. On the basis of this researches the important conclusion has been drawn: after carrying out operations within rehabilitation and the subsequent use to establish to the recommendation immediately bionic artificial limbs as eventually without trainings and also because of psychology of people "experience of management" the hand is lost, and without trainings of the muscle atrophy. But restoration is possible, alas, it will demand much more time, than in cases of immediate prosthetics by bionic/myoelectric artificial limbs. The current researches have also shown requirement of rehabilitation of disabled people before use of bionic artificial limbs of hands, use of an electromyographic bracelet of LLC Bi-oN EMG is offered as option.

Keywords: the bionic artificial limb, neuronal net, electromyographic signals, system of control, EMG, Bionic Natali, Bi-oN EMG, recognition the electromyographic signals, artificial intelligence, machine learning, feedback of the signals, Bi-oN

1. Introduction

Practical developments of LLC "Bionic Natali" and LLC "Bi-oN EMG" companies' researches and creation of technology of management of limbs on recognition of signal EMG on the basis of neural network were presented in the current article, and also the use of the given technology at rehabilitation of people with loss of an extremity, after an acute stroke and even in the game sphere for children and young people, such as virtual reality, radio control by machine, quadcopters, etc. was presented. In the article the practical results of a research of feedback on the basis of EMG of signals at disabled people and people without loss of limbs are given.

Within the project of the LLC "Bionic Natali" company, the hi-tech bionic artificial limb which surpasses all domestic functional electromechanical and cosmetic artificial limbs in the Russian Federation has been developed and also will surpass foreign bionic artificial limbs in functionality by industrial production. Within the project the functional control system, the system of tactile feedback which has increased controllability of a functional artificial limb is realized and integrated and also the functional bionic artificial limb of the hand is developed.

Now, in most cases, in the absence of a hand, the cosmetic artificial limbs bearing in themselves only the cosmetic purposes are used, being, in fact, a hand model. Electromechanical artificial limbs which allow to replace partially functionality of a full-fledged hand are widespread poorly at present, have limited functionality, and also are available to still a limited circle of users. Especially, this situation is characteristic of Russia that is explained by the influence of several factors: the certain structure of schemes of social insurance causing an order of financing of prosthetics for the state account of low consumer ability of the people who have lost a hand and, of course, absence in the market of decisions in various price segments with the significant level of functionality.

In a prosthetic repair, active transition from static prostheses to robotic bionic is now observed; in the light of this, it is possible to allocate tendencies in creation of cheap and low-quality prostheses from the 3D press and on cheap accessories and also development of more expensive prostheses, but the second tendency is bound to larger problems available for a technological base, namely, small capacious accumulators, small drives, plateaus of processing, processors, and so on. But, despite all difficulties, the last conform to requirements which are exposed by the state at a prosthetic repair, namely, the long-term use of prostheses, 2–3 years.

As for the most electromyographic bracelet, a control system on the basis of EMG—that decision on his allocation in the separate project that has been made after the prototype has been created and the architecture of work of a bracelet became clear, namely, that the bracelet can work independently and he can be tied to any electronic product with Bluetooth for management of this product. By the results of the works done, the LLC "Bi-oN EMG" company has been open, and its application is found in the sphere of rehabilitation and game devices. It is important to note that the game sphere for children has been chosen in connection with market width and also the need to reduce the price of product cost.

The sensing technology of gestures of electromyographic activity on the basis of a neural network is the cornerstone. The bracelet is put on a hand (in case of disabled people, a stump); further noninvasive electrodes remove potential difference of neuromuscular activity, by means of an electric circuit there is data handling and their transmission to the processor where by means of a neural network there is a recognition of a gripper, further data are transferred for control of any electronic device with the set special software (the executive mechanism), back coupling is carried out from the executive mechanism to a bracelet by means of signal transmission of back coupling and on a bracelet the vibromotor is launched in action.

2. Implementation of the project based on the neural network for the recognition of the gripper for bionic artificial limbs and for virtual reality and game devices

As it was already noted earlier, within the project the hi-tech bionic artificial limb which surpasses all internal functional electromechanical and cosmetic artificial limbs is developed and also will surpass foreign bionic artificial limbs in functionality by industrial production. And, the LLC "Bionic Natali" company is faced by a task to make him available to most disabled people due to considerable reduction of cost in comparison with foreign bionic artificial limbs, about by five to six times. Also, it should be noted about a know-how the project, creation of innovative system of reading on bigger quantity of electrodes, than in the current foreign bionic artificial limbs which is also radio and it is constructed on the principles of neural network and other algorithms.

The technology of recognition of gestures of electromyographic activity based on neural network or an analog of network is the cornerstone. The bracelet is put on a hand (in case of disabled people, a stump), further noninvasive electrodes remove potential difference of neuromuscular activity; by means of an electric circuit, there is data handling and their transmission to the processor where by means of a neural network there is a recognition of a gripper or movement of a knee, further data are transferred for control of a bionic hand or leg.

Information on how usually artificial limbs are working can be found in article [1].

Within the carried-out scientific research works of more than 1 year, the basic divergences with data of muscular activity were found in disabled people and given to muscular activity at people without amputation. Distinctive feature is the range of frequencies at which the signal registers, and importance of maintenance of a tone of muscular activity at disabled people, otherwise there are artifacts of the movement, which at people without amputations are not registered. For this task now with Ilizarov's center, the system of rehabilitation is studied, and also the separate product "an electromyographic bracelet" which is taken out in the separate company LLC "BioN EMG" has been created. In **Figure 1**, the picture on a control system of any executive mechanism of the recognition of EMG based on the neural network is given below.

General explanation of EMG can be found in the book [2].

