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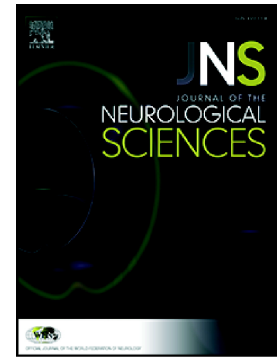
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## Using real-time fMRI brain-computer interfacing to treat eating disorders

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**Keywords:** Anorexia nervosa; Binge eating disorder; Brain-computer interfacing; Bulimia nervosa; Eating disorders; Neurofeedback; Real-time fMRI; Self-regulation

## Abstract

*Real-time functional magnetic resonance imaging based brain-computer interfacing (fMRI neurofeedback) has shown encouraging outcomes in the treatment of psychiatric and behavioural disorders. However, its use in the treatment of eating disorders is very limited. Here, we give a brief overview of how to design and implement fMRI neurofeedback intervention for the treatment of eating disorders, considering the basic and essential components. We also attempt to develop potential adaptations of fMRI neurofeedback intervention for the treatment of anorexia nervosa, bulimia nervosa and binge eating disorder.*

**Keywords:** Anorexia nervosa; Binge eating disorder; Brain-computer interfacing; Bulimia nervosa; Eating disorders; Neurofeedback; Real-time fMRI; Self-regulation

## 1. Introduction

Eating disorders are mental and psychological disorders characterised by abnormal eating habits and behaviour that can cause damaging effects to health and wellbeing. They include anorexia nervosa, bulimia nervosa and binge eating disorder. Treatment methods for eating disorders typically include psychological therapies and medication such as the use of antidepressants. The success rates of treating eating disorders with psychological therapies are modest for adults with anorexia nervosa (Bartholdy et al., 2013), while the use of medication has shown more benefit for the treatment of bulimia nervosa (Bulik et al., 2007; Shapiro et al., 2007). Eating disorders have also been treated using methods based on neuromodulation. These include transcranial magnetic stimulation (TMS), transcranial direct current stimulation (TDCS) and deep brain stimulation (DBS). TMS, TDCS and DBS involve electrical stimulation. DBS is also invasive and involves the surgical insertion of an electrode into the brain. Attention bias modification treatment (ABMT) is another interesting treatment option for patients with eating disorder. ABMT is a novel method that arose from contemporary cognitive theories of anxiety and from experimental studies concerning threat-related attentional biases in anxiety disorders (Bar-Haim, 2010). Since anxiety plays a major

role in the development and maintenance of eating disorders, ABMT is being used for the treatment of such disorders (Renwick et al., 2013). However, there are very limited studies providing evidence for the effectiveness of ABMT for treating eating disorders. Although, all these methods have shown encouraging results (Renwick et al., 2013; Van den Eynde and Guillaume, 2013), new treatment methods such as real-time brain-computer interfacing (rtBCI) that are safer, more beneficial and adjustable to each patient's needs are required.

RtBCI, also known as neurofeedback, is a feedback technique based on neuroregulation (self-regulation) of brain signals. Here, a person receives real-time information continuously, about changes in neural activity in certain brain regions, which they then use to learn self-regulation and control of neural activity in that brain region to produce changes to their behaviour (Stoeckel et al., 2014). Neurofeedback being the core of brain-machine interfaces has enabled a new way of investigating brain function and neuroplasticity (Sitaram et al., 2017). Neurofeedback based on electroencephalography (EEG) has been used to treat many types of clinical disorders including eating disorders. It has been used to treat binge eating in a randomized controlled trial of female subclinical threshold sample (Schmidt and Martin, 2016) and adolescent anorexia nervosa (Lackner et al., 2016). EEG neurofeedback provides good temporal resolution, is inexpensive and portable when compared to functional magnetic resonance imaging (fMRI). However, the clinical applications of EEG neurofeedback are limited by poor spatial resolution and the inverse problem issue. Irrespective of fMRI's poor temporal resolution and slow hemodynamic response, it is able to map the whole brain and localise specific brain function whereas EEG is limited to cortical regions. Real-time functional magnetic resonance imaging based brain-computer interfacing (RtfMRI-BCI; fMRI neurofeedback) has been used to treat clinical disorders such as chronic pain, depression, schizophrenia, addiction, attention deficit hyperactivity disorder (ADHD), stroke,

tinnitus and obesity (Frank et al., 2012; Spetter et al., 2017), just to mention a few. The use of rtfMRI-BCI (fMRI neurofeedback) to treat eating disorders is very limited. The aim of this paper is to give an outline and procedure of how to design and implement rtfMRI-BCI interventions for the treatment of eating disorders such as anorexia nervosa, bulimia nervosa and binge eating disorder.

