UNIVERSITI PUTRA MALAYSIA

PRE-FRONTAL CORTEX STIMULATION BY EEG-NEUROFEEDBACK ON FOOD INTAKE BEHAVIOR IN OBESITY AND OVERWEIGHT CASES

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FK 2019 96

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By

MOHAMMED ISAM NAJI AL-HIYALI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

May 2019

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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May 2019

Chairman : Asnor Juraiza Bt. Ishak, PhD
Faculty : Engineering

EEG-Neurofeedback is a mode of brain stimulation that is potentially valuable for improving self-regulation skills in cases of behaviours disorder. This study proposed the EEG- neurofeedback can be accompanied by a change in the EEG waves power which that associated with general symptoms of food intake behavior in overweight and obesity cases. The previous studies indicated the personal decision about eating under effect of environment factors such as (visually, smelling, tasting) is related to neural activity of prefrontal lobe of brain. Therefore, there were many attempts made to modify the food intake behavior in overweight and obesity cases through the stimulation of the PreFrontal Cortex (PFC). However, the empirical viewing of EEG- neurofeedback experiments haven't explicated the details about the effect the EEG-NF on the electrical activity of PFC in these cases, it is not yet well explored.

This study is cue-exposure EEG-NF experiment constructed into two groups with two conditions (pre-post phases) and two variables types (quantitative and qualitative variables) to verify the hypothesis of effecting the EEG-NF on the electrical activity of PFC and modifying the general symptoms of food intake behavior in excess weight individuals.

Twenty-four of excess weight participants (BMI more than 25 kg/m2) were recruited. These participants assigned randomly into two groups; the EX-Group (N=12) who had enrolled in 8 sessions of EEG-NF experiment during the stimulation phase, and the C-Group (N=12) who's had listed in a waiting and not enrolled in EEG-NF experiment.

The participants provided researchers with a self-report questionnaire relating to their observation of general symptoms of food intake behavior for qualitative analysis, and EEG waves recordings for quantitative analysis into pre and post stimulation phase. The results of two-way analysis of variance (ANOVA) explained that a significant variance in variables between two groups after EEG-NF experiment. The quantitative variables indicated the effect of EEG-NF experiment was significant decrement in the mean of whole EEG power from (59.98) to (47.44) dB\Hz and decrement in the mean of Theta\Beta Ratio (TBR) from (2.30) to (1.84). The qualitative variables indicated the effect of EEG-NF experiment which that influenced significantly in changing the median of self-report questionnaire responses that relating with general symptoms of food intake behavior. The Spearman correlation analysis indicated to significant correlation between these variables at post stimulation phase. The correlation analysis within stimulation phase was explaining more details about the effect of amount of EEG-NF sessions on PFC electrical activity which that indicated to 75% the strength of correlation between TBR and amount of NF sessions.

The R^2 is 56% of the decrement in TBR can be explained by an increment in EEG-NF sessions, this percentage in an acceptable range to proves the impact of EEG-NF sessions on the TBR for PFC electrical activity that means this manipulating in TBR that influences in improving the food intake behaviours in overweight and obesity cases.

This study provides preliminary support for the therapeutic potential of cue-exposure EEG-NF experiment that targets the prefrontal cortex, to influence neural processes underlying food intake behavior in overweight and obesity cases.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

SIMULASI KORTEKS PRA-HADAPAN OLEH EEG-TINDAK BALAS NEURO TERHADAP TINGKAH LAKU PENGAMBILAN MAKANAN UNTUK KES-KES KEGEMUKAN DAN BERAT BADAN BERLEBIHAN

Oleh

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EEG-tindak balas neuro adalah mod rangsangan otak yang berpotensi berharga untuk meningkatkan kemahiran kendiri dalam kes-kes kelakuan tingkah laku. Kajian ini mencadangkan EEG- tindak balas neuro boleh disertai dengan perubahan dalam kekuatan selombag EEG yang berkaitan dengan gejala umum pengambilan makanan dalam kes kelebihan berat badan dan obesiti. Kajian terdahulu menunjukkan pemilihan individu tentang perahanan dipengarahi oleh faktor persekitaran seperti (visual, berbau, merasa) berhubung dengan aktiviti saraf lobus prefrontal otak. Oleh itu, terdapat banyak percubaan untuk mengubah suai tingkah laku pengambilan makanan dengan berat badan berlebihan dan kes obesiti melalui rangsangan kortex pra-hadapan. Walau bagaimanapun, maklumat berhenaan empirikal eksperimen EEG-tindak balas neuro tidak menjelaskan butir-butir mengenai kesan EEG-NF mengenai aktiviti elektrik kortex pra-hadapan dalam kes-kes ini, ia masih belum diterokai dengan baik.