2.1. Technology of bionic artificial limbs

Technical tasks, realized within works and development, were the following:

- Reliable functional intellectual bionic artificial limb of an extremity with return of tactile communication by means of neuromuscular signals
- Way and control system of the auxiliary device, such as extremity artificial limb

The main problems, which have been put before LLC "Bionic Natali" company at implementation of the project, are the following:

1. Increase in accuracy of positioning of engines
2. Increase in accuracy of the obtained data at recognition of gripper
3. Increase in accuracy and probability of recognition of gripper
4. Making decision on the capture of a subject and increase in controllability of gripper

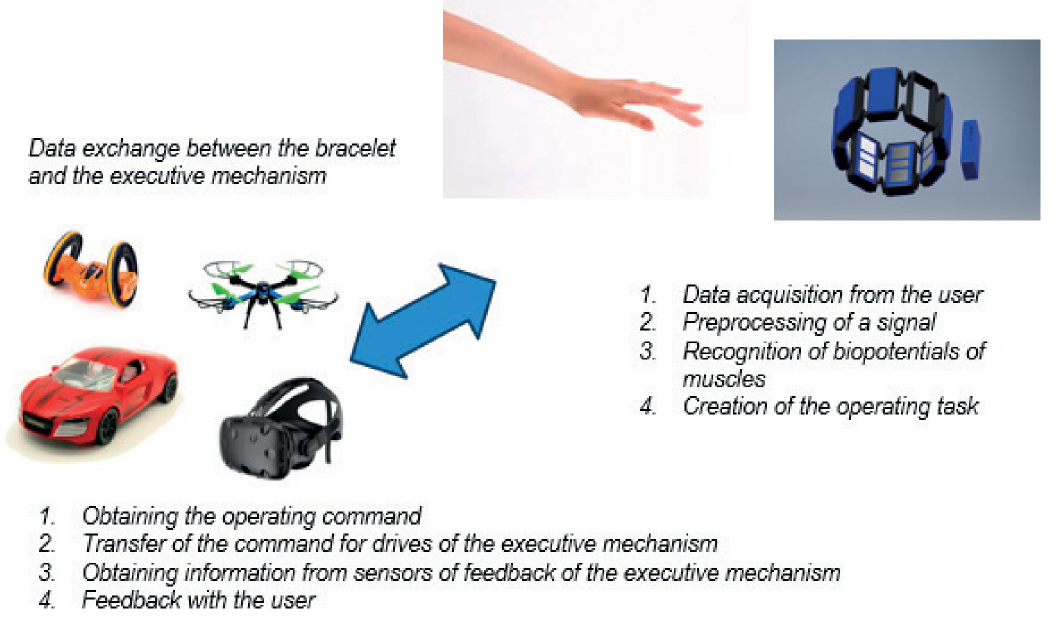

Figure 1. The scheme of control of any executive mechanism of the recognition of EMG based on the neural network.

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Emphasis on a project know-how, creation of innovative system of reading on bigger quantity of electrodes than in the current foreign bionic artificial limbs which also is wireless and constructed on the principles of the neural network, is worth placing. The matter is that in all foreign artificial limbs at the moment the management is based on the basis of management from two sensors and threshold value of a signal, grippers are programmed by means of phone or the button on an artificial limb. There is selection of an algorithm of data processing of electromyographic activity of muscles for the best recognition of the gripper and experimental confirmation of developments.

Materials are the knowledge of developers and experience of the advising experts (the mentor on algorithms—professor of Skoltech Victor Lempitsky; prosthetists Levon Kirakozov, S. Golovin, V. Golovin, and A. Dozhdev; experts of the Federal State Budgetary Institution SPb NCEPR of G.A. Albrecht of Ministry of Labour and Social Protection of the Russian Federation; experts of the center of Ilizarov; etc.) and also completely experimental data that had been used.

The method which was used in the course of selection of an algorithm is the experimental "trial-and-error method."

It is important to mark that at the first stages of the project it was planned to select algorithms, processing collected these electromyograms of muscular activity of disabled people from open sources, but as it was clarified later, in open access information was practically not, and what managed to be found, was very far from reality and is poorly described regarding process of removal of data that does not exclude existence of an error in data. As a result, the decision to create an own experimental database that was successfully realized was made.

As for the solution of a task of optimization of gripper, decrease in cognitive load of the person and increase in effective management of an artificial limb is reached due to use of a hybrid control system which combines ways of decoding electro-neuromyosignals with elements of autonomous robotic manipulations on capture of a subject at achievement of threshold value of distance to him by means of the decision-making which is not demanding participation of the user on the beginning or the termination of implementation of the gripper by means of information from additional sensors (temperature and distance), and about force of compression of a subject by means of information from sensors.

Also, in a picture, the example of an arrangement of sensors on the hand artificial limb has been shown below (**Figure 2**).

Example of the scheme of realization of the data acquisition in the form of the myoelectric system (poses 1—system of reading, poses 2—sensor of registration of biopotential, poses 3—elastic cuff) (**Figure 3**).

The use of wireless data transmission between the artificial limb and the system of control provides usability of system and interchangeability of components, besides a possibility of their use independently of each other.

It is important to notice that in the course of the analysis of putting off data it was revealed that a bracelet for management of a prosthesis of the hand and a forearm in a case with the use of

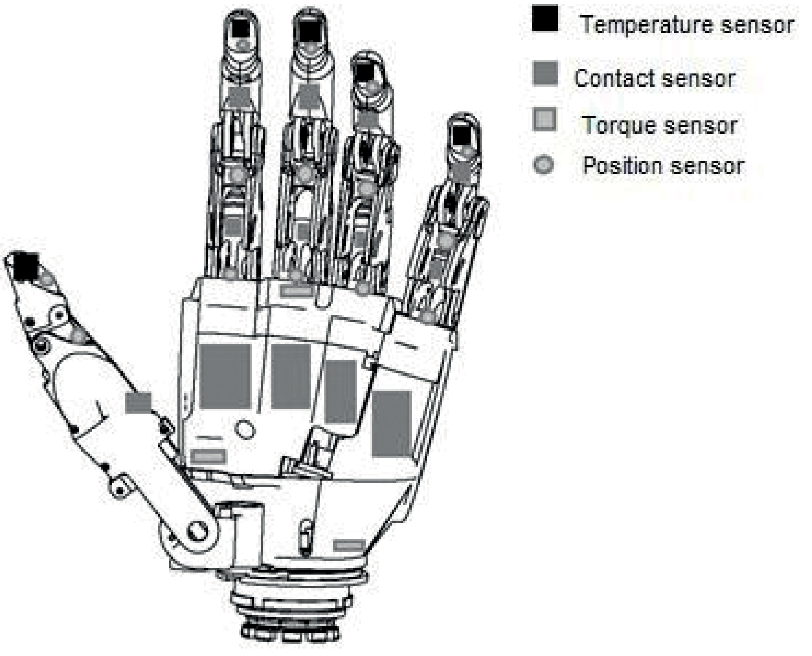

Figure 2. Example of the arrangement of sensors on the hand artificial limb.