In this paper, we propose a step-by-step guide of how to implement fMRI neurofeedback for the treatment of eating disorders based on a review of the literature. The remaining part of this paper is organised as follows: Section 2 entails the methods section which include a step-by-step guide of how to implement fMRI neurofeedback for the treatment of eating disorders. The steps that make up the guide are ethics and safety, study design, recruitment of participants, assessment, criteria for stimulus selection, RtfMRI-BCI (fMRI neurofeedback) intervention and data analyses. Section 3 gives an overview of other eating related conditions and behaviours such as food craving, addiction, lean, overweight and obese people. The eating related condition called “Diabulimia” is also highlighted in section 3. Section 4 of the paper briefly discussed the factors that need to be considered for the successful implementation of fMRI neurofeedback for the treatment of eating disorders. Section 5 gives an account of how the literature on fMRI neurofeedback for the treatment of eating disorders was reviewed while considering specific selection criteria. Section 6 entails the conclusion of the paper.

## **2. Methods**

### **2.1 Ethics and safety**

The study protocol should be approved by the relevant local ethics committee, especially in accordance with the “Declaration of Helsinki”. Potential participants of the study should be

screened for magnetic resonance imaging (MRI) contraindications with a safety-screening questionnaire before the brain scan. All participants with MRI contraindications such as metal implants in their bodies should be excluded from the study. All personal information and data collected from the participants during the study should be coded and kept confidentially by the research team.

## **2.2 Study design**

The study should be designed in such a way that it would include an experimental and a control group of participants diagnosed with a specific eating disorder e.g. anorexia nervosa. A randomisation protocol should be used to sort the participants into both groups. The experimental group will receive rtfMRI-BCI training in addition to treatment as usual while the control group should receive treatment as usual and sham neurofeedback (sham rtfMRI-BCI training) (deCharms et al., 2005).

## **2.3 Recruitment of participants**

The recruitment of participants could be done in a variety of ways. It could be through the primary clinicians of the patients or through the relevant staff from the health research boards. If not already done, the diagnosis of patients (e.g. anorexia nervosa) should be done using the Structured Clinical Interview for Diagnostic and Statistical manual of Mental Disorders, fifth edition (DSM-V) (Leppanen et al., 2017). Patients whose diagnosis has been confirmed should be invited to participate in the study and offered more information about the study. Information such as study procedures and tasks should be provided to the interested patients who should be asked to provide written informed consent. Other screening assessments such as the Eating Disorder Examination Questionnaire (EDEQ), which is a 36-item self-report measure used to assess eating disorder behaviours and attitudes (Fairburn and

Beglin, 1994) and measures such as the patient's body mass index (BMI) should be completed by the participants. The mental health of the participants may also be assessed by using the Depression, Anxiety and Stress scale (DASS) which is a 21-item self-report measure assessing the severity of depression, anxiety and stress (Lovibond and Lovibond, 1995). Other behavioural measures and factors relevant to the study may also be assessed. Participants should also be informed that they are free to withdraw from the study at any time if they wish to.

#### **2.4 Assessment**

Assessments, where participants complete various relevant questionnaires, clinical and psychometric measures should be done before, during and after the study. Baseline assessment should be carried out on all the participants before they are randomised into one of two groups; experimental and control groups. Thereafter, assessments should also be administered at the experimental group sessions and control group sessions. Finally, there should be follow-up assessments for both the experimental and control groups some time after the study task sessions. For more information on assessments during rtfMRI-BCI interventions, see Cox and colleagues (Cox et al., 2016).

