Chapter 3

Neurorehabilitation Techniques in Obese and Bariatric Patients

Clara Lombardo[1], Abed Hadipour Lakmehsari[2], Federica Arena[3], Marusca Fazio[3], Helene Sciacca[4], Antonio Bruno[5], Carmela Mento[*]

[1]*Psychological Doctor at Psychiatric Unit, Policlinico University Hospital, via Consolare Valeria 1, Messina Italy.*

[2]*Department of Cognitive sciences, University of Messina, Italy.*

[3]*Psychiatry Unit, Polyclinic Hospital, University of Messina, Via Consolare Valeria 1, Contesse, 98125 Messina, Italy.*

[4]*Psychological Student in training, University of Messina at Psychiatric Unit Policlinico University Hospital Messina.*

[5]*Department of Biomedical and Dental Sciences and Morphofunctional Imaging, University of Messina, Psychiatric Unit at Policlinico University Hospital, Via Consolare Valeria 1, Messina 98125, Italy.*

[*]***Correspondence to: Carmela Mento,*** *Department of Biomedical and Dental Sciences and Morphofunctional Imaging, University of Messina, Psychiatric Unit at Policlinico University Hospital, Via Consolare Valeria 1, Messina 98125, Italy.*

Email: antonio.bruno@unime.it & cmento@unime.it

Introduction

Following World Obesity Day on 4 March 2022, WHO Europe published a report, highlighting the extent of the problem in the general population stating that as of the date of the report, approximately 60% of adults and 1 in 3 children are overweight or affected by obesity. The diagnosis of obesity is based on the ratio of weight to height squared, a formula known as the body mass index (BMI). Although there are specific thresholds beyond which the disorder is diagnosed, it can be argued that BMI is too simplistic since an inherently heterogeneous population that is hugely diverse in terms of comorbidities and general health status, receives a single diagnostic label. Obesity compromises the psychophysical well-being of those affected and exposes them to additional physical risks such as hypertension, characterized by high blood pressure, type 2 diabetes mellitus with high blood glucose levels, and liver complications due to accumulation of fat in the liver, as well as psychological risks such as depression, low self-esteem, and suicidal ideation, among many others. The COVID-19 lockdown

Citation: *Mento Carmela, (2023) Neurorehabilitation Techniques in Obese and Bariatric Patients, Vol. 1, Chapter 3, pp. 41-51.*

of course had a negative impact on the obesity issue. Sedentariness, boredom, and stress as a result of social isolation were shown to be directly affecting eating habits. The studies included in this review, both longitudinal and cross-sectional observations, reported a general increase in the consumption of carbohydrates such as sugary foods and drinks, and an increase in the intake of bread, pizza, and junk food. In addition, snacking outside daily meals were also found to have increased, all of which contributed to an overall increase in weight in the general as well as clinical population.

These data emphasize the importance of a balanced diet coupled with daily physical activity, both to prevent overweight and obesity and to enable healthy weight loss; however, there are factors, both internal and external, that do not allow the balance to exist or be maintaned which can sometimes even aggravate the pre-existing conditions.

Obesity and bariatric patients: psychological aspects

Bariatric surgery, i.e., a minimally invasive operation performed laparoscopically, is one of the most effective methods for substantial and long-lasting weight loss. Different forms of this intervention are sleeve gastrectomy, which involves a vertical resection of a part of the stomach, or gastric bypass, which alters the volume of the stomach and the processes of digestion and absorption of food by creating a small pocket in the upper part of the stomach. The aim of both interventions is to reduce the sense of hunger and increase the feeling of satiety.

Despite the evidence regarding the effectiveness of this intervention, not all obese individuals undergo bariatric surgery. For example, a specialized center for bariatric surgery in Toronto [1], only 36% of patients took advantage of this intervention. Among the main known factors for avoiding this intervention is the desire to lose weight on one's own, fear of post-operation status and respective restrictions in daily routines, lack of support, and financial worries. In addition, the quality of the doctor-patient relationship seems to play a crucial role in the decision, as does the severity of one's condition.