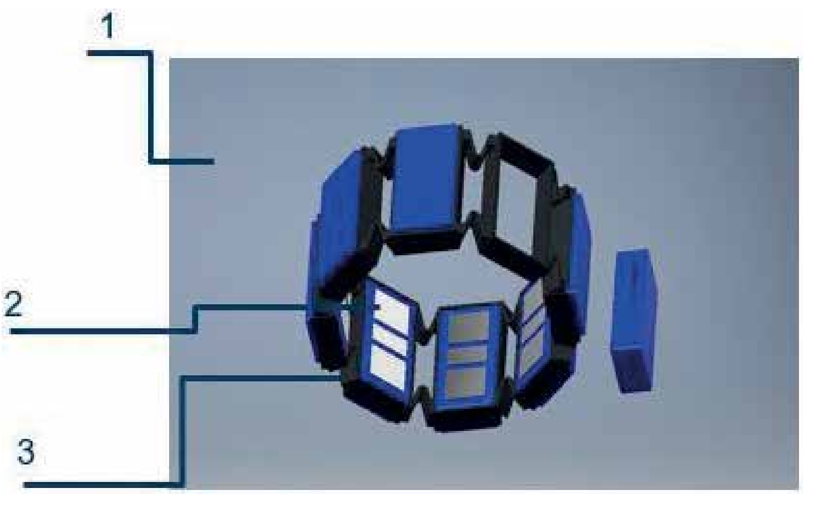

Figure 3. The scheme of realization of the data acquisition in the form of the myoelectric system.

neural network, it is possible to wear not only on a forearm and to take off data from a forearm, but also for management of the hand to take off data from a brachium that considerably dilated opportunities at a prosthetic repair by bionic prostheses of arms (of course, there is a restriction on number of gripper and features of management, at some disabled people different grippers are defined variously in connection with features of a stump).

2.2. Technology of the work of the virtual reality and game devices with the use of the electromyographic bracelet

The control of the virtual reality happens as follows: the myoelectric device of reading in the form of a bracelet (or a similar design the device) is put on a forearm or an arm, or other parts of an extremity, as the example, legs, occurs calibration and control of a bracelet, it can be made on the computer, the phone (**Figure 4**), as also without the computer or the phone.

Points of virtual reality consist at least of different types of lenses, the display, the details of the case, the computing system, the accelerometer, the gyroscope, and the sensor of the wireless communication (Bluetooth) (**Figure 5**).

Communication between the bracelet and points of virtual reality is been organized by means of any wireless communication, in our case are used by Bluetooth at what by Bluetooth of a bracelet it is ready as conducted, and Bluetooth of points of virtual reality as the master. The myoelectric device for reading, in the form of the bracelet (or the similar design of the device), carries out registration and filtration of the electromyogram (EMG), defines position of the hand, depending on it sends the corresponding command to points of virtual reality, or obtains information on feedback. It is important that the myoelectric device of reading besides the gripper given according to numbers sends to points information from the gyroscope and the accelerometer that allows to define position of the hand in space better. The arrangement of the myoelectric device for reading not only on hands but also on legs, the back, and the neck

Figure 4. The virtual reality and bracelet.

Figure 5. Example of the scheme of the device of points of the virtual reality.

is possible allowing to define better an arrangement of other parts of the body in space. In addition, points of virtual reality are capable to transfer information of feedback and to start the vibromotor on the myoelectric device for reading that allows to create feedback; also, additional arrangement and other sensors of feedback and sensors is possible.

Management of radio-controlled model of the machine happens as follows: the myoelectric device of reading in the form of a bracelet (or a similar design the device) is put on the forearm or the arm, there is the calibration and setup of the device of the bracelet, it can be made on the computer, the phone (**Figure 6**), as also without the computer or the phone.

The radio-controlled model consists at least of a chip, sensor of the wireless communication (Bluetooth), and engines of motors (**Figure 7**).

Communication between a bracelet and radio-controlled model the machine is organized by means of any wireless communication, in our case are used by Bluetooth at what by Bluetooth of a bracelet it is ready as the master, and machine model Bluetooth as conducted. After start of both devices, with connection without intermediaries, the device of a wireless communication of a bracelet is connected to the communication device of the executive mechanism; in our case communication requires knowledge by the master of the name and password of the communication device of the executive mechanism. In this case devices are connected through the intermediary device (the computer, phone), and then the intermediary device participates in

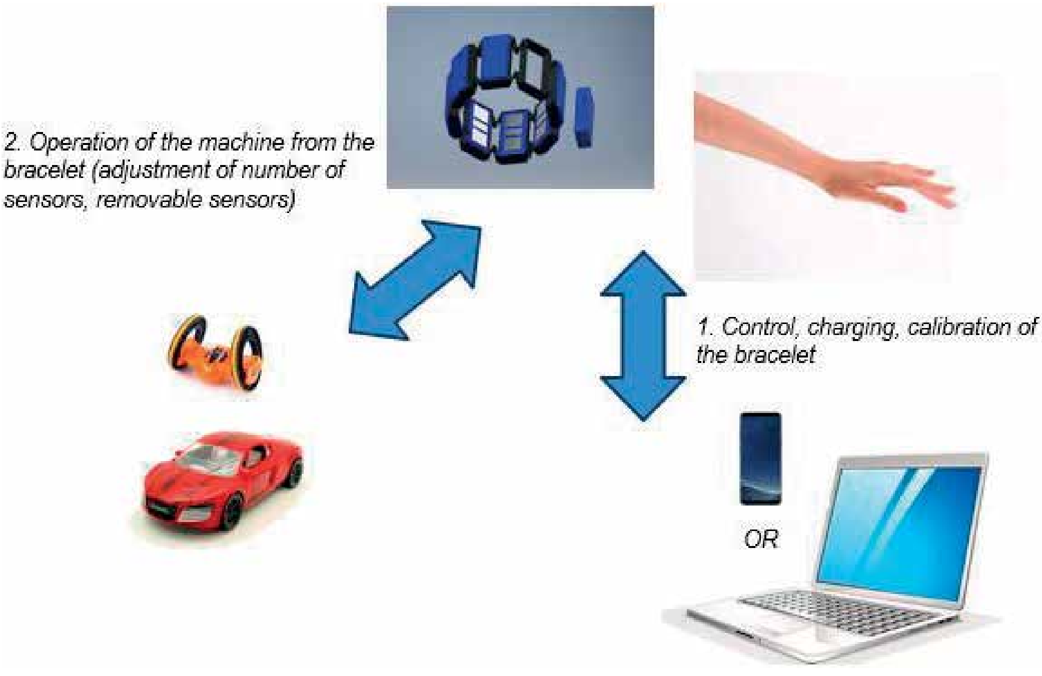

Figure 6. Example of the scheme of setup of the machine or other executive mechanisms.