#### **2.5 Criteria for stimulus selection**

The stimuli that would be used to localise the specific brain region-of-interest (ROI) relevant to a particular eating disorder is also of interest because this is where neural feedback would be given from. Normally, localising the ROI entails contrasting food pictures against neutral non-food pictures. These stimuli are of different dimensions and so a validated database of stimuli (Blechert et al., 2014; Feroni et al., 2013; Miccoli et al., 2014) would be very helpful and useful to select images from, depending on the type of eating disorder being studied. For

example, the FoodCast Research Image Database (FRIDa) by Foroni and colleagues (Foroni et al., 2013) entails 877 images that have been put into eight different categories: natural-food (e.g., strawberry), transformed-food (e.g., French fries), rotten-food (e.g., mouldy banana), natural-non-food items (e.g., pinecone), artificial food-related objects (e.g., teacup), artificial objects (e.g., guitar), animals (e.g., camel), and scenes (e.g., airport). FRIDa is a well-controlled, flexible, validated, and freely available (<http://foodcast.sissa.it/neuroscience/>) database of stimuli with multiple variables such as valence, familiarity, calorie content, brightness and high frequency power, etc. Depending on the particular eating disorder under investigation, it would also be important to consider other properties of the food images like calorie density (Frank et al., 2010; Toepel et al., 2009) as well as physical properties of the images (Foroni et al., 2016).

## **2.6 RtfMRI-BCI intervention**

RtfMRI-BCI (fMRI neurofeedback) intervention entails putting participants in the bore of an MRI scanner and asking them to self-regulate a specific brain region-of-interest (ROI). Here, we attempt to develop potential adaptations of fMRI neurofeedback for the treatment of eating disorders (anorexia nervosa, bulimia nervosa and binge eating disorder). FMRI neurofeedback intervention entails two set-up runs; the localiser and the neurofeedback runs (Sokunbi, 2017). The localiser run is the first step of applying fMRI neurofeedback intervention to the participants. From the name localiser, the run localises the ROI to be used for subsequent neurofeedback runs. The localisation of a ROI would normally depend on the knowledge of the neural mechanism underlying the behavioural output of interest. For example, the amygdala, putamen/caudate, insula, thalamus and parahippocampal gyrus were localised as ROIs when highly palatable and energy-dense food pictures were contrasted against neutral household objects in alternating order in a rtfMRI neurofeedback food craving



study of healthy participants (Ihssen et al., 2017; Sokunbi et al., 2014). In table 1 below we give possible examples of ROIs that can be used for subsequent neurofeedback runs for the treatment of anorexia nervosa (AN), bulimia nervosa (BN) and binge eating disorder (BED). These ROIs were detected when patients with eating disorders performed visual food image discrimination tasks (food > non-food). The patients passively viewed and discriminated between food images and non-food images by pressing a button each time the picture changed. The food images were matched for complexity and colour composition (Kim et al., 2012). In table 1, patients with anorexia nervosa (AN) and bulimia nervosa (BN) exhibited both hyperactivity (over activation) and hypoactivity (reduced activity) in brain regions when compared with healthy controls (HC) while patients with binge eating disorder (BED) exhibited only hyperactivity (over activation) at the right medial orbitofrontal cortex (OFC). It is worth mentioning that a number of factors modulate the neural response to food. Some of such factors include salience of food, the reward value of the stimulus, the degree of hunger, endocrine factors, affective state, habits, efforts to restrict food intake, decision-making processes, ageing and gender effects (García-García et al., 2013). Hence, these factors need to be properly controlled for, when designing and localising a ROI for fMRI neurofeedback studies for eating disorders. For example, in patients with anorexia nervosa (AN), investigators have reported hyperactivation of the anterior cingulate cortex after a 12-hour fasting period (Kim et al., 2012), while hypoactivation of the same brain region was reported after 6 hours of fasting (Gizewski et al., 2010). Also, it has been reported that oxytocin levels were higher in women with anorexia nervosa compared with healthy women (Lawson et al., 2012). In patients with bulimia nervosa, hyperactivation was found in the anterior cingulate cortex after 12 hours fasting (Schienle et al., 2009) whereas hypoactivation was found in the same brain region by another study that did not control for the fasting period

(Joos et al. 2011). In patients with binge eating disorder, hyperactivation was found in the medial OFC after a 12 to 14-hour fasting period (Schienle et al., 2009).

