Chapter

Introductory Chapter: Smart Biofeedback – Perspectives and Applications

Edward Da-Yin Liao

1. About this book

This book is about the *perspectives and applications in smart biofeedback*. The chapters of this book provide a glimpse of the research projects and clinical applications that are underway in smart biofeedback as well as the perspectives of smart biofeedback.

Biofeedback is an autonomic feedback mechanism to let people (1) observe their physiologic information such as muscle tension, blood pressure, heartbeat rates, and brain wave signals, (2) develop awareness of their physiological reactions, and (3) learn to change these physiologic responses accordingly. The biofeedback mechanism helps people take responsibility for their cognitive, emotional, and behavioral changes for better health. A biofeedback process may utilize many and various sensors to measure physiologic functions and parameters. Sensory data are first collected, analyzed, and then fed back to the human sensor nervous system in a simple, direct and immediate way.

Modern biofeedback experiments began in the early 70's of the last century [1–3], with a promising evidence observed on the efficacy of clinical biofeedback applications [4–7]. For past five decades, uses of biofeedback techniques have been widely seen in health, wellness, awareness, and computer interactive entertainment, including therapies of self regulation of psychiatric and physiologic disorders [8–21], rehabilitation [22–28], healthcare [29–31], training activities such as balancing [32, 33], postural [34, 35], relaxation [36] and sports [37, 38], development of socio-emotional interactions [39, 40], assessment of psychophysiological stress [41–44], falling prevention and detection [45], computer game design [46], and more.

Smart biofeedback [47–52] is receiving attentions because of the widespread, available building blocks of advanced technologies and smart devices that are used in effective collection, analysis and feedback of physiologic data. Researchers and practitioners have been working on various aspects of smart biofeedback methodologies and applications by using wireless communications [53, 54], Internet of Things (IoT) [55, 56], wearables [57, 58], biomedical sensors [59–61], artificial intelligence [62], big data analytics [63], clinical virtual reality [64], smartphones [65, 66], APPs [67], and so forth. The current paradigm shift in information and communication technologies (ICT) such as smart and ultra-compressed sensing, generative adversarial network (GAN), analog bio-inspired machine learning, trainable neuromorphic signal converting, and quantum computing, has been propelling the rapid pace of innovation in smart biofeedback. As a new technology regime of research and applications we only scratch the surface of smart biofeedback.

2. Perspectives and applications in smart biofeedback

This book addresses five important topics of the perspectives and applications in smart biofeedback—*Brain Networks*, *Neuromeditation*, *Psychophysiological Psychotherapy*, *Physiotherapy*, and *Privacy, Security, and Integrity of Data*, described as below.

2.1 Brain networks

Human brain is an information-sharing network which is connected by many spatially distributed, but functionally linked regions of the brain. Exploration of dynamic interactions of the large-scale brain network can construct the relationships among brain regions. It helps understand which and how brain regions actually cooperate during creative cognition and artistic performance. In past decades, neuroimaging studies have investigated the functional connectivity by measuring the level of co-activation of resting-state functional magnetic resonance imaging (fMRI) time series between brain regions [68]. Recent advancements in smart biofeedback technology have paved a promising avenue for real-time, *in vivo* analysis and modeling of nerve synapses in the brain. Electrical neuroimaging [69] that uses electroencephalography (EEG) biofeedback [70] as the neuroimaging technique has the advantages of online recording of the neuronal activity in real time. As a window into the brain, EEG has been used to localize the neural activity in the brain non-invasively. Biofeedback, also known as neurobiofeedback or neurofeedback (NFB) [71, 72], is a psychophysiological mechanism for training of self-regulation and has shown compelling findings about brain function and the neural correlates of behavior and cognition.

2.2 Neuromeditation

Over the last years, the soaring public interest in mindfulness meditation has raised scientific attention. For many people, mindfulness meditation brings a lot of benefits and is considered useful for training attention on cognition and emotion simultaneously. However, some of them are either difficult to maintain a disciplined practice regularly, or lack of methodologies or tools to develop their meditation practice more rapidly. Research studies have observed that many similarities of changes in EEG frequency bands trained in cognitive NFB therapeutic protocols are found in the mental activity involved in meditation practices [73]. As both meditation and NFB are techniques to train mental states, systems or applications based on NFB or real-time EEG biofeedback techniques have the potentials to help develop meditation. However, the reliability and accuracy of signal detection remain questionable in current neuromeditation applications. It is challenging to describe the complex brain activity during meditation by basic EEG analyses [74].