Kajian ini adalah eksperimen isyarat EEG- tindak balas neuro yang dibina kepada dua kumpulan dengan dua syarat (fasa sebelum dan selepas) dan dua jenis pembolehubah (pembolehubah kuantitatif dan kualitatif) untuk mengesahkan hipotesis terhadap hesan EEG- tindak balas neuro pada aktiviti elektrik kortex pra-hadapan dan mengubah gejala pengambilan makanan pada individu berlebihan berat badan.

Dua puluh empat peserta berlebihan berat badan (BMI lebih daripada 25 kg / m2) dipilih sbg responden. Para pesertg tekandipecahkan secara rawak ke dalam dua kumpulan; Kumpulan EX (N = 12) yang telah mendaftar dalam 8 sesi

eksperimen EEG- tindak balas neuro semasa fasa rangsangan, dan C-Group (N = 12) yang telah disenaraikan dalam menunggu, dan tidah terlibat dalam EEG- tindak balas neuro eksperimen.

Peserta telah menyediakan penyelidik dengan soal selidik diri berkaitan dengan pemerhatian mereka terhadap gejala pengambilan makanan untuk analisis kualitatif, dan rekod gelombang EEG untuk analisis kuantitatif ke dalam fasasebelum rangsangan dan selepas fasa rangsangan.

Hasil analisis varians dua hala (ANOVA) menjelaskan, bahawa varians yang signifikan dalam pembolehubah kuantitatif dan kualitatif antara dua kumpulan selepas eksperimen EEG. menganalisis pembolehubah kuantitatif menunjukkan kesan eksperimen EEG adalah penurunan signifikan dalam min keseluruhan EEG kuasa dari (59.98) hingga (47.44) dB \ Hz dan penurunan dalam purata Theta \ Beta Ratio (TBR) dari (2.30) hingga (1.84) yang mempengaruhi dengan ketara dalam mengubah median tindak balas soal selidik diri yang berkaitan dengan gejala umum pengambilan makanan. Hasil Analisis korelasi Spearman menunjukkan korelasi yang signifikan antara dua pemboleh ubah selepas fasa rangsangan. Analisis korelasi dalam fasa rangsangan menjelaskan lebih mendalam mengenai kesan jumlah sesi EEG- tindak balas neuro pada aktiviti elektrik kortex pra-hadapan yang menunjukkan 75% kekuatan korelasi antara TBR dan jumlah sesi NF. Hasil nilai R^2 adalah 56% daripada penurunan dalam TBR boleh dijelaskan dan kenaikan dalam sesi EEG- tindak balas neuro.

Oleh herana nilai di dalam julat ys dibenarhan, maha ia membuhtiran yang boleh diterima untuk membuktikan kesan sesi EEG- tindak balas neuro pada TBR untuk aktiviti elektrik kortex pra-hadapan yang bermaksud memanipulasi ini dalam TBR yang mempengaruhi peningkatan tingkah laku pengambilan makanan masalah berat bodan berlebihan dan obesiti.

Kajian ini memberikan sokongan pendahuluan untuk potensi terapeutik eksperimen isyarat EEG- tindak balas neuro yang mensasarkan korteks prefrontal, untuk mempengaruhi proses saraf yang mendasari kelakuan pengambilan makanan dalam masalah kegemukan dan obesiti.

ACKNOWLEDGEMENTS

In the name of Allah, the most gracious, the most merciful.

All praise and thanks are due to Allah and pray and peace and blessings be upon his Prophet Mohammed and his family and all his Companions. First and foremost, I would like to express my gratitude and thanks for my supervisor, **Dr. Asnor Juraiza Bt. Ishak**. In the last two years ago, she welcomed me into her office and gave me the opportunity to study something I had dreamed. My dream of studying and finding my place within the field of biomedical instrumentations has been fulfilled, honestly, I will always appreciate our experiences together.