What are the motivations for obese individuals to undergo bariatric surgery? An online survey was conducted among individuals who had previously had surgery for severe obesity, using social groups run by people who suffer, or have suffered from the same problem, however, using a self-designed and unvalidated questionnaire [2]. Of the 665 participants, the majority were female with an average age of 35 years. A high percentage of the subjects attributed the cause of their obesity to a sedentary lifestyle and uncontrolled eating, 40.1% to genetic causes, and 25.4% to psychological and social trauma or poor family eating habits. On the other hand, among the main factors that prompted them to undergo the procedure were: limitations in everyday life such as difficulties in moving around, discomforts related to small seats in transport vehicles, search for suitable clothing, and/or the health risks associated with the condition. Therefore, it can be noted that the reasons why people undergo surgery are the same reasons for not seeking the intervention: quality of life and state of health must be severely compromised and, equally, the relationship established with the surgeon must be of value. The choice of the specific center, in turn, depends not only on the proximity to one's home but also on the medical staff. This draws attention to the importance of creating a therapeutic alliance and of informing patients adequately and with empathy.

The same problem seems to also play a role in post-operative adherence. It often happens that patients who decide to undergo bariatric surgery do not follow the medical recommendations after the operation. There are reports [3] showing that 44% of patients did not stick to the recommended snacks and 37% did not exercise, while 40% had missed at least one of the scheduled appointments [4]. By not adhering to the treatment, patients who undergo the intervention decrease their success rates in terms of weight loss despite the investment of money, time, and energy and taking the health risks. Motivational interviewing in such cases could be of great help, as on the one hand, it prompts subjects to undergo the intervention before their health or quality of life is seriously compromised, and on the other hand, it increases the chances of success once it is carried out [5]. In such a scenario, it is often the case that individuals experience decision-making with ambivalence, i.e., getting stuck between what they want to do and what they have to do.

As well as the practical issues, the underlying motivations can also be emotional as some individuals experience the social marginalization resulting from their severe obesity with discomfort [6].

Neuromodulation techniques

Our brain continuously receives stimuli from the environment and constructs our perceptions and the consequent behavioral strategies thus shaping our experiences in the real world. Experience in turn both functionally and structurally affects the synaptic connections of our nervous system [7]. Taken together, the feedbacks from the external environment and the individual's own actions are both involved in and affected by the dynamic process known as neuronal plasticity, a distinctive but not exclusive characteristic of the developing nervous system.

Genes guide the early stages of brain development and the formation of synaptic junctions, however, proper and specific adaptations occur via multiple and continuous interactions that the individual has with their environment throughout their existence [8]. Neural plasticity underlies a phenomenon involving the strengthening of some connections and the 'pruning' of others, in response to physiological changes, brain damage or neurological pathologies. Although the time window, during which experience plays an essential role in the formation of the nervous system, falls in the so-called sensitive or critical period, learning can still occur at any given time in different ways and for different reasons. Brain development does not have a single critical period due to the different stages of maturation of brain functions, occurring at different stages of life [9].

Therefore, the brain's ability to learn continuously can be taken advantage of, encouraged, and enhanced, through different manipulations in the clinical setting, using specific protocols and standard procedures [10]. This is the rationale for using neuromodulation techniques to improve psychopathological symptoms or cognitive performance across psychiatric disorders such as attention-deficit hyperactivity disorder (ADHD), schizophrenia, Alzheimer's disease, anxiety, depression, eating disorders, obesity, etc., [11,12].

Of particular importance and interest to many neuromodulation investigations are the irregularities observed in the frontal and prefrontal lobes, areas crucial for working memory, abstract thinking, and executive function planning. Malfunctions in these areas can lead to difficulties in solving everyday problems and result in impairments in social functioning [11]. It is therefore necessary for health professionals to adopt a biopsychosocial perspective to be able to fully assist the patients seeking mental health services to improve their emotional and psychological well-being [13].