2.3 Psychophysiological psychotherapy

While psychophysiological and behavioral interventions manifest equivalent effectiveness for some kinds of psychological problems, most psychotherapeutic practices focus on the cognitive procedures. Even though psychophysiological approaches that use heart rate variability (HRV) biofeedback in muscle relaxation and breathing interventions have shown significant effects in clinical psychotherapies, psychophysiological methods are often downplayed [75, 76]. Psychotherapy is increasingly emphasizing clinical processes and mechanisms in developing smart biofeedback protocols in psychotherapeutic training programs to mitigate patient's physical and psychological disorders such as headache [77], depression [78], and anxiety [79]. As the engagement of an efficacious patient-therapist relationship is prominent in psychotherapy [80], development of innovative, artificial-intelligence-augmented tools and systems for interpersonal biofeedback [81] is required to optimize therapists' awareness of unconscious interpersonal regulation dynamics on a moment-to-moment basis.

2.4 Physiotherapy

Biofeedback has been an established, non-pharmacologic technique in physiotherapy and rehabilitation to mitigate migraine headache [82], relax pelvic floor muscles [83–86], help stoke patients regain movement in paralyzed muscles [87, 88], relieve chronic pains [89], and reduce Raynaud's phenomenon [90]. Recently, a combined approach, named Imagined Imitation [91], that integrates traditional physiotherapy with NBF appears to establish more therapeutic benefits. In conjunction with electromechanical physiotherapy, participants who receive NFB training sessions get better improved in motor control of their affected arms [92]. The mechanism of the effectiveness by combining NFB with physiotherapy to modulate brain activity is still yet to explore. However, such a combined approach opens a grand door to both researchers and practitioners for design of user interfaces and user experience scenarios which drive sound user engagement with proper match of the level of challenge, according to the participant's ability and conditions.

2.5 Privacy, security, and integrity of data

The prospectives and applications in smart biofeedback have to embrace the advanced ICT integration. In addition to diagnosis information, demographic, medical, and psychological data, as well as historical information such as duration of complaints and treatment history, should be well managed [93]. Simultaneous acquisition of data from multiple physiological sensors introduces new challenges to data management along the path of data life cycle of each data, from sensing, measuring, interpreting, transmitting, storing, analyzing, predicting, learning, to optimizing. Smart biofeedback belongs to highly interconnected systems and applications that demand end-to-end privacy, security, and integrity of data for proper operations [94]. Smart biofeedback systems and applications are all built on the assumption of reliable and secure communication but are vulnerably exposed to various treats and attacks. As more and more smart biofeedback systems and applications with IoT, cloud and edge computing implementation are emerging, new system architectures and approaches such as blockchains are to develop for massively distributed processing, to ensure the privacy, security, and integrity of data.

3. How the book is organized

This book consists of six chapters. The remaining of the book is into five sections to cope with the five specific topics of the perspectives and applications in smart biofeedback described above. All the chapters are from academic researchers and clinical practitioners on various areas of smart biofeedback. This introductory chapter, Chapter 1, describes the nature and purpose of this book and outlines the scope, logic and significance of the contents of this book.

Chapter 2 in the *Brain Networks* section overviews the recent advances in electrical neuroimaging, brain networks and neurofeedback protocols. It starts with a review of live Z-score NBF training which uses an EEG normative reference database to identify the possibly dysregulated brain regions from the probabilities estimated by auto and cross-spectrum of EEG. New advances in electrical neuroimaging provide a 12,700-voxel resolution, three-dimensional EEG source location that uses swLORETA (weighted standardized low resolution electromagnetic tomography) and 19 channels for NBF. Such technologies enable the NFB approach to cerebellar and subcortical brain hubs like the thalamus, amygdala and habenula. Linking symptoms to dysregulated brain hubs and networks is crucial to help patients of NBF training. New development in cerebellar z-score NBF research has shown a bright future in NBF for brain networks. Potential applications of future swLORETA z-score NBF include helping people with cognition problems as well as balance problems, and Parkinsonism.