installation of communication between devices. The myoelectric device of reading carries out registration and filtration of the electromyogram (EMG), defines position of a hand and, depending on him, sends to model the machine the corresponding team. List of tasks: F—the machine begins advance will not receive the next task, B—model the machine begins the movement back will not receive the next task yet, L—model the machine begins the movement on the left so far this task comes, after its termination continues action which executed before receiving commands (advance, back, inaction), R—model the machine begins the movement to the right so far this task comes, after its termination continues action which executed before receiving commands (advance, back, inaction), S—the model stop the machine.

Model of the machine receives the task, and the chip processes it depending on the task and carries out manipulations over motors, to begin rotation, to change the direction of rotation, and to stop. After implementation of the current command, the device is ready to perform the following. Also, from model, the machine can come to the bracelet information of feedback and start the vibromotor on the bracelet or other types of sensors.

Also it is possible a realization chance of the systems of rehabilitation with points of virtual reality, and without them. Namely, when there is a removal of data, for example, on gripper from a forearm or an arm of a hand, and transfer on the computer or phone for performance of certain gripper or three-dimensional motions, movements, on the computer or phone is started the program which obtains information and signals about successful or unsuccessful performance of a task, giving of a signal of feedback on a bracelet is also possible.

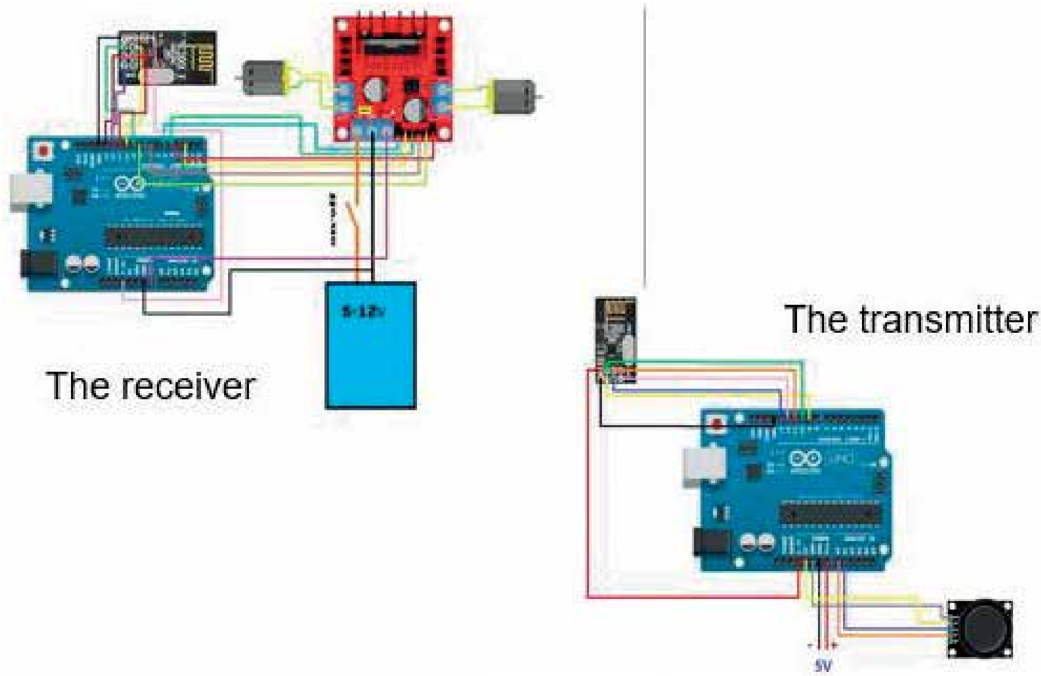

Figure 7. Scheme of the device of the executive mechanism of the car.

2.3. Algorithms of the recognition of EMG: approaches on the work with EMG

In this work we recognize the electromyogram removed from the skin (i.e., it is noninvasive), the recognition purpose—to understand what the gripper has been made by the hand.

Working with data, which has been obtained from muscular activity, it has been shown that for optimum work of algorithms on capture recognition, it is necessary to execute the following main stages of processing:

- Filtration
- Preprocessing
- Then, there is already a submission of data on neural network or an algorithm similar to it
- Post-data processing and additional training of neural or similar network

Assessment of the efficiency of algorithms is carried out in two main parameters—the accuracy of work of the algorithm and volume of calculations—as the most important for use in real time. Signs for an algorithm of classification have been distinguished from the initial signal; thus, the compactness hypothesis was carried out, where each gripper is the class. To achieve performance of this hypothesis, then practically any qualifier, including the simplest, such as can be suitable for classification: "classification by a minimum of Euclidean distance." Each certain canal is not of a particular interest since it is not possible to differentiate gesture on one channel. Whether from the channel it was possible to select only information on that reduction of the muscle. Further on what muscles have been reduced and what are not present to distinguish concrete gripper. The algorithm of preprocessing allows, quite precisely defining whether muscles, on this channel (**Figure 8**) have been reduced.

When algorithms were tested, two main variants were developed; the first one used simple preprocessing of the signal. Moreover, the second neural network hash function as additional preprocessing.

Without the neural network hash function, the results were shown in **Figure 9**.

Results of tests without the neural network hash function are shown in **Figure 10**.