Neuromodulation techniques have enabled faster and novel rehabilitation strategies in many domains, whose focus is not only on the individual's goals and needs but also involves the patient's own self-regulating resource mechanisms.

In feedback oriented neuromodulation, the goal is to make the patient aware of his or her physical state and consequently reach psychophysiological self-control. In addition to the neural processes, it is possible to train the self-regulation of muscle tone, heart and respiratory rate, skin conductance, body temperature and pain perception, using appropriate feedback loop protocols in a process called biofeedback [9]. Non-invasive neurofeedback is, however, realized by recordings of magnetoencephalography (MEG), electroencephalogram (EEG), or functional magnetic resonance imaging [10, 14].

The first attempts in this regard date back to the 1960s implementing electroencephalographic neurofeedback (EEG-NFB). Despite the initial enthusiasm, EEG-NFB underwent a period of decline in the 1980s [10], but arousing interest again in the new millennium [14].

By examining a family of such protocols in which behavioral training is combined with physiological tracings, such as heart rate (biofeedback) or cortical signals (neurofeedback), participants acquire real-time information on their brain/bodily functions. The difficulty of the administered task is variable [15]. Basically, the brain activity will somehow be returned to the subject in one way or another depending on the type of the selected approach. In a typical session, the participant will be taught how to inhibit or enhance specific and atypical electrophysiological parameters through operant conditioning, i.e. the learning process by which a behavior will be modified by the use of immediate feedback and reinforcement [16].

This is made possible by the inherent ability of our nervous system to modify its activity patterns and thus, bring about the usefulness of neurofeedback in improving certain behavioral responses and specific cognitive functions [15]. For example, in specific neurofeedback procedures, the participant will be able to hear his brain activity and the intensity of the brain signal will be proportionally translated to the intensity of a sound signal [2].

The very essence of EEG-NFB therapy is the enhancement of "*good"* waves and reduction of "*bad"* ones with specific amplitudes and frequencies [17], reflecting the subject's neuropsychological state. The distinction and determination of specific waves are based on previous investigations regarding the activity patterns in a specific region of the brain in a specific psychological condition, which is of course is a challenging matter and still open to question and investigation [11]. For example, agitation is associated with a higher frequencies, while relaxation is associated with lower frequencies in the brain.

The use of NF has been suggested as an alternative direction for patients who react negatively to pharmacotherapy and psychotherapy [18]. There is evidence that support these therapies to be effective, however, the mechanisms underlying the effects are still hugely unknown and require further investigations. This article aims to present NF and BF interventions and their potential effects and applications for overweight and obese individuals with the hope to motivate further research and more investigations on the topic to fully explore the potential of these methods to help the clinical and subclinical populations.

Neurorehabilitation techniques in obese and bariatric patients

The ever growing number of obese individuals worldwide shows that multidisciplinary approaches, i.e., a combination of nutritional, psychological, and pharmacological interventions, are still not sufficient to stop this phenomenon. This type of intervention is usually recommended in the context of eating disorders, although it has long been proven to be of little long-term effectiveness [19-21]. Therefore, providing alternative therapeutic interventions to improve one's ability to control their impulses to facilitate dysfunctional eating behavior is of great importance [22].