**Table 1** Examples of brain region of interest (ROI) of eating disorder (Anorexia nervosa, Bulimia nervosa and Binge eating disorder) patients while performing visual food image discrimination task (food > non-food ) that can be adapted for real-time fMRI neurofeedback

Eating disorder	Type of comparison	Brain Region
Anorexia nervosa (AN)	Within group (AN)	Brain activation in the left and right Inferior frontal gyrus, right Superior frontal gyrus, left Anterior cingulate cortex (ACC), left Anterior insula, left Precuneus, left Cuneus and, left and right Cerebellum (Kim et al., 2012).
	Between group (AN > HC)	Hyperactivity in the right Inferior frontal gyrus, left and right Superior frontal gyrus, left Anterior cingulate cortex, right Cerebellum (Kim et al., 2012) and Posterior cingulate/Precuneus (Gizewski et al., 2010; Rothmund et al., 2011).
	(AN < HC)	Hypoactivity in the right inferior parietal lobe (Kim et al., 2012; Santel et al., 2006), orbitofrontal cortex (OFC) (Holsen et al., 2012; Uher et al., 2003) and lateral Prefrontal cortex (PFC) (Gizewski et al., 2010; Uher et al., 2003).
Bulimia nervosa (BN)	Within group (BN)	Brain activation in the right Lingual gyrus, left and right insula, left and right ACC, left and right lateral OFC, left amygdala, right ventral striatum (Schienle et al., 2009), left anterior insula, left cuneus and, left and right cerebellum (Kim et al., 2012).
	Between group (BN > HC)	Hyperactivity in the right ACC, left and right insula (Schienle et al., 2009), right Middle frontal gyrus and right Cerebellum (Kim et al., 2012).
	(BN < HC)	Hypoactivity in the right Postcentral gyrus, left Inferior parietal lobule (Kim et al., 2012), temporal lobe (Brooks et al., 2013; Joos et al., 2011) and visual cortex (Brooks et al., 2013).
Binge eating disorder (BED)	Within group (BED)	Brain activation at left Middle occipital gyrus, left Middle frontal gyrus, left and right insula, left and right anterior cingulate cortex, left and right lateral orbitofrontal cortex (OFC) and, left and right Medial orbitofrontal cortex (Schienle et al., 2009).
	Between group (BED > HC)	Hyperactivity in the right medial OFC (Schienle et al., 2009).

AN: Anorexia nervosa, BN: Bulimia nervosa, BED: Binge eating disorder, HC: Healthy control

The neurofeedback run is a closed-loop system which entails feeding back the fMRI signal from the ROI selected for eating disorder during the localiser run and mapping the percentage signal change of the fMRI signal on a feedback presentation tool such as a thermometer bar

(Sitaram et al., 2007), functional maps of the brain (Yoo and Jolesz, 2002), 3D animated character (Sitaram et al., 2007), scrolling time series graphs (Weiskopf et al., 2004), video based feedback (Sitaram et al., 2007) or the changing size of food pictures (Sokunbi et al., 2014). We will now attempt to develop a neurofeedback run for the 3 eating disorders (anorexia nervosa, bulimia nervosa and binge eating disorder) in the experimental group. We will use some of the ROIs in table 1 and the changing size of food pictures mapped to the fMRI signal change, developed by Sokunbi and colleagues (Sokunbi et al., 2014), as feedback presentation tool (see Figure 1). For patients with anorexia nervosa, using the right Inferior frontal gyrus in table 1 as the ROI where feedback will be sent from, during self-regulation training (at the regulation block), the patients would be asked to down-regulate the fMRI signal by reducing the size of the food picture through “motivational feedback” of mental imagery (Sokunbi et al., 2014). This is because as shown in table 1, the right Inferior frontal gyrus is hyperactive and hence down-regulation should help to bring the fMRI signal to the level of the healthy controls. During the rest block they do nothing. As the patients are engaged with the down-regulation and rest blocks, the MRI scanner acquires functional images associated with the down-regulation training which are analysed and presented as feedback (changing size of food pictures), thereby forming a closed-loop. Figure 1 depicts a schematic representation of a neurofeedback run using the changing size of food pictures as the feedback presentation tool. For hypoactive ROIs such as the right inferior parietal lobe, orbitofrontal cortex (OFC) and lateral Prefrontal cortex (PFC) in patients with anorexia nervosa, the patients would be asked to up-regulate the fMRI signal by increasing the size of the food picture (see Figure 1) so as to bring the fMRI signal to the level of the healthy controls. For hyperactive and hypoactive ROIs of patients with bulimia nervosa, they would be asked to decrease and increase the size of the food pictures respectively. While patients with binge eating disorder having hyperactive ROI at the right medial OFC would be asked to

decrease the size of the food pictures. For hyperactive ROIs of patients with anorexia nervosa and hypoactive ROIs of patients with bulimia nervosa, it may be more appropriate to use a thermometer display as feedback presentation tool (Sitaram et al., 2007).