Chapter 3 in the *Neuromeditation* section introduces the science and practice of neuromeditation. Combining NFB and meditation, neuromeditation monitors brainwave activity to help meditators learn to quickly enter a desired state of consciousness and then maintain the state for a period of time for improvements in mental health. The history, examples, and research evidence on neuromeditation are reviewed. As researches on both NFB and meditation have found effective in the treatment of various mental health concerns, respectively, the efficacy of neuromeditation is reviewed with a case study about a middle-aged, Caucasian female with anxiety, eating disorder, and post traumatic stress disorder (PTSD) mental health history. Assessment results, including a quantitative EEG (qEEG) assessment comparing her baseline EEG activity to a clinical database, indicate that her concerns most closely match the Quiet Mind style of meditation. A mindfulness meditation protocol with eight neuromeditation sessions is identified as the best for her concerns and background. Most of the improvements are found directly related to the goals and concerns identified in the intake process.

Chapter 4 in the *Psychophysiological Psychotherapy* section surveys the most common eight modalities of biofeedback in clinical psychology and provides the perspectives of how biofeedback is applied to manage the psychophysiological conditions. It aims to elucidate the clinical settings in psychotherapy practices and point out the psychophysiological conditions for biofeedback training. It reviews the basic principles of psychophysiology, including the balance mechanism between the fight-or-flight (sympathetic) versus the rest-and-digest (parasympathetic) pathways in the autonomic nervous system (ANS) where biofeedback can regulate and provide balance between sympathetic and parasympathetic responses to mitigate psychopathological symptoms and to improve cognitive performance. It demonstrates several successful biofeedback training protocols in clinical psychology, including managing stress in anxious patients, managing hyperactivity of children with attention deficit hyperactivity disorder (ADHD), managing depression.

Chapter 5 in the *Physiotherapy* section deals with the problems of chronic pains. It surveys six NBF protocols to evaluate the efficacy of NBF training for treatment to chronic pains. At first, it introduces the mechanisms and neural pathways underlying pain perception, and describes the brain rhythms associated with chronic pains and the identification of neurophysiological correlates of chronic pains. The efficacy of the two key NBF modalities, EEG and fMRI, for chronic pains are discussed. A NBF protocol with EEG target brain rhythms is provided. It surveys the efficacy of various NFB training protocols applied in the management of chronic pains, including fibromyalgia, central neuropathic pains in paraplegic patients, traumatic brain injury, chemotherapy-induced peripheral neuropathy, primary headache, complex region pain syndrome type I, post-herpetic neuralgia, and chronic lower back pains. The feasibility and availability of home-based NFB therapy for chronic pains are reviewed. Finally, it discusses the adverse effects associated with NFB training and limitations, and provides future recommendations.

Chapter 6 in the *Privacy, Security, and Integrity of Data* section presents the design and applications of the Blockchain-based Medical Data Management System (BMDMS) for management of medical health records and biofeedback data. As an emerging and prospective technology in ICT, blockchain is featured by its privacy, security, and integrity of data so that blockchain-enabled information and data will remain safe and secure. BMDMS adopts the smart contract approach to reduce the need in trusted intermediators, fraud losses, and accidental or malicious exceptions, in order to protect the privacy of patients and medical practitioners. Patients can take biofeedback training at home or in any local clinics, hospitals, or large medical centers and their medical health records and collected biofeedback data can be shared among medical facilities within BMDMS in a secure and safe way. The proposed BMDMS framework utilizes big data, analytics, and edge/cloud computing technologies, to smartly retrieve the exact amount of data to optimize the computing and storage capabilities. BMDMS thus avoids the possible deluge of clinic or laboratory data, such as massive data collected from biofeedback sensors.

Author details

Edward Da-Yin Liao
Straight and Up Intelligent Innovations Group Co., San Jose, CA, USA

*Address all correspondence to: eliao@miicg.com

References

[1] Karlins, M. and Andrews, L.M., 1972. Biofeedback: Turning on the power of your mind. Lippincott Williams & Wilkins.

[2] Kater, D. and Spires, J., 1975. Biofeedback: The beat goes on. *The School Counselor*, *23*(1), pp.16-21.

[3] Tarler-Benlolo, L., 1978. The role of relaxation in biofeedback training: a critical review of the literature. *Psychological Bulletin*, *85*(4), p.727.

[4] Blanchard, E.B. and Young, L.D., 1974. Clinical applications of biofeedback training: A review of evidence. *Archives of General Psychiatry*, *30*(5), pp.573-589.

