A Review in Modification Food-Intake Behavior by Brain Stimulation: Excess Weight Cases

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ABSTRACT

Obesity and overweight are frequently prescribed for dysfunction in food-intake behavior. Due to the widely prevalence of obesity in last year’s, there is demand for more studies which are aimed to modify the food-intake behavior. For the past decades many researches has applied in modify food-intake by brain training or stimulation. This review for neuroscience studies in modifying food-intake behavior, it’s involved three sections; The first section explained the role of brain activity in food-intake regulation, general ideas about biomedical devices in food-intake behavior are discussed in second section and third section focused on brain-stimulation systems. Finally, this paper concluded with main points that need to be taken into account when designing experimental study for modification food-intake behavior by brain stimulation according to previous studies recommendation and challenges.

Key Words: Obesity, overweight, EEG-Neurofeedback, biomedical devices


Introduction

Over the last few years, the prevalence of overweight and obesity has increased substantially in various societies globally. Based on the WHO's report in 2016, more than 1.9 billion adults are overweight and more than 650 million are obese (World Health Organization, 2017). Also, the Institute for Public Health (IPH) in Malaysia has reported that 47.7% of the Malaysian population is made up of excess weight individuals. From this number, 17.7% percent suffer from obesity whereas 30% percent are overweight (Institute for Public Health, 2015).

The ever-increasing number of obesity individuals in society is commonly due to excessive food intake and lack of physical activity. Another contribution factor is the increase in availability and consumption of high-calorie meals are rich in carbohydrates and fat (Vos MB, Kimmons JE, Gillespie C, Welsh J, 2008). Besides excessive consumption of fat and carbohydrates, daily meal patterns have varied over the last decades, noting an increased meal number (i.e. snacking meals) (Forslund et al., 2005). Thus, a decrease in bodily activity and a rising of high-calorie food in taking all lead to gain in weight.

The prevalence of excess weight individuals can be said to have reached an epidemic situation, thus proving that part of the individuals are unable of regulating their own food intake which is key to weight gain.

Food-Intake (FI) regulation is a complex process involving the combination of internal factors such as genetics, neural and endocrine signals, as well as external factors including the contextual factors that stimulate eating desire such as sight, smell and taste (Huang, Marsh and Moodie, 2012). Furthermore, the physiologists have considered that a FI regulation forms part of behavioral regulator of weight due to the food consumption is a form
of behavior (RICHTER, 1943), that refers to the particular role of brain activity in regulating this behavior.

This review will describe the role of brain activity in food intake regulation. Also, it will study and discuss on the various biomedical devices in food-intake behavior, brain-stimulation systems that have been used in modifying food intake behavior.

**Brain In Food-intake Regulation**

The brain is senses the hunger as an alteration in energy stored and activates metabolic and behavioral responses for maintaining energy balance (Ahima, R. S., Antwi, 2008). The regulation of hunger and satiety, as well as 'like' and 'dislike' of food, is organized by the brain and it is a commonly accepted view that dysregulation of brain functions involved in regulation of food-intake could consequentially lead to weight gain (Morton et al., 2006). The brain regulates the food-intake by two complementary ways called the homeostatic and hedonic pathways. The dysregulation might be explained by either dysfunctional homeostatic control (mainly regulated by the hypothalamus) or by dysfunctional reward control (mainly orchestrated in hedonic circuits), or a combination of both. Since overall FI behavior results from a partially interpreted complex interaction between these major pathways, both pathways are explained in figure 1.

The homeostatic pathway governs energy balance by regulating appetite, hunger and satiety to match energy consumption or energy expenditure in individuals, it includes a coordinated response of signals that governs the desire to eat according to the individual's metabolic requirements. Thus, it is responsible for ensuring optimal nutritional intake, weight and health status.

The hypothalamus is the main brain region included in the control of metabolism and energy intake according to physical status. It is necessary to note the mechanisms regulating homeostatic eating but these will not be explained in detail as this research focuses on the association of the hedonic pathway to the food intake behavior (Lau et al., 2017).