For appropriate control conditions, we will employ two control mechanisms both at the level of the experimental and control groups. For the experimental group, immediately after each neurofeedback run we will implement a mirror run. During the mirror run the patients would be instructed not to regulate their fMRI brain responses during exposure to the food images but should passively watch the size of the food picture sequences instead (Sokunbi et al., 2014). Each mirror run will always be presented after its corresponding regulation run showing the same picture exemplar and size sequence (Sokunbi et al., 2014). Hence, the mirror run will serve as a perceptual control (Sokunbi et al., 2014). For the control group, a sham neurofeedback mechanism would be implemented. The sham neurofeedback would entail giving feedback to patients in the control group derived from a different patient's brain, for example from patients in the experimental group (deCharms et al., 2005). These two control mechanisms would help to test the efficacy of the neurofeedback training in the experimental group. Depending on the study design and assessments, the experimental group may engage in a number of neurofeedback runs. For example, in Cox et al. (Cox et al., 2016), the experimental group engaged in six neurofeedback sessions across 4 months while the control group attended four behavioural assessment sessions.

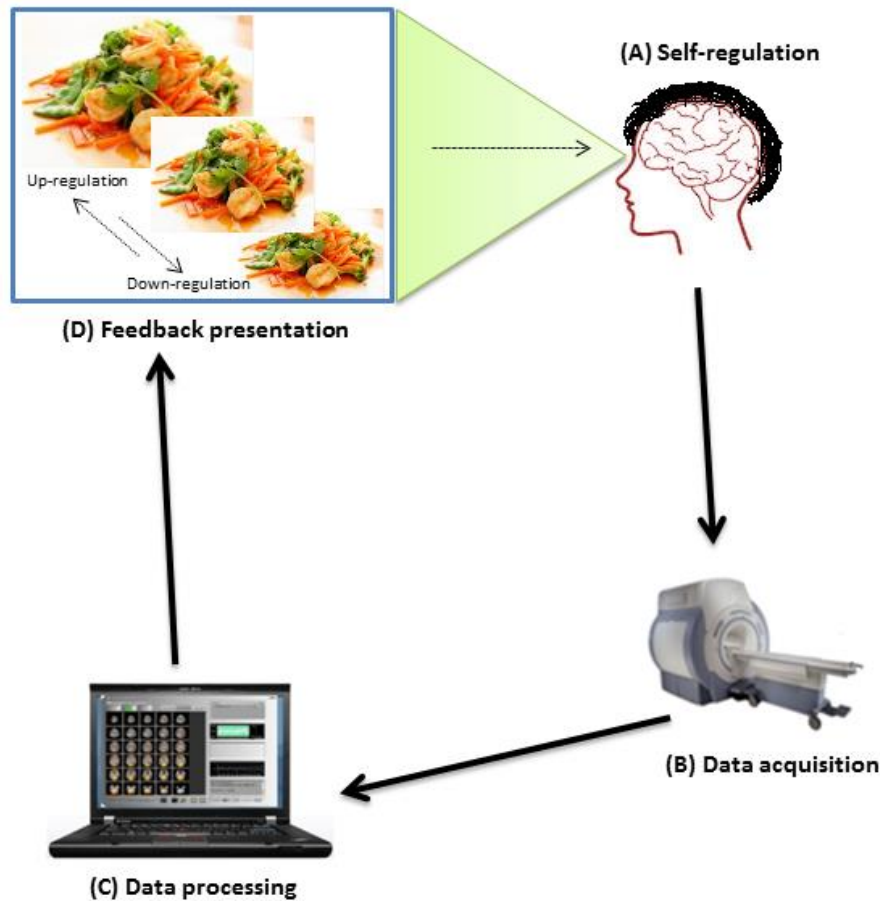


Figure 1: Schematic representation of a neurofeedback run. This entails a closed-loop system where activated fMRI signal from a target region of interest (ROI) mapped to the changing size of food pictures is regulated (up/down) through feedback by a participant in the MRI scanner. (A) Self-regulation: Participant learns to regulate (up/down) activated signal at target region of interest (ROI) mapped to changing size of food cues through feedback. (B) Data acquisition: The MRI Scanner is used for fMRI data acquisition. (C) Data processing: PC running real-time signal processing, statistical analysis and presentation of feedback signal at a target region of interest (ROI). (D) Feedback presentation: Presentation of feedback signal at a target ROI mapped to the changing size of food pictures.