[5] Miller, N.E., 1978. Biofeedback and visceral learning. *Annual review of psychology*, *29*(1), pp.373-404.

[6] King, N.J. and Montgomery, R.B., 1980. Biofeedback-induced control of human peripheral temperature: A critical review of literature. *Psychological Bulletin*, *88*(3), p.738.

[7] Duckro, P.N. and Cantwell-Simmons, E., 1989. A review of studies evaluating biofeedback and relaxation training in the management of pediatric headache. *Headache: The Journal of Head and Face Pain*, *29*(7), pp.428-433.

[8] Futterman, A.D. and Shapiro, D., 1986. A review of biofeedback for mental disorders. *Psychiatric Services*, *37*(1), pp.27-33.

[9] Enck, P., 1993. Biofeedback training in disordered defecation. *Digestive diseases and sciences*, *38*(11), pp.1953-1960.

[10] Riegel, B., Warmoth, J.E., Middaugh, S.J., Kee, W.G., Nicholson, L.C., Melton, D.M., Parikh, D.K. and Rosenberg, J.C., 1995. Psychogenic cough treated with biofeedback and psychotherapy. A review and case report. *American journal of physical medicine & rehabilitation*, *74*(2), pp.155-158.

[11] Trudeau, D.L., 2000. The treatment of addictive disorders by brain wave biofeedback: A review and suggestions for future research. *Clinical Electroencephalography*, *31*(1), pp.13-22.

[12] Palsson, O.S., Heymen, S. and Whitehead, W.E., 2004. Biofeedback treatment for functional anorectal disorders: a comprehensive efficacy review. *Applied psychophysiology and biofeedback*, *29*(3), pp.153-174.

[13] Maryn, Y., De Bodt, M. and Van Cauwenberge, P., 2006. Effects of biofeedback in phonatory disorders and phonatory performance: a systematic literature review. *Applied psychophysiology and biofeedback*, *31*(1), pp.65-83.

[14] Medlicott, M.S. and Harris, S.R., 2006. A systematic review of the effectiveness of exercise, manual therapy, electrotherapy, relaxation training, and biofeedback in the management of temporomandibular disorder. *Physical therapy*, *86*(7), pp.955-973.

[15] Nestoriuc, Y., Martin, A., Rief, W. and Andrasik, F., 2008. Biofeedback treatment for headache disorders: a comprehensive efficacy review. *Applied psychophysiology and biofeedback*, *33*(3), pp.125-140.

[16] Sokhadze, T.M., Cannon, R.L. and Trudeau, D.L., 2008. EEG biofeedback as a treatment for substance use disorders: review, rating of efficacy, and recommendations for further research. *Applied psychophysiology and biofeedback*, *33*(1), pp.1-28.

[17] Schoenberg, P.L. and David, A.S., 2014. Biofeedback for psychiatric disorders: a systematic review. *Applied psychophysiology and biofeedback*, *39*(2), pp.109-135.

[18] Fazeli, M.S., Lin, Y., Nikoo, N., Jaggumantri, S., Collet, J.P. and Afshar, K., 2015. Biofeedback for nonneuropathic daytime voiding disorders in children: a systematic review and meta-analysis of randomized controlled trials. *The Journal of urology*, *193*(1), pp.274-280.

[19] Tremback-Ball, A., Gherghel, E., Hegge, A., Kindig, K., Marsico, H. and Scanlon, R., 2018. The effectiveness of biofeedback therapy in managing Bladder Bowel Dysfunction in children: A systematic review. *Journal of pediatric rehabilitation medicine*, *11*(3), pp.161-173.

[20] Jokubauskas, L. and Baltrušaitytė, A., 2018. Efficacy of biofeedback therapy on sleep bruxism: A systematic review and meta-analysis. *Journal of oral rehabilitation*, *45*(6), pp.485-495.

[21] Sugden, E., Lloyd, S., Lam, J. and Cleland, J., 2019. Systematic review of ultrasound visual biofeedback in intervention for speech sound disorders. *International journal of language & communication disorders*, *54*(5), pp.705-728.

[22] Basmajian, J.V., 1981. Biofeedback in rehabilitation: a review of principles and practices. *Archives of physical medicine and rehabilitation*, *62*(10), pp.469-475.

[23] Cozean, C.D., Pease, W.S. and Hubbell, S.L., 1988. Biofeedback and functional electric stimulation in stroke rehabilitation. *Archives of physical medicine and rehabilitation*, *69*(6), pp.401-405.