The hedonic pathway relates to feeding for pleasure in the absence of physiological status. The palatability of a food item is identified by sensory devices involving sight, smell and taste. These sensory inputs are delivered to the gustatory cortices, which process information related to taste and pleasant sensations of food. The hedonic pathway is essentially directed by the interaction between environmental factors and reward-related brain areas.

However, studies have shown that specific areas of the brain are involved in the interactive processing of food vs. nonfood-related visual
stimuli in the different states of hunger and satiety. These include the PFC and the amygdala. Another study shows that food, even when presented only as an image, will cause a larger CNS “hunger response” in evolutionarily conserved brain areas, sustaining survival, in particular, because the visual presentation of the food was possibly the first way of food contact (Führer, D., Zysset, S., & Stumvoll, 2008). The recent progress in brain activity research found a therapeutic program that targeted stimulation in the decision-making process may lead to an encouraging approach in the prevention of weight gain (McClelland et al., 2013).

**Biomedical Devices in Food-Intake Behavior**

Food-Intake Behavior is the way in which a person conducts toward the food. The features of this behavior in high BMI individuals are over-food consumption, food-craving, emotional eating, unhealthy food choice (Chao et al., 2014). There is a growing body of literature that recognizes the importance of FI behavior in addressing the issue of obesity and overweight. As shown in figure 2, the biomedical devices in this topic have been classified into two approaches, modifying and monitoring. Recent evidence suggests to modifying or monitoring food-intake behavior as a therapeutic tool to reduce weight in obesity and overweight individuals.

**Monitoring devices**

It has previously been observed that modern life is a key aspect of overconsumption of food, including increased availability of food, advertising and consumption of fast-food, therefore, the researchers proposed that monitoring food-intake could be a contributing factor in reducing obesity. Previous studies have been used the biomedical instrumentations with questionnaires for monitoring food-intake. In another context, it’s important to measure and analysis a calories amount (dietary assessment) to assist the people to know what they are eating and avoid the high calories or fatty food (Shim, Oh and Kim, 2014).

The previous study implemented a built-up embedded system to monitoring calories intake that assist the obesity individuals to maintain food choices (Abisha P and Rajalakshmy, 2017). Other study applied smartphone camera to measure the calories of food picture (Pouladzadeh et al., 2016). However, The resent review about monitoring approach argued to some challenges such as not all the users able to deal with it, it’s difficult to measurement of analysis the calories in mix meals (Pouladzadeh, Shir Mohammadi and Yassine, 2016).

**Modifying devices**

Studies over the past two decades have provided important information on modifying food-intake behavior, it’s aimed to modification by brain training, there are two interventions have been used in this approach, the first intervention is Cognitive Training (CT) and second is Brain-Stimulation (BS). Both of these interventions are non-pharmacological and the recent researchers have shown an increased interest in using these interventions in obesity and overweight treatment (Liu, Wen and Jia, 2017; Higuera-Hernández et al., 2018).

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**Figure 2. Biomedical devices in Food-Intake Behavior**
The term cognitive training is used to enhance cognitive skills through brain training with psychological treatment sessions. Several techniques have been used to train the brain for food-intake modification. The recent review classified three types of these techniques called (Response Inhibition, Implementation Intentions and Attentional Bias Modification) have a positive outcome in diet and eating habits (Montesi et al., 2016; Song, 2017). The term of brain-stimulation is the hypothesis that the brain training through stimulation techniques. There are four techniques applied for modifying FI in excess weight individuals (Lewis et al., 2016).

The (Forcano et al., 2018) systematic-review had discussed 50 studies in CT and BS intervened in unhealthy eating and overweight, 35 studies in cognitive training, and 15 studies in brain-stimulation. However, the previous section has shown that more studies are needed in brain-stimulation approach in obesity study case.