## 2.7 Data analyses

The primary analysis of the data should entail comparing the neurofeedback runs and mirror runs of the experimental group, and also comparing the experimental group with the control group so as to estimate the efficacy of the rtfMRI-BCI intervention. Analyses at the different

points of assessments will be useful to estimate the impact of the intervention on the experimental group. The behavioural data can be analysed using SPSS or any other statistical package. The neuroimaging data (anatomical and functional brain data) can be analysed using BrainVoyager (<http://www.brainvoyager.com>), Statistical Parametric Mapping software (SPM; The Wellcome Department of Imaging Neuroscience, UCL, London, UK) or other neuroimaging software packages. Also, more advanced neuroimaging methods such as connectivity measures, multivariate pattern analysis and nonlinear measures such as entropy (Sokunbi, 2016) can be applied to estimate the effects of the rtfMRI-BCI intervention on brain activation at the ROI and whole-brain levels.

### **3. Other eating related conditions and behaviours**

Eating related behaviours and conditions such as food craving, addiction, lean, overweight and obese people can also benefit from fMRI neurofeedback. We recently showed that there was evidence for a reduction of hunger after fMRI neurofeedback and an association between down-regulation of food cues and the degree of hunger reduction (Ihsen et al., 2017; Sokunbi et al., 2014). Using fMRI neurofeedback, lean participants learned to regulate the anterior insular cortex within one day over four training sessions (Caria et al., 2007). In another fMRI neurofeedback study they also demonstrated that successful regulation compared to no regulation of the anterior insular cortex resulted in increased negative valence ratings of emotional pictures (Caria et al., 2010). It was also shown that obese subjects' regulation ability during an fMRI based neurofeedback paradigm was higher compared to lean subjects (Frank et al., 2012). FMRI neurofeedback training for alcohol dependence has also been implemented (Cox et al., 2016). FMRI neurofeedback intervention can also be implemented in other neurological disorders that have been associated with dysfunctional eating habits in order to improve diet choice and eating behaviours. Such neurological

disorders include Parkinson's disease (Aiello et al., 2017; Sauleau et al., 2014) and dementia (Rumiati et al., 2016; Rumiati and Foroni, 2016). Another interesting group of patients could also be patients undergoing gastric bypass surgery for treatment of obesity (Shin and Berthoud, 2011). There is also another eating related condition called "Diabulimia". Diabulimia is the combination of "diabetes" and "bulimia". It is an eating related condition specific to patients with diabetes characterized by limiting and/or skipping insulin dosing due to concerns over their body weight and/or shape (Kıncık et al., 2017). Diabulimia is not a recognised medical condition (Wilson, 2012) but it is a common term in the diabetes community.

#### **4. Discussion**

Real-time fMRI-BCI intervention offers great promise for the treatment of eating disorders because it provides a safer, more beneficial and individually tailored treatment for each patient. Here, each patient learns to voluntarily regulate localised brain activity through repeated training which consequently influence behaviour and cognition. A number of factors need to be considered in order to employ rtfMRI-BCI intervention for the treatment of eating disorder. Factors like study design, assessments, diagnosis of patients, randomisation, duration of illness of patients, age, gender, body mass index, types of medication, mental health and behavioural measures, just to mention a few. For example, in an electroencephalography (EEG) study, Pergola and colleagues showed the link between body mass index of the participants and food semantics (Pergola et al., 2017) While Nummenmaa et al. (Nummenmaa et al., 2012) found that there was a link between body mass index (obese and normal-weight subjects) and viewing appetizing versus bland foods in fMRI. Also, the impact of gender (Frank et al., 2010; Killgore and Yurgelun-Todd, 2010), hunger level and mood (Killgore and Yurgelun-Todd, 2006; van der Laan et al., 2011) has been investigated in

a number of studies. Furthermore, other studies investigated the interaction between gender and motivational level and self-control (Del Parigi et al., 2002; Killgore and Yurgelun-Todd, 2010; Toepel et al., 2012). Hence, inclusion and exclusion criteria need to be carefully considered and determined for a well-designed study. In this review, we have reflected on the basic components essential for implementing rtfMRI-BCI intervention for the treatment of eating disorders. Table 2 depicts a basic outline for using rtfMRI-BCI intervention to treat eating disorders. Other neuroimaging modalities for neurofeedback treatment of eating disorders are EEG, magnetoencephalography (MEG) and near-infrared spectroscopy (NIRS) (Bartholdy et al., 2013).