All gestures were recognized with the probability greater than 70%, of these, two gestures were recognized with a probability of less than 80%, six with recognized with probability <90%, but >80%, eight gestures >90% and two with the probability of a business to 100%.

This method has been tested for real-time amputations. Its accuracy is averaged to about 90%.

Figure 11 shows the algorithm for recognizing gestures with neural network hash function.

In the first stage, a feature space has been generated from the signal. After that, a hash function has been used based on neural networks. After, the code classifier with the hash function recognizes gestures.

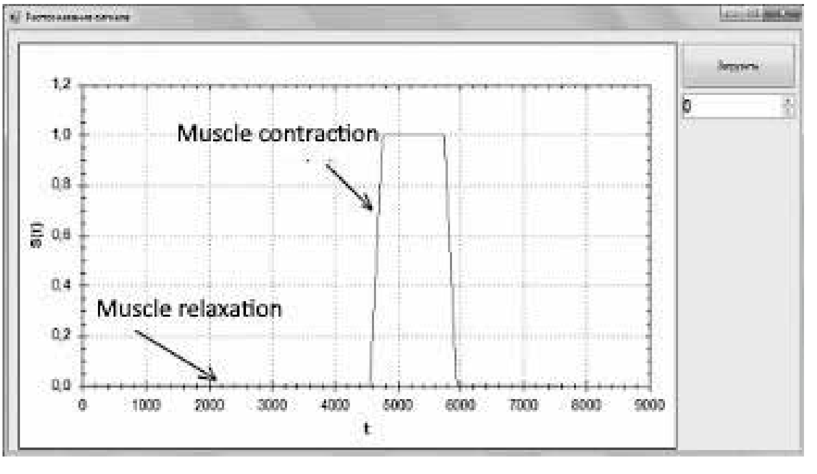

Figure 8. Recognition of the signal of EMG.

Figure 9. The process without the neural network hash function.

Recognition precision. Class №1: 95,6%
Recognition precision. Class №2: 81,2%
Recognition precision. Class №3: 96,9%
Recognition precision. Class №4: 89,2%
Recognition precision. Class №5: 79,3%
Recognition precision. Class №6: 85,9%
Recognition precision. Class №7: 68,8%
Recognition precision. Class №8: 73,7%
Recognition precision. Class №9: 79,7%
Recognition precision. Class №10: 80,7%
Recognition precision. Class №11: 85,9%
Recognition precision. Class №12: 83,5%
Recognition precision. Class №13: 64,3%
Recognition precision. Class №14: 93,6%
Recognition precision. Class №15: 95,2%

Figure 10. Results of tests without the neural network hash function.

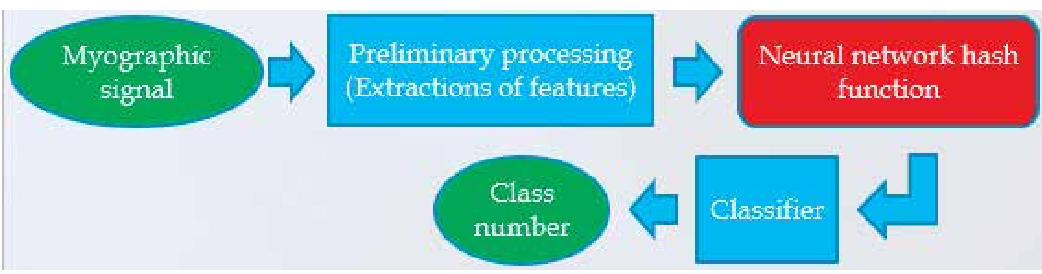

Figure 11. The process with the neural network hash function.

However, in this test, the signals have been recorded beforehand. Real-time mode had been simulated.

This algorithm has been tested on various amputees; the algorithm gives a high accuracy of determining the gesture. Below is the test of the algorithm on a person with shoulder amputation; seven gestures were recognized.

The picture shows the results of the test on seven gestures (**Figure 12a**), and the picture shows the results of the tests on 11 gestures (**Figure 12b**).

Neural network hash function consists not from one algorithm of neural net; it is complex of transformations, exactly five levels of different algorithms. On the entrance on the example, there are eight EMG signals, which had been modified with different neural networks and number of neurons. The details cannot be open because it is trade secret of the LLC “Bionic

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(a)

Recognition precision. Class № 1: 99,6666666666667%
Recognition precision. Class № 2: 99%
Recognition precision. Class № 3: 98,3333333333333%
Recognition precision. Class № 4: 99,3333333333333%
Recognition precision. Class № 5: 98,3333333333333%
Recognition precision. Class № 6: 99%
Recognition precision. Class № 7: 100%

(b)

Recognition precision. Class № 1: 98,3333333333333%
Recognition precision. Class № 2: 99%
Recognition precision. Class № 3: 100%
Recognition precision. Class № 4: 99,6666666666667%
Recognition precision. Class № 5: 98%
Recognition precision. Class № 6: 98,6666666666667%
Recognition precision. Class № 7: 99%
Recognition precision. Class № 8: 97,3333333333333%
Recognition precision. Class № 9: 98,3333333333333%
Recognition precision. Class № 10: 95,3333333333333%
Recognition precision. Class № 11: 99,6666666666667%

Figure 12. (a) Results of the test on seven gestures. (b) Results of the test on 11 gestures.

Natali" company and on this base had been created unique product of recognition of EMG signals of the hand.

According to the previous researches described in a source of information [3] for a condition of implementation of requirements of work in real time, the time of recognition of a signal has to occupy no more than 250 ms. For comfortable work of the user productivity or recognition accuracy (percentage of right cases of classification to all considered cases), it has not been lower than 95%, as shown in a source [4]. Most details about recognition can be found in a source of information [5].

Methods of recognition of EMG:

- For recognition at the first stage from a signal, various signs then the vector of these signs moves on the system of recognition are been taken.

- Most often as signs, counting bending around from different zones at the moment of time is used. As it is been made in work [6]. In addition, the system of recognition represents a set of rules. But approach at which the value bending around at the moment is chosen has one essential shortcoming. Mix-ups of gripper are possible in an area (**Figure 13**).

It is possible to fight against it in several ways: to pass the function which increases (falls down) quicker, than bending around, to use search of the maximum value bending around on an interval, to complicate the qualifier (e.g., to use recurrent or convolutional neural networks) that he considered not only the current values, but also some history or to use counters of operations for each class.