Brain-Stimulation Devices

Technology advancements in neuroscientific equipment have enabled scientific researchers to present the evidence of brain plasticity, which is supporting the brain training approach (Kolb, Bryan, 2014). Brain stimulation is a physiological process aiming to manipulate brain waves via implementing weak direct current or visually, auditory stimuli. Brain stimulation approach is being applied clinically for the treatment of a variety of medical, psychological, and learning disorders such as Parkinson's disease (Odekerken et al., 2016), essential tremor (Baizabal-Carvallo et al., 2014), chronic pain (Boccard SG, Fitzgerald JJ, Pereira EA, Moir L and Tj, Kringlebach ML, 2014), stress reduction (Teufel et al., 2013), and epilepsy (Krishna, Vibhor and King, Nicolas Kon Kam and Sammartino, Francesco and Strauss, Ido and Andrade, Danielle M and Wennberg, Richard A and Lozano, 2016). Neuromodulation is also observed in neuropsychiatry, as a therapy for combating depression and obsessive compulsive disorder (Downar, Jonathan and Blumberger, Daniel M and Daskalakis, 2016).

During the last few decades, the researchers have explored the use of brain-stimulation techniques as an alternative intervention to address modifying FI in excess weight cases. As shown in Table 1, the previous studies have used medical devices in four techniques, Transcranial Magnetic Stimulation (TMS), Transcranial Direct Current Stimulation (tDCS), Deep Brain Stimulation (DBS) and Neurofeedback (NF). The below sections will describe these techniques deeply.

tDCS Devices

The tDCS device implements of a weak (1-2mA) direct electrical current (by using DC-stimulator) into the skull via a pair of non-invasive electrodes (Anode and Cathode), figure 3 is shown of tDCS device.

The stimulation of tDCS on neural circuitry is dependent on the direction. The excitability of neural circuitry is increased by anodal stimulation (depolarization) whereas the excitability is decreased by cathodal stimulation (hyperpolarizing) (Antal et al., 2007).

In the context of food-intake behavior, the previous studies followed the same protocol of electrodes placement, place the anode on right-side and cathode on left-side of PFC. Generally, the Dorsolateral Prefrontal Cortex (DLPFC) was the target area of stimulation, therefore, some study places the anode on F4 and cathode on F3 according to 10/20 EEG electrodes placement. The electrical current is believed to alter the cell membrane potential by locking and unlocking voltage flows (Fregni et al., 2008). Also, the long-term effects on cell membrane potential have also been pointed with longer stimulation period.

As illustrated in Table 1, most of tDCS studies have examined the hypothesis based on questionnaire to assess the stimulation impact. The data are collected in pre and post phases and designed according to Randomized Controlled Trail (RCT) for participant's distribution. (Jauch-chara et al., 2014) has demonstrated the tDCS utilized in decrease of food intake behavior by repeated tDCS in 18 females with...
Table 1. Brain Stimulation Studies in Modification Food-Intake Behavior