Recently, there has been an increased focus of scientific research on neuromodulation-based treatments for example, attention bias modification treatment (ABMT), transcranial magnetic stimulation (TMS), deep brain stimulation (DBS), transcranial direct current stimulation (TDCS), and biofeedback (BF) as additional intervention modalities for eating disorders. In this regard, Imperatori et al. [23] analyzed 5 BF and 8 NF studies, which provided promising data on the use of these interventions. Specifically, the experimental study conducted by Teufel et al. [24] set out to investigate the effects of two electrodermal biofeedback (ED-BF) paradigms in obesity, one precisely aiming at eating behavior and the other at relaxation. Patients noted a reduction in stress and an increased ability to relax, with beneficial effects on self-efficacy, eating behavior, and the sympathetic stress reaction to eating cues. Pop-Jordanova used DB-BF in a sample of obese subjects with anorexia nervosa and found a decrease in electrodermal activity [25]. Barba et al. [26] and Halland et al. [27] used electromyographic biofeedback (EMG-BF) and DB-BF in patients suffering from rumination, respectively, reporting benefits on both the clinical and physiological outcomes. While, other studies using heart rate variability biofeedback (HRV-BF), showed that 12 training sessions in a sample of non-clinical cravers resulted in a reduction of subjective food cravings (such as chocolate) linked to lack of control and weight and eating problems (guilt and preoccupation with food in specific) [28].

Similarly, through the use of neurofeedback, Spetter et al. [29] found that real-time functional magnetic resonance imaging (rt-fMRI) neurofeedback training could regulate the functional interaction between the dorsolateral prefrontal cortex (dlPFC) and the ventromedial prefrontal cortex (vmPFC), involved in executive control and reward processing. The four-day training comprised of three training sessions each day, consisting of six over-regulation and six passive visualization trials. The recruited participants, men who were overweight or obese, experienced a weight loss and an inclination towards less caloric food choices as a result of the training, linked, however, to an increase in snacking.

Specifically, in the study by Ihssen et al. [8], 10 healthy women underwent a course of 'motivational neurofeedback' after a 4-hour fasting period. The feedback, provided using functional magnetic resonance imaging, consisted of real-time increase or decrease of images of palatable, high-calorie foods, and thus guided the subjects to orient their response in terms of signal approach/avoidance. The results suggest that motivational neurofeedback is associated with a decrease in affected regional brain activity (mainly limbic and subcortical areas)[30]. The remaining six studies focused on the use of EEG. Specifically, two employed beta EEG training (involving a reduction in beta activity at the CZ electrode) in a non-clinical sample and binge eaters, reporting a decrease in overeating episodes and the associated discomfort [31].

Two studies used EEG alpha/theta power training in a non-clinical sample and overweight women, resulting in a decrease in food cravings and reporting benefits on mental health. The study by Lackner et al. [32] subjected 22 girls with anorexia nervosa to a ten-session neurofeedback training of EEG alpha training and found an improvement in emotional competence and a reduction in restriction or diet-related behavior. The parallel randomized study by Leong et al. [33] explored the efficacy of infrared neurofeedback (ISF-NF) on the posterior cingulate cortex (the integrative focus of self-referential thoughts and activities) on food cravings in obese women with symptoms of food addiction. The participants, following six sessions of ISF-NF carried out over three weeks, reported significant increases in infrared activity and infrared/beta nesting compared to the control group, two days after the last intervention, resulting in a decrease in food cravings.

As can be seen, the review by Imperatori et al. [23] highlighted how the use of neuromodulation led to a reduction in food cravings and episodes of overeating, regurgitation and rumination, limiting eating and weight problems.

Neurofeedback

There is evidence showing that individuals with obesity, compared to normal-weight controls, show a lower dorsolateral prefrontal cortex (dlPFC) activity. Several studies have investigated the use of neurofeedback to on the basis of this evidence.

A study with an experimental procedure similar to that of Spetter et al. [34] and corroborating those findings is that of Kohl et al. [35], whose sample consisted of 38 overweight or obese individuals that underwent a single-day training of six up-regulation and passive visualization trials. The results confirmed modulations in the targeted brain areas, with a consequent effect on eating behavior. At the follow-up four weeks later, the subjects rated high-calorie but not low-calorie foods as less palatable. Snack intake, however, remained unchanged.

In the investigation conducted by Percik et al. [36], 6 male participants underwent ten sessions of near-infrared Hemoencephalography (NIRHEG) neurofeedback and reported an improvement in eating behavior and appetite control, resulting in a statistically significant weight loss. Furthermore, their results suggest that a cycle of ten sessions produces effects for up to six months, which can be extended through maintenance sessions.