[24] Glanz, M., Klawansky, S. and Chalmers, T., 1997. Biofeedback therapy in stroke rehabilitation: a review. *Journal of the Royal Society of Medicine*, *90*(1), pp.33-39.

[25] Huang, H., Wolf, S.L. and He, J., 2006. Recent developments in biofeedback for neuromotor rehabilitation. *Journal of neuroengineering and rehabilitation*, *3*(1), p.11.

[26] Giggins, O.M., Persson, U.M. and Caulfield, B., 2013. Biofeedback in rehabilitation. *Journal of neuroengineering and rehabilitation*, *10*(1), p.60.

[27] Prinsloo, G.E., Rauch, H.L. and Derman, W.E., 2014. A brief review and clinical application of heart rate variability biofeedback in sports, exercise, and rehabilitation medicine. *The Physician and sportsmedicine*, *42*(2), pp.88-99.

[28] Richards, R., van den Noort, J.C., Dekker, J. and Harlaar, J., 2017. Gait retraining with real-time biofeedback to reduce knee adduction moment: systematic review of effects and methods used. *Archives of physical medicine and rehabilitation*, *98*(1), pp.137-150.

[29] Andrasik, F., 2010. Biofeedback in headache: an overview of approaches and evidence. *Cleve Clin J Med*, *77*(Suppl 3), pp.S72-S76.

[30] Klich, U., 2015. The integration of mindfulness-based biofeedback and compassion in the healthcare setting. *Biofeedback*, *43*(3), pp.111-116.

[31] Badawi, H.F. and El Saddik, A., 2020. Biofeedback in healthcare: State of the art and meta review. In *Connected Health in Smart Cities* (pp. 113-142). Springer, Cham.

[32] Zijlstra, A., Mancini, M., Chiari, L. and Zijlstra, W., 2010. Biofeedback for training balance and mobility tasks in older populations: a systematic

review. *Journal of neuroengineering and rehabilitation*, *7*(1), p.58.

[33] Ma, C.Z.H., Wong, D.W.C., Lam, W.K., Wan, A.H.P. and Lee, W.C.C., 2016. Balance improvement effects of biofeedback systems with state-of-the-art wearable sensors: A systematic review. *Sensors*, *16*(4), p.434.

[34] Liao, D.Y., 2016, June. Design of a secure, biofeedback, head-and-neck posture correction system. In 2016 IEEE First International Conference on Connected Health: Applications, Systems and Engineering Technologies (CHASE) (pp. 119-124). IEEE.

[35] Cerqueira, S.M., Da Silva, A.F. and Santos, C.P., 2020. Smart Vest for Real-Time Postural Biofeedback and Ergonomic Risk Assessment. *IEEE Access*, *8*, pp.107583-107592.

[36] Yu, B., Hu, J., Funk, M., Liang, R.H., Xue, M. and Feijs, L., 2018. RESonance: Lightweight, room-scale audio-visual biofeedback for immersive relaxation training. *IEEE Access*, *6*, pp.38336-38347.

[37] Umek, A., Zhang, Y., Tomažič, S. and Kos, A., 2017. Suitability of strain gage sensors for integration into smart sport equipment: A golf club example. *Sensors*, *17*(4), p.916.

[38] Raymond, J., Sajid, I., Parkinson, L.A. and Gruzelier, J.H., 2005. Biofeedback and dance performance: A preliminary investigation. *Applied psychophysiology and biofeedback*, *30*(1), pp.65-73.

[39] Liao, D.Y., 2018. Collaborative, Social-Networked Posture Training with Posturing Monitoring and Biofeedback. In *Biofeedback*. IntechOpen.

[40] Ciolacu, M.I., Binder, L. and Popp, H., 2019, October. Enabling IoT in Education 4.0 with BioSensors from Wearables and Artificial Intelligence. In *2019 IEEE 25th International Symposium for Design and Technology in Electronic Packaging (SIITME)* (pp. 17-24). IEEE.

[41] Weatherall, M., 1999. Biofeedback or pelvic floor muscle exercises for female genuine stress incontinence: a meta-analysis of trials identified in a systematic review. *BJU international*, *83*, pp.1015-1016.