<table>
<thead>
<tr>
<th>#</th>
<th>Authors (year)</th>
<th>Purpose of study</th>
<th>System</th>
<th>Sample size</th>
<th>Study case</th>
<th>Sessions Number</th>
<th>Target area</th>
<th>Study design</th>
<th>Challenges</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(Mengotti et al., 2018)</td>
<td>Modifying the ability of food energy estimation by stimulating the left DLPFC</td>
<td>tDCS</td>
<td>30</td>
<td>Normal and overweight Female with restrained eating disorder</td>
<td>2 sessions</td>
<td>Left DLPFC</td>
<td>Pre-post design and study the hypothesis is based on questionnaire.</td>
<td>Neuroimaging technique to assess the stimulation impact on brain activity. Follow-up assessment</td>
<td>Sample size calculation</td>
</tr>
<tr>
<td>2</td>
<td>(Ljubisavljevic et al., 2016)</td>
<td>Long-term in food craving modification by repeated tDCS</td>
<td>rTMS</td>
<td>28</td>
<td>Normal and overweight</td>
<td>Single session</td>
<td>Right DLPFC</td>
<td>Pre-post design and study the hypothesis is based on questionnaire.</td>
<td>Neuroimaging technique to assess the stimulation impact on brain activity.</td>
<td>rTMS could be used in obesity treatment</td>
</tr>
<tr>
<td>3</td>
<td>(Georgii et al., 2017)</td>
<td>Effect on trait impulsivity by tDCS</td>
<td>tDCS</td>
<td>42</td>
<td>Female, Normal weight</td>
<td>Single session</td>
<td>Right DLPFC</td>
<td>Pre-post design and study the hypothesis is based on questionnaire.</td>
<td>The trait impulsivity not related with overeating behavior.</td>
<td>tDCS impact on food choice and consumption</td>
</tr>
<tr>
<td>4</td>
<td>(Jauch-chara et al., 2014)</td>
<td>Decrease in food intake behavior by repeated tDCS</td>
<td>rTMS</td>
<td>14</td>
<td>Normal and overweight</td>
<td>8 sessions</td>
<td>Right DLPFC</td>
<td>Pre-post design and study the hypothesis is based on questionnaire.</td>
<td>Gender: male only.</td>
<td>Reduce the appetite and calories intake by rTDCS</td>
</tr>
<tr>
<td>5</td>
<td>(Heinitz et al., 2017)</td>
<td>Modifying eating behavior by rtDCS</td>
<td>rtDCS</td>
<td>23</td>
<td>Obesity</td>
<td>15 sessions</td>
<td>Left DLPFC</td>
<td>Pre-post design and study the hypothesis is based on questionnaire.</td>
<td>Gender: male only.</td>
<td>Decrease the food intake behavior in obesity by longer period of stimulation (DLPFC)</td>
</tr>
<tr>
<td>6</td>
<td>(Montenegro et al., 2012)</td>
<td>Study the impact of combine the tDCS stimulation with aerobic exercise</td>
<td>tDCS + physical activity</td>
<td>9</td>
<td>Obesity</td>
<td>3 sessions</td>
<td>Left DLPFC</td>
<td>Pre-post design and study the hypothesis is based on questionnaire.</td>
<td>Neuroimaging technique to assess the stimulation impact on brain activity.</td>
<td>This combination leads to greater reduce in desire to eat compared to stimulate tech. or physical activity alone.</td>
</tr>
<tr>
<td>7</td>
<td>(Lapenta et al., 2014)</td>
<td>Aim to assess the stimulation impact on brain activity</td>
<td>tDCS + EEG</td>
<td>9</td>
<td>Normal weight</td>
<td>2 sessions</td>
<td>DLPFC</td>
<td>RCT</td>
<td>Reduce the number of tests to avoid the error. Small sample size maybe cause to false negative result.</td>
<td>Combine between neuroimaging assessment and stimulation tech.</td>
</tr>
<tr>
<td>8</td>
<td>(Gluck et al., 2015)</td>
<td>Increase the PFC activity by tDCS to improve control of eating behavior</td>
<td>tDCS</td>
<td>9</td>
<td>Obesity</td>
<td>3 sessions</td>
<td>Left DLPFC</td>
<td>Double-blind, randomized, placebo-controlled crossover.</td>
<td>Side effect of tDCS, there was high rate in skin redness according to participant report.</td>
<td>Proof of PFC stimulation concept in food intake and overweight.</td>
</tr>
<tr>
<td>9</td>
<td>(Grundeiis et al., 2017)</td>
<td>Study the impact of tDCS on food choices and calorie intake</td>
<td>tDCS</td>
<td>25</td>
<td>Obesity</td>
<td>1 sessions</td>
<td>Left DLPFC</td>
<td>Double-blind, randomized, placebo-controlled crossover.</td>