In our work, it has been used as signs of window dispersion. Properties of window dispersion of EMG are considered in work [7]. In addition, contrasting and scaling of value of dispersion have been applied. Then, at reduction of a muscle above which there is a sensor, the value is established in 1, and at relaxation it is in 0 (**Figure 14**).

After the previous processing, the signal arrives on the autoencoder to reduce entrance space of signs. Reduction of dimension of space of signs positively influences quality of the classification, in case of the use of metric qualifiers, because of a so-called "damnation of dimension" [8]. Later, there is a metric qualifier. Further, there is the counter of operations with the comparison block. After distinguished gripper goes to the operated device. The scheme of an algorithm has been submitted in **Figure 15**.

More detailed description is provided in the article [9, 10].

Also, alternatives for algorithms of the recognition exist; details can be found in articles [11–16].

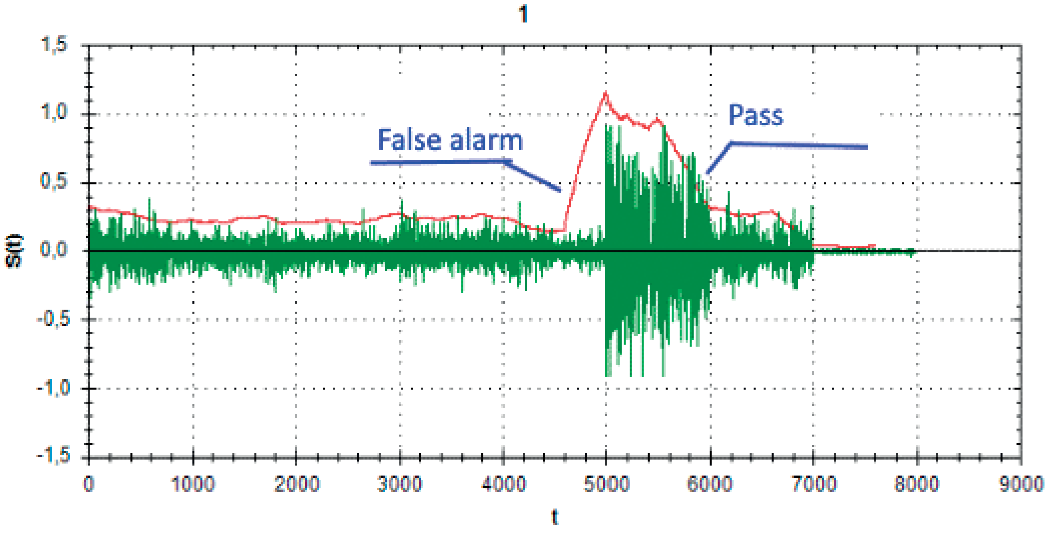

Figure 13. The bending-around signal EMG.

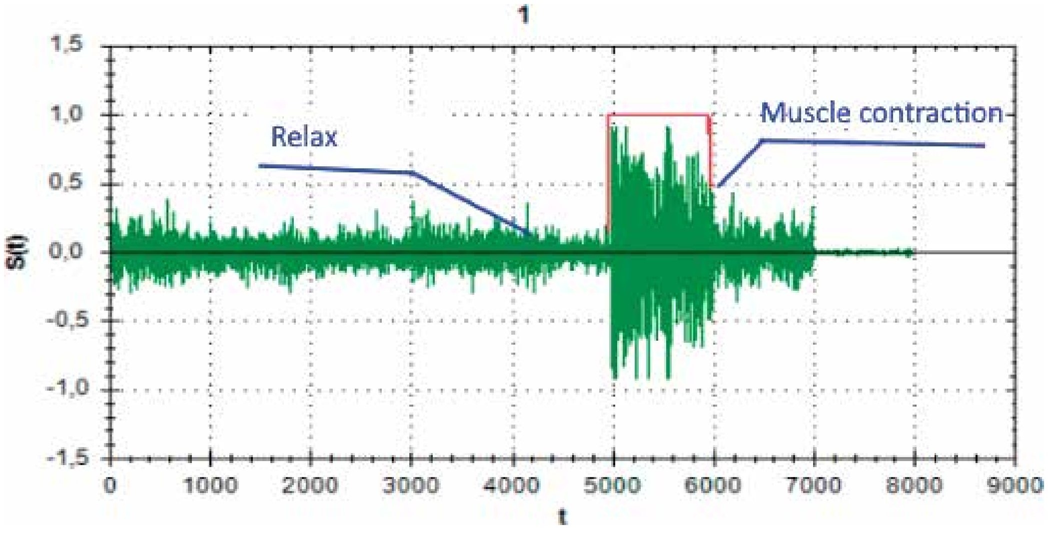

Figure 14. The algorithm of the previous processing.

2.4. Realization of developments with projects of LLC "Bionic Natali" and LLC "Bi-oN EMG"

Despite the fact that huge amount of works has been made, there is still a big area for activity concerning the choice and improvement of an algorithm on recognition of gripper, improvement of mechatronics, and the skin for an artificial hand. Similar work can be compared to art as we will compare the choice of an algorithm, the skin, and the solution of other technical problems with creativity. The current results of the LLC "Bionic Natali" company in this sphere—it is recognition with probability of 98% on 14 grippers on 8 sensors with amplifiers from a forearm. The concerning removal of data and recognition of capture in disabled people then in practice were difficulties at movements of muscles and pain at a spasm in long muscular tension. In this regard, a decision together with many medical centers to develop a method of restoration of muscles and to create the tool for their training has been made—the electromyographic bracelet from the LLC "Bi-oN EMG" company has been made. An important component is the mathematical analysis of these artifacts and their elimination for the possibility of practical application of bionic artificial limbs based on neural network and other algorithms in practice.

The same methods of control had been analyzed for movement of the knee, the first results just showed amazing implementation, and muscular activity of stump of leg can be used for control of movements of the knee. The control of sole does not need such instruments, because people usually use running artificial limbs for legs. Theoretical and preliminary practical results have shown big prospects in this direction, namely, the use of muscular activity and recognition of movements on the basis of neural network; in the process of completion of works in this sphere, they will be published.