[42] Peake, J.M., Kerr, G. and Sullivan, J.P., 2018. A critical review of consumer wearables, mobile applications, and equipment for providing biofeedback, monitoring stress, and sleep in physically active populations. *Frontiers in physiology*, *9*, p.743.

[43] Kennedy, L. and Parker, S.H., 2019. Biofeedback as a stress management tool: a systematic review. *Cognition, Technology & Work*, *21*(2), pp.161-190.

[44] De Witte, N.A., Buyck, I. and Van Daele, T., 2019. Combining biofeedback with stress management interventions: A systematic review of physiological and psychological effects. *Applied Psychophysiology and Biofeedback*, *44*(2), pp.71-82.

[45] Horta, E.T., Lopes, I.C., Rodrigues, J.J. and Misra, S., 2013, October. Real time falls prevention and detection with biofeedback monitoring solution for mobile environments. In *2013 IEEE 15th International Conference on e-Health Networking, Applications and Services (Healthcom 2013)* (pp. 594-600). IEEE.

[46] Nacke, L.E., Kalyn, M., Lough, C. and Mandryk, R.L., 2011, May. Biofeedback game design: using direct and indirect physiological control to enhance game interaction. In *Proceedings of the SIGCHI conference on human factors in computing systems* (pp. 103-112).

[47] Mavroidis, C., Nikitczuk, J., Weinberg, B., Arango, R., Danaher, G., Jensen, K., Leahey, M., Pavone, R.,

Pelletier, P., Provo, A. and Prugnarola, J., 2005, January. Smart portable rehabilitation devices. In *International Design Engineering Technical Conferences and Computers and Information in Engineering Conference* (Vol. 47446, pp. 501-510).

[48] Senanayake, S.A. and Naim, A.G., 2019. Smart sensing and biofeedback for vertical jump in sports. In *Modern Sensing Technologies* (pp. 63-81). Springer, Cham.

[49] Anandh, S., Vasuki, D.R., Al Baradie, D. and Saleem, R., 2020. Smart Biofeedback Expectorant System for Improving the Lung Capacities. *International Journal of Advanced Research in Engineering and Technology (IJARET)*, *11*(3), pp.240-248.

[50] Kos, A. and Umek, A., 2018. Smart sport equipment: SmartSki prototype for biofeedback applications in skiing. *Personal and Ubiquitous Computing*, *22*(3), pp.535-544.

[51] Shen, T.W., Hsiao, T., Liu, Y.T. and He, T.Y., 2008, November. An ear-lead ECG based smart sensor system with voice biofeedback for daily activity monitoring. In *Tencon 2008-2008 IEEE Region 10 Conference* (pp. 1-6). IEEE.

[52] Meriggi, P., Mandalà, M., Brazzoli, E., Piacente, T., Mazzola, M. and Olivieri, I., 2018, July. Smart objects and biofeedback for a pediatric rehabilitation 2.0. In *Italian Forum of Ambient Assisted Living* (pp. 105-119). Springer, Cham.

[53] Johansson, A., Shen, W. and Xu, Y., 2011, September. An ANT based wireless body sensor biofeedback network for medical e-health care. In *2011 7th International Conference on Wireless Communications, Networking and Mobile Computing* (pp. 1-5). IEEE.

[54] Kos, A., Milutinović, V. and Umek, A., 2019. Challenges in wireless communication for connected sensors and wearable devices used in sport biofeedback applications. *Future generation computer systems*, *92*, pp.582-592.

[55] De Venuto, D., Annese, V.F. and Sangiovanni-Vincentelli, A.L., 2016, May. The ultimate IoT application: A cyber-physical system for ambient assisted living. In *2016 IEEE International Symposium on Circuits and Systems (ISCAS)* (pp. 2042-2045). IEEE.

[56] Rastogi, R., Chaturvedi, D.K. and Gupta, M., 2020. Tension Type Headache: IOT and FOG Applications in Healthcare Using Different Biofeedback. In *Handbook of Research on Advancements of Artificial Intelligence in Healthcare Engineering* (pp. 318-358). IGI Global.

[57] Umek, A., Tomažič, S. and Kos, A., 2015. Wearable training system with real-time biofeedback and gesture user interface. *Personal and Ubiquitous Computing*, *19*(7), pp.989-998.