<td>Gender: Female Only</td>
<td>tDCS not supported as promise tool for overweight treatment</td>
</tr>
<tr>
<td>10</td>
<td>(Kim et al., 2018)</td>
<td>Study the influence of repeated TMS on BMI</td>
<td>rTMS</td>
<td>60</td>
<td>Obesity</td>
<td>4 sessions</td>
<td>Left DLPFC</td>
<td>Pre-post design and study the hypothesis is based on questionnaire.</td>
<td>Neuroimaging technique to assess the stimulation impact on brain activity.</td>
<td>rTMS could be used in weight gain treatment.</td>
</tr>
<tr>
<td>11</td>
<td>(Barth et al., 2011)</td>
<td>Reduce the frequent food craving by single session rTMS</td>
<td>rTMS</td>
<td>18</td>
<td>Normal, overweight and obesity</td>
<td>1 session</td>
<td>Left DLPFC</td>
<td>Pre-post design and study the hypothesis is based on questionnaire.</td>
<td>Gender: female only. Side effect of rTMS (mild pain).</td>
<td>Reducing in food craving by rTMS/DLPFC stimulation.</td>
</tr>
</tbody>
</table>
| Study Number | Year | Title | Authors | Study Design | Group 1 | Group 2 | Intervention | Follow-up | Sample Size | Outcome
--- | --- | --- | --- | --- | --- | --- | --- | --- | --- | ---
| 12 | 2018 | Study the impact of rTMS on food consumption and social cognition | Hall et al., 2018 | RCT | 21 | Normal weight | 1 session | Left DLPFC | RCT | Gender: female only. Normal weight sample size -
| 13 | 2016 | Reduce BMI by DBS | Harat et al., 2016 | DBS | 1 | Obesity | 1 | nucleus accumbens | Surgical intervention, and follow-up 14 months | Invasive electrodes | Support to overweight treatment by nucleus accumbens stimulation
| 14 | 2017 | Modifying the food choice behavior by stimulation the PFC using FMRI-neurofeedback | Spetter et al., 2017 | FMRI-NF | 8 | Male, overweight and obesity | 6 sessions | PFC | Pre-post design and study the hypothesis based on questionnaire. | FMRI Expensive compared with other techniques such as EEG. Neurofeedback training could be a usefulness in maintaining BMI. Sample size and gender.
| 15 | 2017 | Examine the usefulness of FMRI-NF in down-regulation of food or drug craving. | Ihssen et al., 2017 | FMRI-NF | 10 | Normal weight | 1 session | Whole brain-MRI scan | - | Gender: female only, normal weight, MRI scan. | Reduce in food craving by FMRI-NF stimulation.
| 16 | 2017 | Examine the usefulness of EEG-NF in modifying food craving | Imperatori et al., 2017 | EEG-NF | 50 | Normal and overweight | 10 sessions | parietal lobe | Pre-post design and study the hypothesis based on questionnaire. | Assess the training on long term with food craving only. Using multielectrode for EEG assessment and training. Obesity out of study. | Brain stimulation methods are useful in eating behavior modification in excess weight case.
| 17 | 2015 | Study the Cue exposure based EEG-NF in overeating episodes | Schmidt and Martin, 2015 | EEG-NF | 27 | Normal, overweight and obesity | 10 sessions | Vertex (Cz) | Pre-post design and study the hypothesis based on questionnaire. | Female with restrained eater. EEG data analysis. | EEG-NF in eating behavior still need to be explored in future research.
| 18 | 2016 | AN treatment by EEG-NF | Lackner et al., 2016 | EEG-NF | 22 | Underweight | 10 sessions | Pz | Pre-post design and study the hypothesis based on questionnaire. | Female underweight AN subjects | Support to AN treatment by EEG-NF without medication interventions
| 19 | 2016 | Binge eating treatment by EEG-NF | Schmidt and Martin, 2016 | EEG-NF | 75 | Normal and overweight | 10 sessions | Vertex (Cz) | Pre-post design and study the hypothesis based on questionnaire. | Female with binge eating | Brain directed treatment is a good approach in eating behavior.
| 20 | 2017 | Change food craving in overweight cases | Fattahi et al., 2017 | EEG-NF | 30 | Overweight | 10 sessions | Pz | Pre-post design and study the hypothesis based on questionnaire. | Female only. Brain activity assessment is required | EEG-NF haven’t side effect and could be applied in overweight or obesity treatment.