I would also like to thank my supervisor committee, Assoc. Prof. Dr. Siti Anom Bt. Ahmad and Dr. Hafiz Rashidi b Harun @ Ramli for all their help in editing and revising my proposals and thesis drafts, I am grateful to your support during this wonderful journey. Also, I owe very special thanks for all who's supported me during the preparation of this thesis or data collection, especially Dr. Ahmed Faeq Hussein from Al-Nahrain university-Iraq.

Finally, no one can deny the fact that family is the most important part of a successful life, so I express my gratitude to my mother, she is the icon of affection and warmth, to my wife, she is the source of confidence in my life, and my sweet daughter Rawan, she is my soul and my heart forever, my brother, my sister and their families.

Declaration by graduate student

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LIST OF ABBREVIATION

WHO	World Health organization
BMI	Body Mass Index
IPH	Institute For Public Health
FI	Food Intake
PFC	PreFrontal Cortex
TMS	Transcranial Magnetic Stimulation
tDCS	transcranial Direct Current Stimulation
DBS	Deep Brain Stimulation
EEG-NF	Electroencephalography-Neurofeedback
FMRI-NF	Functional Magnetic Resonance Imaging-Neurofeedback
PSD	Power Spectral Density
RCT	Randomized Control Trial
Na	Sodium
Ca	Calcium
K	Potassium
Cl	Chlorine
O	Occipital
P	Parietal
C	Central
T	Temporal
F	Frontal
Fp	Frontopolar

Hz	Hertz
CNS	Central Nervous System
CT	Cognitive Training
BS	Brain-Stimulation
DLPFC	Dorsolateral Prefrontal Cortex
rTMS	repeat Transcranial Magnetic Stimulation
MRI	Magnetic Resonance Imaging
ADHD	Attention Deficit Hyperactivity Disorder
qEEG	Quantitative EEG
SPSS	Statistical Package in Social Sciences software
ANOVA	Analysis of Variance
FFT	Fast-Fourier Transform
FD	Frequency Domain
FIB	Food-Intake Behaviour
CA	Craving Action
PWF	Preoccupied With Food
TSE	Trouble Stopping Eating
EX-Group	Experimental Group
C-Group	Control Group
EDF	European Data Format
ICA	Independent Component Analysis
TAR	Theta\Alpha Ratio
TBR	Theta\Beta Ratio
P(SB)	Power of Slow Band

P(FB)	Power of Fast Band
dB	decibels
P-value	Probability Value
F-value	Fisher Statistics test

CHAPTER 1

INTRODUCTION

Over the last 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 2018). Also, the Institute for Public Health (IPH) in Malaysia has reported that 47.7% of the Malaysian population is made up of high BMI individuals. From this number, 17.7% percent suffer from obesity whereas 30% percent are overweight as explained in Figure 1-1(Institute for Public Health 2015).