[58] Marta, G., Simona, F., Andrea, C., Dario, B., Stefano, S., Federico, V., Marco, B., Francesco, B., Stefano, M. and Alessandra, P., 2019. Wearable biofeedback suit to promote and monitor aquatic exercises: a feasibility study. *IEEE Transactions on Instrumentation and Measurement*, *69*(4), pp.1219-1231.

[59] Rodrigues, J.J., Pereira, O.R. and Neves, P.A., 2011. Biofeedback data visualization for body sensor networks. *Journal of Network and Computer Applications*, *34*(1), pp.151-158.

[60] Caetano, I., Alves, J., Gonçalves, J., Martins, M. and Santos, C.P., 2016, May. Development of a biofeedback approach using body tracking with Active Depth sensor in ASBGo smart walker. In *2016 International Conference on Autonomous Robot Systems and Competitions (ICARSC)* (pp. 241-246). IEEE.

[61] Wang, Y., Wan, B., Li, H. and Shan, G., 2016. A wireless sensor system for a biofeedback training of hammer throwers. *SpringerPlus*, *5*(1), pp.1-14.

[62] Mongan, W.M., 2018. Predictive Analytics on Real-Time Biofeedback for Actionable Classification of Activity State. Drexel University.

[63] Janatova, M., Uller, M., Stepankova, O., Brezany, P. and Lenart, M., 2019. A Novel Big Data-Enabled Approach, Individualizing and Optimizing Brain Disorder Rehabilitation. In *Big Data for the Greater Good* (pp. 101-127). Springer, Cham.

[64] Repetto, C., Gorini, A., Vigna, C., Algeri, D., Pallavicini, F. and Riva, G., 2009. The use of biofeedback in clinical virtual reality: the INTREPID project. *JoVE (Journal of Visualized Experiments)*, (33), p.e1554.

[65] Franco, C., Fleury, A., Guméry, P.Y., Diot, B., Demongeot, J. and Vuillerme, N., 2012. iBalance-ABF: a smartphone-based audio-biofeedback balance system. *IEEE transactions on biomedical engineering*, *60*(1), pp.211-215.

[66] Kos, A., Tomažič, S. and Umek, A., 2016. Suitability of smartphone inertial sensors for real-time biofeedback applications. *Sensors*, *16*(3), p.301.

[67] Rastogi, R., Chaturvedi, D.K., Gupta, M. and Singhal, P., 2020. Intelligent Mental Health Analyzer by Biofeedback: App and Analysis. In *Handbook of Research on Optimizing Healthcare Management Techniques* (pp. 127-153). IGI Global.

[68] Van Den Heuvel, M.P. and Pol, H.E.H., 2010. Exploring the brain network: a review on resting-state fMRI functional connectivity. *European neuropsychopharmacology*, *20*(8), pp.519-534.

[69] Michel, C.M., Koenig, T., Brandeis, D., Wackermann, J. and Gianotti, L.R. eds., 2009. *Electrical neuroimaging*. Cambridge University Press.

[70] Enriquez-Geppert, S., Huster, R.J. and Herrmann, C.S., 2017. EEG-neurofeedback as a tool to modulate cognition and behavior: a review tutorial. *Frontiers in human neuroscience*, *11*, p.51.

[71] Hammond, D.C., 2007. What is neurofeedback?. *Journal of neurotherapy*, *10*(4), pp.25-36.

[72] Sitaram, R., Ros, T., Stoeckel, L., Haller, S., Scharnowski, F., Lewis-Peacock, J., Weiskopf, N., Blefari, M.L., Rana, M., Oblak, E. and Birbaumer, N., 2017. Closed-loop brain training: the science of neurofeedback. *Nature Reviews Neuroscience*, *18*(2), pp.86-100.

[73] Cahn, B.R., Delorme, A. and Polich, J., 2013. Event-related delta, theta, alpha and gamma correlates to auditory oddball processing during Vipassana meditation. *Social cognitive and affective neuroscience*, *8*(1), pp.100-111.

[74] Travis, F. and Shear, J., 2010. Focused attention, open monitoring and automatic self-transcending: categories to organize meditations from Vedic, Buddhist and Chinese traditions. *Consciousness and cognition*, *19*(4), pp.1110-1118.

[75] Lehrer, P., 2017. Biofeedback: An important but often-ignored ingredient in psychotherapy. *Policy Insights from the Behavioral and Brain Sciences*, *4*(1), pp.57-63.