normal and overweight, 8 sessions was the duration of study. Other study have deceased the food intake behavior in 23 male obesity by repeated tDCS in long period of stimulation on left DLPFC, 15 sessions in 31 days was the study duration (Heinitz et al., 2017). (Ljubisavljevic et al., 2016) suggested that repeated tDCS could be used in obesity treatment according to result in modification food craving behavior by repeated tDCS, single session have been applied to stimulate the right DLPFC. (Mengotti et al., 2018) aimed to modify the ability of food energy estimation by 2 sessions of tDCS in 30 females with restrained eating disorder, the target area was left DLPFC.

(Georgii et al., 2017) utilized the tDCS to effect on trait impulsivity in 42 female in normal weight, single session to stimulate the right DLPFC. (Montenegro et al., 2012) combined tDCS stimulation with physical exercise (Aerobic) and the result is greater reduce in desire to eat compared to stimulate tech. or physical activity alone. The above studies have not dealt with neuroimaging devices such as (EEG , FMRI) to assess the impact of stimulation on brain activity , only one study aimed to assess the tDCS stimulation impact on brain activity after stimulate the DLPFC in normal weight cases (Lapenta et al., 2014). Also, there are other studies aimed to reduce the calorie intake and improve the eating by stimulation left DLPFC, But the authors had included the participants report about the side effect of tDCS, their reports referred to high rate in skin redness (Lapenta et al., 2014; Gluck et al., 2015). In another side, (Grundeis et al., 2017) implemented one session of tDCS stimulation over DLPFC for nine obesity females and shown that tDCS not supported as promise tool for overweight treatment.

**TMS devices**

The TMS device is stimulate the brain cortex by electromagnetic induction. Coil is placed over scalp to implement electric current that resultant of changing in magnetic field as shown in Fig. 4. This current penetrates the scalp to influence on the neuronal current in the underlying cortex and induce the short-term changing in neural circuitry. the pulses applied via a The effect of neural circuitry alteration can exceed the period of stimulation by applying a series of pulses, a technique known as repetitive Transcranial Magnetic Stimulation (rTMS) (Barr et al., 2008).

The implementation of rTMS on PFC has shown that it manages to effectively reduce desires for smokes, alcoholic beverages and drugs (cocaine), especially when applied in multiple sessions (Feil Jodie and Zangen, 2010). In the context of food intake behavior, rTMS has also been used in reducing food craving by implementing a single session of rTMS over the left DLPFC (Hall et al., 2018). The (Barth et al., 2011) have applied rTMS to stimulate the left DLPFC in 18 normal and overweight females for 1 session, the result supported that rTMS can reducing the food craving, also the (Kim et al., 2018) Shown the impact of rTMS in overweight treatment by implemented 4 sessions of rTMS stimulation over left DLPFC in 60 obesity individuals. All above studies are RCT and pre and post design and have not dealt with neuroimaging technique to assess the effect of TMS stimulations on brain activity. Regarding to side-effect of TMS, the participant’s reports referred to mild pain during the stimulation session.

**Deep brain stimulation (DBS)**

Deep brain stimulation (DBS) is an invasive technique intended to alter the brain activity through the transfer of electrical stimulation signals directly (Karas et al., 2013). These signals are provided by a pair of electrodes that are implanted in a specific brain area through surgical interventions and controlled by a generator (Neuro-Stimulator) implanted in the chest. In the literature, a previous study has applied DBS to control food consumption via modulation of homeostatic pathway that consequent to reduce BMI (Harat et al., 2016).

However, this technique is supporting the overweight treatment by nucleus accumbens stimulation but can't be considered safe intervention.
Neurofeedeback devices

Neurofeedback (NF) is non-invasive stimulation technique refer to therapeutic process in which information about individuals brain activity is monitored electronically and respond back by means of (auditory or visually) formations. NF devices are classified depending on the method of brain signals are acquired: either using Functional Magnetic Resonance Imaging (FMRI-NF) or Electroencephalography (EEG-NF) (Cardo et al., 2013).