Biofeedback

Manzoni et al. [37] subjected a sample of 60 obese women with emotional hunger to a three-week relaxation protocol, enhanced by virtual reality and portable MP3 players. The aim was to test its effectiveness on reducing emotional eating. The intervention was comprised of 12 individual sessions of relaxation training, delivered under imaginary or virtual reality conditions. The training proved effective in reducing emotional eating episodes, depressive and anxious symptoms and improved the subjects' perceived sense of self-efficacy on eating control at follow-up 3 months after discharge. The virtual reality mode had a better effect on aspects of emotional awareness.The sample also showed a weight loss in all three conditions, with no significant differences between them.

Transcranial direct current stimulation (tDCS)

Transcranial direct current stimulation (tDCS) has demonstrated its utility in reducing food cravings and consumption in healthy adults [38],[39]. Obese participants in a study performed by Gluck et al. [40] reported a lower consumption of daily calories from fat and fizzy drinks, and a greater percentage of weight loss during anodal compared to cathodal tDCS on the left DLPFC. A strand of research has implemented the use of transcranial direct current stimulationto assess its effects on eating behaviour in different patients [41,42].

Specifically, the aim of the study of Burgess et al. [41] was to examine the effect of tDCS on food intake, craving, and binge eating, and on the frequency of the latter in subjects with uncontrolled eating disorder. Their results showed a significant reduction in both food intake and cravings (particularly sweet and salty protein foods) in a laboratory setting, and less desire to binge at home. Furthermore, their results suggest the presence of sex-determined differences in the neural substrates underlying binge craving. Ray et al. [42] replicated the results of the previously mentioned study by testing the efficacy of tDCS in reducing food craving and consumption in patients with frank obesity, i.e. in the absence of binge eating, and the moderating role of cognitive functions. Participants were subdivided by gender, as men and women had given different responses to treatment in the previous study.

The data showed reduced food cravings in women with lower scores on attention-type impulsivity, lower food consumption in men with lower intentions to restrict calories, and reduced food consumption in men with higher scores on uncontrolled type impulsivity. The results also highlight the importance of assessing baseline cognitive differences, as these affect how subjects respond to tDCS.

The preliminary results of a study, which is still being completed, suggest that tDCS can regulate the mechanism in prefrontal reward processing regions that drives food-induced craving. Their research continues to date with the aim of identifying the mechanistic neural substrates through which stimulation of these areas induces a reduction in food craving, in order to make therapeutic protocols customizable [43].

The review by Saeki et al. [44] supports the studies in the literature investigating the role of tDCS on eating behaviour. Here, the aim was to specifically identify the effects of tDCS on body weight, food craving, and appetite intake in obese adult individuals.

Conclusions

The results consolidate the theory that these neuromodulation techniques provides benefits, in combination with other strategies, in the treatment of obesity. Furthermore, two of the studies had a follow-up period after the intervention and found positive effects even in the long term [45,46].

The recent narrative review by de Klerk et al. [47] supports the idea that in obese patients there is a lower inhibitory control of food and reduced activation in the inhibitory regions of the brain when hungry. This turns out to be strongly predictive of the resulting weight gain, just as weight reduction can easily be predicted in association with an increased activation of the targeted brain areas. The problem of weight, regain and body image in obese patients is related to psychological disease [48].

Overall, the studies reported and reviewed here are only part of a literature that is still in its infancy. Although future studies are needed to deepen our knowledge in this field and draw definitive conclusions, neuromodulation-based techniques have been shown to be useful in the treatment of different eating disorders and weight problems and they are emerging as adjuvants for more comprehensive interventions and treatments also prevention of obesity.

References

1. Pitzul KB, Jackson T, Crawford S, Kwong JCH, Sockalingam S, Hawa R, et al. Understanding disposition after referral for bariatric surgery: when and why patients referred do not undergo surgery. Obesity surgery. 2014;24(1):134-40.