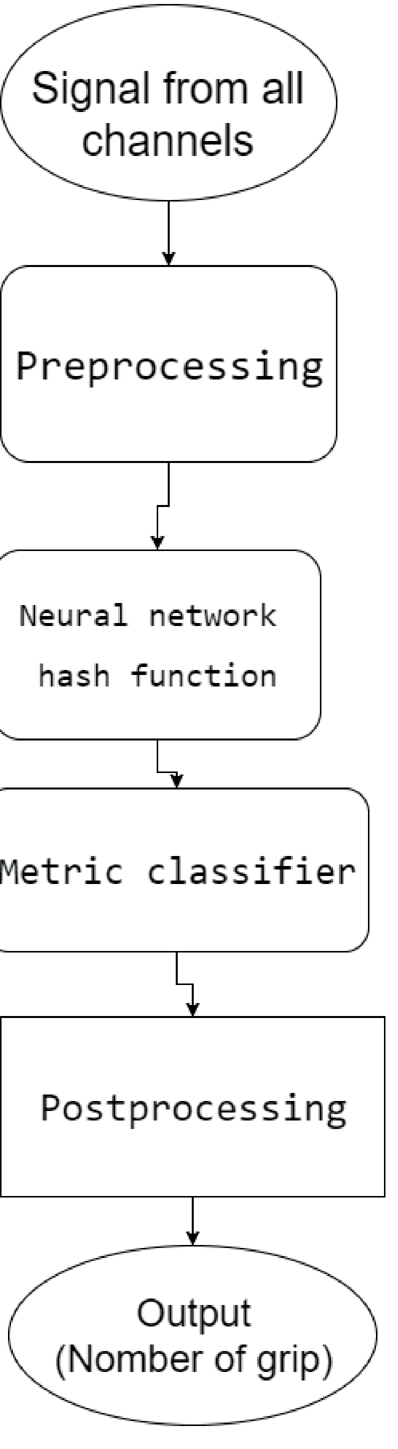

Figure 15. Flowchart of the algorithm.

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The electromyographic bracelet has found practical application in rehabilitation and game devices as it has been told earlier. And, researches and testing of bionic artificial limbs of hands on disabled people and testing of a bracelet on game devices for the last year have yielded new results which have allowed to draw a number of the main conclusions regarding formation of feedback at users, on the principles of receiving in general feedback on the basis of EMG.

It is important to note that because of these developments, four patents for the invention are created [17, 18].

3. Results of the practical application of developments of the recognition of EMG based on the neural network for disabled people at the management of bionic artificial limbs of hands and for game devices for people without disability

As already it has been noted above, thanks to the created technology researches of innovative feedback based on EMG for people without loss of limbs and also with loss of limbs regarding management of the systems of recognition of EMG based on the neural network have been conducted. Categories of people who participated in the research are the following:

- Without loss of an extremity (18 people): from 12 to 65 years with different functional adaptabilities to new devices and psychological outlook
- People with loss of an extremity (16 people): from 22 to 60 years with different psychological views and speed of reaction

Results of the analysis of an experiment have not included people who took only single part in a research as to reveal certain regularities, and there are needs to hold regular testing and checks; single participation is not natural and does not give understanding about feedback which is formed, and also in connection with complex psychological structure of people, the probability of obtaining wrong data is high.

The research objective is to reveal regularities using the control system of recognition of EMG from the shoulder and the forearm based on the neural network for different groups of people.

If to carry out the comparative analysis at people without amputation and with amputation, then results showed that physical training and a training of muscles plays a significant role regarding recognition of an EMG of a signal.

In spite of the fact that the signal in itself at people with an amputation of a hand is much more weak than people without loss have arms, the muscular training sometimes at people with amputation of an amputation allows to receive more accurate signal than a signal at the person of the same age group without loss of the limbs. Regular researches of people with amputation of limbs showed that more often there is a training of muscles and the muscle tone and also a comprehension and “representation” of gripper which are carried out by the person with amputation, and as a result, the subsequent already management of a bionic limb comes back quicker.

If to compare groups of people with the amputation of arms and different age categories, then the research showed that management does not depend on age in any way, but depends on the term of amputation and existence at the disabled person of a bionic/myoelectric prosthesis during this period. People who right after amputation began to use bionic/myoelectric prostheses or had a possibility of a training of muscles, had better discernible signals on frequency, and better coped with a task of management of a bionic prosthesis based on an EMG. There is an assumption that this feature arises because when the person lost a limb, at it the phantom feeling of an arm continues certain time to be held muscle in remembrance (even taking into account that injuries sometimes happen various and a part of muscles cannot remain or undergo other operations), as well as sometimes. If after that are not carried out a series of actions for maintenance of a muscle tone, then eventually there is a sharp atrophy of muscles which is harder and harder for restoring every year.

For example, the girl with amputation of the arm at accident of semiannual prescription, signals are equivalent to signals of the person without loss of a limb, even despite the performed two operations, and arenot comparable with the girl's signals at all with amputation of an arm of 3-year prescription, they after to which loss of a limb established a cosmetic prosthesis. The girl with amputation of semiannual prescription is capable to carry out 8 of 11 grippers of the hand, while the girl from 3-year prescription is capable to execute only 3 grippers taking into account that each user adapts signals for itself, that is, the neural network with the teacher is used and also taking into account that on all grippers the portable electromyograph fixed signals have been in both cases.

Conclusion: after carrying out operations within rehabilitation and the subsequent use to establish to the recommendation immediately bionic artificial limbs as eventually without trainings and also because of psychology of people "experience of management" the hand is lost, and without trainings of the muscle atrophy. However, restoration is possible; alas, it will demand much more time than in cases of immediate prosthetics by bionic/myoelectric artificial limbs.

In the course of the research pattern at the people using myoelectric prostheses and appreciable difference from the framed system on recognition of an EMG on the basis of neural network from eight sensors and more was taped, namely, at amputation of an arm, for example, management of myoelectric prostheses happens at a muscle tension of a biceps and a triceps at amputation of an arm.