FMRI-NF system

The FMRI data acquisition system which recording the brain activity with high spatial resolution and medium temporal resolution. FMRI is mainly used due to fast data acquisition and high computational processing. The FMRI-NF are used in two studies during last year’s in food intake modification. The (Spetter et al., 2017) have proved the usefulness of FMRI-NF in modification food choices behavior in overweight and obesity individuals by PFC stimulation, the RCT was used in these study to assign the participants into 2 groups: intervention NF group and non-NF. The duration of study was 6 sessions in 4 weeks and the target gender was male only. (Ihssen et al., 2017) aimed to examine the usefulness of FMR-NF in down-regulation of food or drug craving. The target gender was female only, 10 normal weight individuals were participated for 1 session, during this session the participants trained to regulate their brain activity when the palatable food pictures are presented inside the FMRI scan-tube. The study result referred to reducing in food craving by FMRI-NF stimulation. In another side, FMRI system are considered high cost and difficulty of usage compared with other system (Sitaram et al., 2007), as mentioned in previous study the participant should be laying inside MRI tube and this condition not suitable for all cases. The basic setup of this system is shown in Fig. 5.

EEG-NF system

The EEG-NF depends on EEG data acquisition, this system consists of three operations, most of which are performed electronically. Fig. 6 shown the basic setup of EEG-NF system.

The first operation is the detection and amplification of the signals by EEG device. These signals can range from the relative occurrence or non-occurrence of certain brain waves. The second operation is the conversion of the amplified signal to an easily understood form. This operation is also performed electronically and consists of converting the amplified electronic impulses from the first operation to the appropriate varying auditory or visual signals. The third operation is the feeding back to the subject in a relatively immediate basis changes in the signals from the second operation, the feedback presented to the subject could be in the form of visual, audio or game. For instance, it can be represented as a color change, bar increase/decrease, vibration, and sound. It can be also be integrated into the Neurofeedback game as character/object appearance, etc. (Liu Hou and Sourina, 2015).

During EEG-NF, the EEG signals of brain activity are monitored using electrodes placed on...
the scalp. The pattern of signals is then recognized by using EEG analysis and the system then provides the subject with feedback as a reward (depending on the desired levels of the EEG signal) (Perronnet et al., 2016).

There are four studies have used in food intake modification. The (Schmidt and Martin, 2015) aimed to examine the EEG-NF in reducing overeating episodes in normal and overweight individuals, the target gender was female only who are suffering from a type of eating disorder called “restrained eaters”. The EEG-NF have implemented to Vertex (Cz) stimulation. The study designed in RCT to assign the participants into two groups, the NF group and non-NF group (waitlist). The hypothesis examined based on the questionnaire data in pre-post stimulation. After 10 sessions of NF, the result mentioned to positive outcome and there is reducing in overeating episodes in NF group compared with waitlist group.

The second study aimed to treatment other type of eating disorder called “binge eating” by EEG-NF stimulation. A total of 75 females were randomly assigned to groups (NF, waitlist). The NF group was under EEG-NF stimulation for 10 sessions over 42 days. Also, the (Cz) was the stimulation area. The EEG-NF led to a reduction of both binge eating and distress that is commonly associated with binge eating. The effects were consistently stable during a 3-month follow-up (Schmidt and Martin, 2016). Overall, these studies recommend to brain stimulation is a good approach in food intake behavior but have not dealt with male in terms of the gender and didn’t support PFC stimulation approach. Also, the obesity and normal cases of overweight “without eating disorder” have not included in study case.

Regarding to outcome assessment, the EEG activity have not assessed as the authors mentioned in their limitations of study.

There is other type of eating disorder called “Anoxia”, the (Lackner et al., 2016) have used the EEG-NF to Pz stimulation in 22 underweight individuals for anoxia treatment. The (Imperatori et al., 2017) aimed to examine the usefulness of EEG-NF in modifying food craving. The EEG-NF implemented to stimulate the Parietal lobe in overweight and normal weight only, obesity was out of study. This study has used the same study design and the participants allocated into 2 groups (NF and waitlist). The hypothesis examined based on EEG power and questionnaire data in pre-post stimulation. The result shown that decrease in food craving behavior in NF group compared with waitlist group. The (Fattahi et al., 2017) have applied EEG-NF to improve food craving in overweight females, the authors concluded that EEG-NF stimulation could using in overweight and obesity treatment without any side-effect.