2. Widmer J, Gero D, Sommerhalder B, Alceste D, Raguz I, Serra M, et al. Online survey on factors influencing patients' motivation to undergo bariatric surgery. Clinical Obesity. 2022;12(2):e12500.

3. Elkins G, Whitfield P, Marcus J, Symmonds R, Rodriguez J, Cook T. Noncompliance with behavioral recommendations following bariatric surgery. Obesity surgery. 2005;15(4):546-51.

4. Toussi R, Fujioka K, Coleman KJ. Pre-and postsurgery behavioral compliance, patient health, and postbariatric surgical weight loss. Obesity. 2009;17(5):996-1002.

5. Zuckoff A. "Why won't my patients do what's good for them?" Motivational interviewing and treatment adherence. Surgery for Obesity and Related Diseases. 2012;8(5):514-21.

6. Peacock JC, Perry L, Morien K. Bariatric patients' reported motivations for surgery and their relationship to weight status and health. Surgery for Obesity and Related Diseases. 2018;14(1):39-45.

7. Berti A. Neuropsicologia della coscienza: Bollati Boringhieri; 2010. ISBN 9788833919201

8. Ihssen N, Sokunbi MO, Lawrence AD, Lawrence NS, Linden DE. Neurofeedback of visual food cue reactivity: a potential avenue to alter incentive sensitization and craving. Brain imaging and behavior. 2017;11(3):915-24. https://doi.org/10.1007/s11682-016-9558-x

9. Enriquez-Geppert S, Huster RJ, Herrmann CS. EEG-neurofeedback as a tool to modulate cognition and behavior: a review tutorial. Frontiers in human neuroscience. 2017;11:51 https://doi.org/10.3389/fnhum.2017.00051

10. Ruiz S, Buyukturkoglu K, Rana M, Birbaumer N, Sitaram R. Real-time fMRI brain computer interfaces: self-regulation of single brain regions to networks. Biological psychology. 2014;95:4-20. https://doi.org/10.1016/j.biopsycho.2013.04.010

11. Markiewcz R. The use of EEG Biofeedback/Neurofeedback in psychiatric rehabilitation. Psychiatria Polska. 2017;51(6):1095-106. https://doi.org/10.12740/PP/68919

12. Berardi N, Pizzorusso T, Maffei L. Extracellular matrix and visual cortical plasticity: freeing the synapse. Neuron. 2004;44(6):905-8. https://doi.org/10.1016/j.neuron.2004.12.008

13. Baroncelli L, Lunghi C. Neuroplasticity of the visual cortex: In sickness and in health. Experimental neurology. 2021;335:113515. https://doi.org/10.1016/j.expneurol.2020.113515

14. Thibault RT, Lifshitz M, Birbaumer N, Raz A. Neurofeedback, self-regulation, and brain imaging: clinical science and fad in the service of mental disorders. Psychotherapy and psychosomatics. 2015;84(4):193-207. https://doi.org/10.1159/000371714

15. Sherlin LH, Arns M, Lubar J, Heinrich H, Kerson C, Strehl U, et al. Neurofeedback and basic learning theory: im-

plications for research and practice. Journal of Neurotherapy. 2011;15(4):292-304. 10.1080/10874208.2011.623089.

16. Larsen S, Sherlin L. Neurofeedback: an emerging technology for treating central nervous system dysregulation. Psychiatric Clinics. 2013;36(1):163-8. https://doi.org/10.1016/j.psc.2013.01.005

17. Kouzak V, da Paz Neto AC, Donner I. Biofeedback in Clinical Psychology: Modalities and Perspectives. Smart Biofeedback-Perspectives and Applications: IntechOpen; 2020. https://doi.org/10.5772/intechopen.94278

18. Loriette C, Ziane C, Hamed SB. Neurofeedback for cognitive enhancement and intervention and brain plasticity. Revue Neurologique. 2021;177(9):1133 44.https://doi.org/10.1016/j.neurol.2021.08.004

19. Treasure J, Claudino A, Zucker N. Eat disord. Lancet. 2010;375(9714):583-93.

20. Amianto F, Ottone L, Abbate Daga G, Fassino S. Binge-eating disorder diagnosis and treatment: a recap in front of DSM-5. BMC psychiatry. 2015;15(1):1-22.