[76] Morgan, S.J. and Mora, J.A.M., 2017. Effect of heart rate variability biofeedback on sport performance, a systematic review. *Applied psychophysiology and biofeedback*, *42*(3), pp.235-245.

[77] Jessup, B.A., Neufeld, R.W. and Merskey, H., 1979. Biofeedback therapy for headache and other pain: An evaluative review. *Pain*, *7*(3), pp.225-270.

[78] Caldwell, Y.T. and Steffen, P.R., 2018. Adding HRV biofeedback to psychotherapy increases heart rate variability and improves the treatment of major depressive disorder. *International Journal of Psychophysiology*, *131*, pp.96-101.

[79] Moore, N.C., 2000. A review of EEG biofeedback treatment of anxiety disorders. *Clinical electroencephalography*, *31*(1), pp.1-6.

[80] Kleinbub, J.R., Mannarini, S. and Palmieri, A., 2020. Interpersonal Biofeedback in Psychodynamic Psychotherapy. *Frontiers in Psychology*, *11*.

[81] Kassel, S.C. and LeMay, J., 2012. Interpersonal biofeedback. *The Therapist*, pp.68-70.

[82] Nestoriuc, Y. and Martin, A., 2007. Efficacy of biofeedback for migraine: a meta-analysis. *Pain*, *128*(1-2), pp.111-127.

[83] Bassotti, G., Chistolini, F., Sietchiping-Nzepa, F., De Roberto, G., Morelli, A. and Chiarioni, G., 2004. Biofeedback for pelvic floor dysfunction in constipation. *Bmj*, *328*(7436), pp.393-396.

[84] Glazer, H.I. and Laine, C.D., 2006. Pelvic floor muscle biofeedback in the treatment of urinary incontinence: A literature review. *Applied Psychophysiology and Biofeedback*, *31*(3), pp.187-201.

[85] Fitz, F.F., Resende, A.P.M., Stüpp, L., Sartori, M.G.F., Girão, M.J.B.C. and Castro, R.A., 2012. Biofeedback for the treatment of female pelvic floor muscle dysfunction: a systematic review and meta-analysis. *International urogynecology journal*, *23*(11), pp.1495-1516.

[86] Herderschee, R., Hay-Smith, E.J., Herbison, G.P., Roovers, J.P. and Heineman, M.J., 2013. Feedback or biofeedback to augment pelvic floor muscle training for urinary incontinence in women: shortened version of a Cochrane systematic review. *Neurourology and urodynamics*, *32*(4), pp.325-329.

[87] Wolf, S.L., 1983. Electromyographic biofeedback applications to stroke patients: a critical review. *Physical therapy*, *63*(9), pp.1448-1459.

[88] Nelson, L.A., 2007. The role of biofeedback in stroke rehabilitation: past and future directions. *Topics in stroke rehabilitation*, *14*(4), pp.59-66.

[89] Jensen, M.P., Gertz, K.J., Kupper, A.E., Braden, A.L., Howe, J.D., Hakimian, S. and Sherlin, L.H., 2013. Steps toward developing an EEG biofeedback treatment for chronic pain. *Applied psychophysiology and biofeedback*, *38*(2), pp.101-108.

[90] Frank, D.L., Khorshid, L., Kiffer, J.F., Moravec, C.S. and McKee, M.G., 2010. Biofeedback in medicine: who, when, why and how?. *Mental health in family medicine*, *7*(2), p.85.

[91] Friesen, C.L., Bardouille, T., Neyedli, H.F. and Boe, S.G., 2017. Combined action observation and motor imagery neurofeedback for modulation of brain activity. *Frontiers in human neuroscience*, *10*, p.692.

[92] Ramos-Murguialday, A., Broetz, D., Rea, M., Läer, L., Yilmaz, Ö., Brasil, F.L., Liberati, G., Curado, M.R., Garcia-Cossio, E., Vyziotis, A. and Cho, W., 2013. Brain–machine interface in chronic stroke rehabilitation:

a controlled study. *Annals of neurology*, *74*(1), pp.100-108.

[93] Crider, A., Glaros, A.G. and Gevirtz, R.N., 2005. Efficacy of biofeedback-based treatments for temporomandibular disorders. *Applied psychophysiology and biofeedback*, *30*(4), pp.333-345.

[94] Pearson, S., 2013. Privacy, security and trust in cloud computing. In *Privacy and security for cloud computing* (pp. 3-42). Springer, London.