As described on the previous pages, the EEG-NF device is a safe, non-surgical interventional and non-side effect, therefore, it could be considered a promising tool in food intake modification but more research in this topic is required, also PFC stimulation by EEG-NF for FI modification, till now have not applied yet.

**EEG-NF signal processing**

The EEG device recorded signals from the continuous tiny electrical signals coming from the brain. These signals are related to cognitive behaviour which is regulated by brain activity. Hence, there is demand for
EEG signals processing to understand the cognitive processes. EEG signal processing can be divided into 3 steps, pre-processing, feature extraction and signal classification.

The pre-processing included the detection and removal of artefacts from the EEG signal, the main artefacts causes are eye-blinking, respiratory activity, and head or body motion and electric power-line source of EEG device. The next step in signal processing is feature extraction, the EEG row signals transferred into set of features called feature vector. It’s included several mathematical methods to extract the data or variable values, previous studies have been utilized time domain, frequency domain and time-frequency domain depend on the study domain and objectives. The classification step can be settled by different analysis methods to utilize the feature information of EEG signals in diagnosis or in communication with a control-external device. traditionally, the features extraction is considered the most significant step in EEG signal processing (Hussein et al, 2018).

In EEG-NF applications, the usual feature extraction method is Frequency Domain (FD). Most of previous studies that aimed to EEG assessment in EEG-NF stimulation have used the absolute EEG power or relative power ratio between slow and fast EEG frequency bands to examine the EEG-NF stimulation impact (Enriquez-Geppert et al., 2017). The (Wang et al., 2016) have used the EEG-NF in children with autism disorder and the ratio of EEG power in pre-post stimulation and during stimulation sessions has been calculated to examine the stimulation effect. Also, (Angelakis et al., 2007) assessment the EEG-NF stimulation for cognitive improvement in the ageing by calculated the absolute power of alpha frequency band. In food craving behaviour context, (Imperatori et al., 2017) have used the theta/alpha ratio to assessment the EEG-NF stimulation.

**Summary and Outlook**

Brain-stimulation approach is a promising tool in obese treatment or in another meaning brain stimulation supported the modification food intake behavior. Based on the literature presented above could be concluded the modification food intake behavior is the main aspect in preventing obesity or being overweight. As mentioned previously, current approaches for therapies are often ineffective in modifying the lifestyle or monitoring food intake behavior, also pharmacology interventions or medical treatment (including surgical in high obesity cases). The Table 1 is shown that current brain-stimulation techniques such (tDCS, rTMS) that have used in PFC stimulation to modify food intake behavior in obesity and overweight individuals, but these techniques may be associated with some mild and temporary effects or be not safe in some cases, this is especially true for the invasive techniques (DBS).

The EEG-Neurofeedback is one of brain stimulation techniques but the published research literature in modifying food-intake behavior is meagre at present. However, the EEG-NF hasn't applied yet in PFC stimulation.

From the literatures are explained, there are three frequent challenges in previous studies, the first challenge is gender, most of previous studies focus on female more than male. The second one is sample size calculation, it’s very important in neurosciences behavioral studies to calculate the target participant number from population study case and to be enough for significant statistical power.

The last challenge is study design, the pre-post design is very familiar in previous work but most of them examine the hypothesis based on questionnaires only without neuroimaging techniques to evaluate the brain activity in pre and post stimulation, that will assist the determine a size effect of stimulation on brain activity.

However, the authors are recommend the EEG-NF devices for PFC stimulation in modification food intake behavior, due to able to stimulate and record brain signals, in order to assessment the brain activity in pre-post stimulation, also, affordable price system and easy to handle compared with other techniques.

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