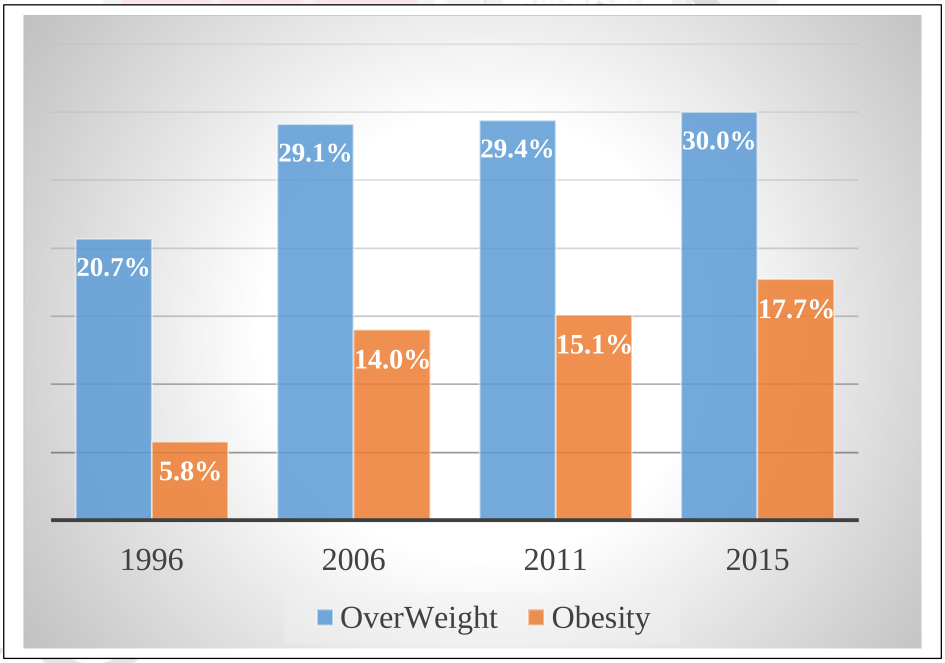

Figure 1 1 : IPH Survey - Prevalence of overweight and obesity in Malaysia

The ever-increasing number of excess weight individuals in society is commonly due to excessive food intake and lack of physical activity. Another contributing factor is the increase in availability and consumption of palatable food rich in sugars and fat (Vos MB, Kimmons JE, Gillespie C, Welsh J 2008). Besides excessive consumption of high caloric food, daily meal patterns have changed over the last decades, noting a trend for increased meal frequency (i.e. snacking behavior). Snacking has been suggested to also contribute to weight gain as well as to its metabolic rate (Bertéus Forslund et al. 2005). Thus, a reduction in physical activity and an increase in calorie dense food and snacking behavior all result in weight gain.

The prevalence of obesity individuals can be said to have reached widespread proportions, thus proving that at least part of the individuals is not capable of regulating their own food intake which is key to weight gain prevention (Sellaro and Colzato 2017).

Food Intake (FI) regulation is a complex process involving the combination of internal factors such as neural signals, as well as external factors including the environmental factors that stimulate eating desire such as sight, smell and taste (Huang, Marsh, and Moodie 2012).

However, studies have shown that specific areas of the brain are involved in the interactive processing of food vs. non-food- related visual stimuli in the different states of hunger and satiety, which includes the PreFrontal Cortex (PFC). 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 that a therapeutic program targeting stimulation in the decision-making process may lead to an encouraging approach in the prevention of weight gain. Also, the physiologists have considered that FI behavior forms part of behavioural regulator of body mass index due to the fact that food consumption is a form of behavior (Barnett 2017; RICHTER 1943), thus the brain plays a in regulating this behavior.

Furthermore, several neuroimaging studies have documented that dysregulation of food intake behavior in obesity individuals indicates an imbalance between neural circuits that prompt and restraint behaviours (VOLKOW, ND; WISE, RA; BALER 2017). This has supported the proposal that the tendency for irregular food intake and lack of physical activity may be related to failure in self-control and decision-making deficits, principally related to the PFC activity of brain (Alonso-Alonso and Pascual-Leone 2007; Brockmeyer et al. 2017; Hollmann et al. 2012; Sellaro and Colzato 2017). It can therefore be assumed that PFC stimulation in certain ways may strengthen restraint circuits that are a core element in governing the executive functions that target FI behavior, thus inhibiting activity in the neural circuits that drives a person to consume food excessively (Alonso-Alonso and Pascual-Leone 2007; Lee et al. 2012).

This indicates that techniques to improve such abilities may prove to be effective tools for maintaining weight loss. The rising numbers of excess weight individuals and repeated failures in attempts to control weight gain traditionally indicates a need for new therapeutic approaches (Macht M 2011).

1.1 Problem Statement

Generally, controlling the subject's FI behavior is the main aspect in preventing obesity or being overweight. The traditional approaches for treatment or therapies such as diet, sports exercises or regulate of FI by using medical treatment including surgical interventions for high obesity cases are often ineffective in modifying the lifestyle and eating habits, that contribute to an increase of BMI (Care and Brauer 2015). The general symptomatology that may be associated with excess weight individuals is a cognitive deficit in the food intake behaviour.

The recent systematic review (Forcano et al. 2018) discussed 50 studies in cognitive training and brain stimulation which intervened to modify food intake behaviours in excess weight individuals (overweight and obesity). 35 of these studies (70%) were related to cognitive training while 15 studies (30%) in this review were focused on brain stimulation approaches. The quality of the studies was determined by Thompson scale for each approach (0-13). Despite the large size of cognitive training studies in this review, the mean quality of brain stimulation studies was 12.25 (SD=1.48) more than the mean quality of cognitive training studies 10.21 (SD=1.17). However, the quality decrease in brain stimulation approaches were due to lack in number of experiments. Therefore, evidence from this systematic review suggests that more brain stimulation experiments are required to successfully in modify the food intake behaviours of excess weight individuals.