21. Herpertz-Dahlmann B. Treatment of eating disorders in child and adolescent psychiatry. Current Opinion in Psychiatry. 2017;30(6):438-45

22. Blume M, Schmidt R, Schmidt J, Martin A, Hilbert A. EEG neurofeedback in the treatment of adults with binge-eating disorder: a randomized controlled pilot study. Neurotherapeutics. 2022;19(1):352-65.

23. Imperatori C, Mancini M, Della Marca G, Valenti EM, Farina B. Feedback-Based Treatments for Eating Disorders and Related Symptoms: A Systematic Review of the Literature. Nutrients. 2018; 10(11):1806.

24. Teufel, Martin; Stephan, Kerstin; Kowalski, Axel; Käsberger, Saskia; Enck, Paul; Zipfel, Stephan; Giel, Katrin E. (2013). Impact of Biofeedback on Self-efficacy and Stress Reduction in Obesity: A Randomized Controlled Pilot Study. Applied Psychophysiology and Biofeedback, 38(3), 177–184

25. Pop-Jordanova, N. Psychological characteristics and biofeedback mitigation in preadolescents with eating disorders. Pediatr. Int. 2000, 42, 76–81

26. Barba E, Burri E, Accarino A, Malagelada C, Rodriguez-Urrutia A, Soldevilla A, et al. Biofeedback-guided control of abdominothoracic muscular activity reduces regurgitation episodes in patients with rumination. Clinical Gastroenterology and Hepatology. 2015;13(1):100-6. e1.

27. Halland M, Parthasarathy G, Bharucha AE, Katzka DA. Diaphragmatic breathing for rumination syndrome: efficacy and mechanisms of action. Neurogastroenterology & Motility. 2016;28(3):384-91.

28. Meule, A.; Freund, R.; Skirde, A.K.; Vogele, C.; Kubler, A. Heart rate variability biofeedback reduces food cravings in high food cravers. Appl. Psychophysiol. Biofeedback 2012, 37, 241–251.

29. Spetter MS, Malekshahi R, Birbaumer N, Lührs M, van der Veer AH, Scheffler K, et al. Volitional regulation of brain responses to food stimuli in overweight and obese subjects: A real-time fMRI feedback study. Appetite. 2017;112:188-95.

30. McDermott, Kathryn E. Demos, et al. "Effects of cognitive strategies on neural food cue reactivity in adults with overweight/obesity." Obesity, 2019, 27.10: 1577-1583.

31. Schmidt J, Martin A. Neurofeedback against binge eating: A randomized controlled trial in a female subclinical threshold sample. European eating disorders review. 2016;24(5):406-16.

32. Lackner N, Unterrainer H-F, Skliris D, Shaheen S, Dunitz-Scheer M, Wood G, et al. EEG neurofeedback effects in the treatment of adolescent anorexia nervosa. Eating disorders. 2016;24(4):354-74.

33. Leong SL, Vanneste S, Lim J, Smith M, Manning P, De Ridder D. A randomised, double-blind, placebo-controlled parallel trial of closed-loop infraslow brain training in food addiction. Scientific reports. 2018;8(1):1-9.

34. Spetter MS, Malekshahi R, Birbaumer N, Lührs M, van der Veer AH, Scheffler K, et al. Volitional regulation of brain responses to food stimuli in overweight and obese subjects: A real-time fMRI feedback study. Appetite. 2017;112:188-95.