The daily training leads to their appreciable development, but in cases when the same people begin to test an innovative control system on recognition of an EMG based on neural network with the teacher of Bi-oN, excellent recognition of signals regarding the turn of the hand has been provided to them. But performance of other grippers is problematic. The similar story at amputation of a hand is slightly higher than a hand at amputation term more than 3 years: management of signals of muscles to which disabled people got used is accurately traced, but at extension of the list of the gripper and a request to involve other muscles, there are problems with management which are surmountable at a training eventually but at the beginning bring difficulties.

It is important to note that the innovation of developments of Bi-oN has allowed to speak about new types of neural-control interface and feedback on the basis of signal EMG (such division as signals which are sent to the executive mechanism which are executed by the mechanism strongly differ has been allocated):

- The neural-control interface of the computer or a mobile application (the person)
- The neural-control interface of the artificial hand (the person)
- The neural-control interface of other executive mechanism (the person)

Moreover, it is important to note that for the first time when people begin to use neural-control interfaces, there is a fear, and after time there is adaptability.

Fundamental difference of the given neurointerfaces at external observation and according to users in how there is a management and receiving feedback. For example, the neurointerface of the computer-person allows to carry out rehabilitation and has no hidden mechanisms of management; for example, the bracelet is put on an arm, the computer is connected, and there is a calibration of a control system. Further, the user has to carry out the gripper or programs of a task at the movement by an arm. The computer signals about successful or wrong performance of a task. It is important to notice that in this "simplest" mechanism of the neurointerface a very important technique of a training of muscles is hidden; in particular the people who lost limbs or after a stroke when performing these tasks train not only muscular activity but also cerebrally, sometimes framing new neuronic communications which allow to cope with tasks more effectively. Special case, for example, of the most successful use of the neurointerface of the computer-person is used by his disabled person with amputation—at amputation of a brachium compression of "fist" took about 6 seconds; the patient that considerably complicatedly use it for control of other devices therefore the user thought up new approach and a signal on compression, that is it not compression of a fist, but compression of four fingers, except a thumb. Its execution lasted about 1–1.5 s; as a result the user learned to control an imaginary arm by means of new signals which very quickly became current. It is important to notice that feedback on gripper turns out by means of visual signals and the additional vibromotor in a bracelet, which can react at successful performance of a task. Possesses the similar scheme neurointerface with virtual reality which, in difference from augmented reality, transfers the person completely to the virtual world, but it is important to notice that psychologists long use of virtual reality because of yet not studied injuries which this reality can cause is not recommended. Therefore, all methods of rehabilitation take no more than 15–30 min, and even it is less.

Absolutely, a new principle regarding the neurointerface the hand person—it fundamental difference is especially shown at disabled people for whom the hand fastens to a sleeve and allows to control an arm actively. It is important to note that according to disabled people, it is perfect other perceptions and adaptations, namely, unlike the previous mechanism when there is a special ligament of people computer, in this case there is a communication of people hands which frames tactile perception and feelings when performing tasks.

And essentially another from all previous diagrams on neurointerface, is neurointerfaces on control of machines, quadcopters, etc. Their distinctive feature is, first of all, existence of the additional software on reassignment of grippers; for example, movement "turn to the right" is transferred “movement of a hand to the right,” “fist”—advance, “disclosure of a palm”—a stop, etc. That is, the use of system of reassignment leads to new perceptions and appearance of neural communications. This development is for the present researches and finishing, but in the next year shall be complete and receive practical application on bigger number of users.

Videos

There are many videos about research; most of them can be found with the following links:

- VR and Bi-oN EMG https://www.youtube.com/watch?v=RdrU28mI6Zk
- Technology of the work of the artificial limb https://www.youtube.com/watch?v=lJGK_rN2PzE
- Electromyographic bracelet Bi-oN EMG https://www.youtube.com/watch?v=6Ert5EShePU
- Archive http://bi-on.ru/arhiv/

4. Conclusion

It is worth noticing about essentially new approach in management of limbs if, for example, earlier the signal of muscular activity above a certain level was required for us, then in a case with neural network and special sensors and a payment of management of production of LLC “Bionic Natali” and LLC “Bi-oN EMG,” any signal, even we can “program” very weak signal somehow now; that is, in the absence of muscles or an atrophy of any muscles, it is possible to create a new type of management which is characteristic only of this patient, and also it is important to note convenience of recalibration which the patient can execute itself in house conditions.

On the basis of researches, the important conclusion was drawn: after carrying out operations within rehabilitation and the subsequent use, it is necessary to establish immediately bionic artificial limbs as eventually without trainings and also because of psychology of people “experience of management” an arm is lost, and without trainings of a muscle atrophy. However, restoration is possible; alas, it will demand much more time than in cases of an immediate prosthetic repair by bionic/myoelectric artificial limbs. The current researches also showed requirement of rehabilitation of disabled people before the use of bionic prostheses of arms; as the option is offered the use of an electromyographic bracelet of LLC “Bi-oN EMG.”

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Edited by Mark Schwartz

The six chapters in this volume form a timely introduction to biofeedback research. The six authors describe how objective electrophysiological data provides useful data for assessment and therapy for physical therapists, psychologists and other healthcare professionals and their clients.

The first chapter, “Biofeedback and neurofeedback in the treatment of migraine”, is written by Ph.D. student Zivoder Ivana. The second chapter by Prof. Dumitrascu looks at pelvic floor rehabilitation and is titled “Factors predicting failure in anorectal biofeedback”. The third chapter by Dr Liao Da-Vin is titled “Collaborative, social-networked posture training with posturing monitoring and biofeedback”. It is a useful and timely description of the role of biofeedback to support rehabilitation therapy at home and describe how objective information of physiotherapy treatments could increase the quality of service and the consistency of treatment outcomes. The fourth chapter by Prof. Silva Hugo is titled “Bridging the clinic-home divide in muscular rehabilitation”. It also covers the role of biofeedback to support rehabilitation therapy at home. The fifth chapter is written by Ph.D. student Grin-Yatsenko Vera and is titled “Effect of infra-low frequency neurofeedback on infra-slow-EEG-fluctuations”. The sixth and final chapter in the volume, “Control systems of bionic limbs of the new generation and control systems with EMG signals of VR and games, toys” by M.A. Ivaniuk Natallia goes beyond the person and shows how biofeedback can be integrated in the behavior of a bionic hand.

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