**Table 2** An outline for using real-time functional magnetic resonance imaging based brain-computer interfacing to treat eating disorders

I.	Ethics and safety Pertinent issues such as ethical approval, screening for magnetic resonance imaging (MRI) contraindications and safety of the personal information of participants should be carefully considered.
II.	Study design The study should be designed such that a randomisation protocol is used to classify the participants into an experimental and a control group.
III.	Recruitment This may include recruitment of participants through a variety of ways, determining the diagnosis of participants through the Structured Clinical Interview for Diagnostic and Statistical manual of Mental Disorders, fifth edition (DSM-V), getting informed consents from participants and screening assessments. Information such as study procedures and tasks should be provided to the interested participants.
IV.	Assessment Assessment points such as baseline assessment, assessment during rtfMRI-BCI intervention and control intervention, and follow-up assessments should be defined for both the experimental and control groups.
V.	Stimulus selection The criteria for selecting stimuli that would be used to localise the specific brain region-of-interest (ROI) for neurofeedback should be defined. Normally, localising the ROI entails contrasting food pictures against neutral non-food pictures.
VI.	RtfMRI-BCI intervention The experimental group will undergo rtfMRI-BCI intervention and mirror neurofeedback runs at defined assessment points while the control group may undergo positive imagery strategies outside the MRI scanner or sham neurofeedback at relevant assessment points.
VII.	Data analyses This entails analysing the acquired data (behavioural and neuroimaging) with statistical software tools. Behavioural data may be analysed with SPSS while the neuroimaging data (anatomical and functional) may be analysed with BrainVoyager, Statistical Parametric Mapping (SPM) software or other neuroimaging software packages. Also, more advanced neuroimaging methods such as connectivity measures, multivariate pattern analysis and nonlinear measures such as entropy may be used.

RtfMRI-BCI: real-time functional magnetic resonance imaging based brain-computer interfacing



## 5. Literature search and selection criteria considerations

We performed a computer search of research articles using PubMed which is an online repository for over 27 million citations of biomedical articles from MEDLINE, life sciences journals and online books. We used the following keywords for the search: real-time fMRI neurofeedback and eating disorders, real-time fMRI neurofeedback and anorexia nervosa, real-time fMRI neurofeedback and bulimia nervosa, or real-time fMRI neurofeedback and binge eating disorder. Using each of these keywords our search produced between 1 and 3 articles; Val-Laillet et al. (Val-Laillet et al., 2015), Bartholdy et al. (Bartholdy et al., 2013) and Frank et al. (Frank et al., 2013). We then applied the following two criteria for the selection of articles to review: (1) the article is an original research study; (2) the study includes a randomized-control trial (RCT). Application of only the first criteria led to the exclusion of all the three articles because they were all review articles that partly discussed fMRI neurofeedback and eating disorders. Furthermore, we did a search on “ClinicalTrials.gov” using all of the above keywords to see if there were studies undergoing or completed, but we did not find any study.

## 6. Conclusions

This is not meant to be an exhaustive procedure but a reflection on how rtfMRI-BCI can be used to treat eating disorders such as anorexia nervosa, bulimia nervosa and binge eating disorder. In this brief review, we have reflected on the design and implementation of rtfMRI-BCI intervention for the treatment of eating disorders, considering the basic and essential components. We have also attempted to develop potential adaptations of fMRI neurofeedback intervention for the treatment of anorexia nervosa, bulimia nervosa and binge eating disorder.

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**Highlights**

- Eating disorders have normally been treated by psychological therapies and medication such as antidepressants.
- Treatment methods based on neuromodulation have also been used to treat eating disorders.
- Real-time functional magnetic resonance imaging (fMRI) based brain-computer interfacing (BCI) offers promising outcomes for the treatment of eating disorders.
- We give an outline for using real-time fMRI based BCI to treat eating disorders.
- We also developed potential adaptations of real-time fMRI based BCI for treating eating disorders.