35. Kohl SH, Veit R, Spetter MS, Günther A, Rina A, Lührs M, et al. Real-time fMRI neurofeedback training to improve eating behavior by self-regulation of the dorsolateral prefrontal cortex: a randomized controlled trial in overweight and obese subjects. Neuroimage. 2019;191:596-609.

36. Percik, R., Cina, J., Even, B., Gitler, A., Geva, D., Seluk, L., & Livny, A.A pilot study of a novel therapeutic approach to obesity: CNS modification by NIRHEG neurofeedback. Clinical Nutrition, 2019, 38.1: 258-263.

37. Manzoni GM, Pagnini F, Gorini A, Preziosa A, Castelnuovo G, Molinari E, Riva G. Can relaxation training reduce emotional eating in women with obesity? An exploratory study with 3 months of follow-up. J Am Diet Assoc. 2009 Aug;109(8):1427-32. doi: 10.1016/j.jada.2009.05.004. PMID: 19631051.

38. Kekic M, McClelland J, Campbell I, Nestler S, Rubia K, David AS, et al. The effects of prefrontal cortex transcranial direct current stimulation (tDCS) on food craving and temporal discounting in women with frequent food cravings. Appetite. 2014;78:55-62.

39. Lapenta OM, Di Sierve K, de Macedo EC, Fregni F, Boggio PS. Transcranial direct current stimulation modulates ERP-indexed inhibitory control and reduces food consumption. Appetite. 2014;83:42-8.

40. Gluck ME, Alonso-Alonso M, Piaggi P, Weise CM, Jumpertz-von Schwartzenberg R, Reinhardt M, et al. Neuromodulation targeted to the prefrontal cortex induces changes in energy intake and weight loss in obesity. Obesity. 2015;23(11):2149-56.

41. Burgess EE, Sylvester MD, Morse KE, Amthor FR, Mrug S, Lokken KL, et al. Effects of transcranial direct current stimulation (tDCS) on binge-eating disorder. International Journal of Eating Disorders. 2016;49(10):930-6.

42. Ray MK, Sylvester MD, Osborn L, Helms J, Turan B, Burgess EE, et al. The critical role of cognitive-based trait differences in transcranial direct current stimulation (tDCS) suppression of food craving and eating in frank obesity. Appetite. 2017;116:568-74.

43. Ghobadi-Azbari P, Malmir N, Vartanian M, Mahdavifar-Khayati R, Robatmili S, Hadian V, et al. Transcranial direct current stimulation to modulate brain reactivity to food cues in overweight and obese adults: study protocol for a randomized controlled trial with fMRI (NeuroStim-Obesity). Trials. 2022;23(1):1-11.

44. Saeki, J. K., Marques Miguel Suen, V., & Giacomo Fassini, P. (2022). A systematic review on transcranial direct current stimulation (tDCS) in the treatment of obesity. Principles and Practice of Clinical Research, 8(1), 18–27.

45. Forcano L, Castellano M, Cuenca-Royo A, Goday-Arno A, Pastor A, Langohr K, et al. Prefrontal cortex neuromodulation enhances frontal asymmetry and reduces caloric intake in patients with morbid obesity. Obesity. 2020;28(4):696-705.

46. Fattahi S, Naderi F, Asgari P, Ahadi H. Neuro-feedback training for overweight women: Improvement of food craving and mental health. NeuroQuantology. 2017;15(2).

47. de Klerk MT, Smeets PAM, la Fleur SE. Inhibitory control as a potential treatment target for obesity. Nutr Neurosci. 2022 Mar 28:1-16. doi: 10.1080/1028415X.2022.2053406. Epub ahead of print. PMID: 35343884.

48. Body Image and Obese Identity in Bariatric Patients: Psychological Factors and Clinical Management. Carmela Mento, Maria Catena Silvestri , Antonio Bruno, Maria Rosaria Anna Muscatello, Amelia Rizzo, Giulia Celona, Giuseppe Navarra, Rocco Antonio Zoccali. Series: Psychology Research Progress BISAC: PSY036000. 2021