The studies of brain-direct stimulation in overweight and obesity individuals have previously shown to have an impact on food intake behaviour. Since the frontal lobe is involved in decision-making and process of cognitive controls, the PFC stimulation has been suggested by many researchers to improve the food intake behaviours in overweight and obese individuals (Gluck, Alonso-alonso, et al. 2015; Gluck, Viswanath, and Stinson 2017). The common non-invasive techniques, such as the Transcranial Magnetic Stimulation (TMS), transcranial Direct Current Stimulation (tDCS) have been applied to stimulate PFC for those cases (Lowe, Vincent, and Hall 2017; Macedo et al. 2016).

According to findings of (Mostafavi, Khaleghi, and Mohammadi 2018) systematic review in tDCS effective in modifying food intake behavior, the PFC stimulation have significant impact on treatment the cognitive deficit which is related in food intake behavior. However, these findings may be somewhat limited in the assessment methods. The experiments efficiency had been assessed mostly based on qualitative variables and rarely focused on quantitative variables. The qualitative variables which were extracted from the behavior report during pre and post stimulation to verify the difference in reports, while the quantitative variables which were extracted from neurocognitive functions.

Due to the importance of quantitative analysis in understanding the experiment performance trends and examining the neurocognitive functions through which PFC stimulation affects food intake behaviours, some studies such as (Lowe et al. 2018) combined two devices, which are a stimulation device and an EEG data acquisition device for collecting the raw EEG signals. However, the experiment procedure involving these two devices takes extra time to replace the electrodes and also requires a larger budget for experiment.

Neurofeedback (NF) is one of the brain-stimulation techniques which involves real-time neuro-signal measurement, immediate data processing with the extraction of neurophysiology parameters and feedback to individuals to make changes in brain functioning and consequently behaviours. This technique can be further classified as either to FMRI-NF and EEG-NF based on neuroimaging data acquisition (Perronnet et al. 2016). This would mean that the NF experiment setup does not require external data acquisition for quantitative variables extraction.

However, the experiments in the previous literature of NF used the FMRI-NF device to perform PFC stimulation in overweight and obese cases to change food intake behaviours (Ihssen et al. 2017; Spetter et al. 2017). There has not yet been any efforts to apply the EEG-NF to PFC stimulation in overweight and obesity cases although the EEG device is affordable and easier to handle compared to FMRI. Also, the total number of EEG-NF studies in the eating behavior research area is very narrow compared to other techniques.

Therefore, in this study, it is hypothesized that EEG-neurofeedback stimulation of the prefrontal cortex activity can leads to modification of the general symptoms of food intake behaviours in experiment participants.

In order to approve or disapprove this hypothesis, there are two research questions which needs to be addressed:

a) What is the quantitative difference in EEG power between pre and post NF stimulation sessions? And
b) What is the qualitative difference in self-report behavior between pre and post stimulation sessions?

1.2 Objective

The aim of this study is to design a new EEG-neurofeedback experiment for prefrontal cortex stimulation in excess weight individuals. Three specific objectives were included to validate this experiment:

i. To extract the quantitative variables from EEG signals and qualitative variables from self-behavioural report.
ii. To verify the variance in experiment variables between groups at pre and post stimulation phases and find the correlation between them in two study phases.
iii. To verify specific EEG bands during stimulation sessions and find out the correlation with amount of EEG-NF sessions.

1.3 Scope of Study

This study focuses on utilizing EEG-NF for PFC stimulation in excess weight individuals to investigate the feasibility of using EEG-NF to modify the food-intake behaviour by cue-exposure neurofeedback protocol. The study design is the Randomized Control Trial (RCT) for recruited participants. Two groups are participating, EX-group and C-groups with two conditions (pre and post-stimulation). The EEG signal and self-report questionnaire are included in data collection procedures. The EEG data is recorded by means of 2 channels clinical system: Plus, BrainAvatar software. This system and software are specializing in EEG systems and neurofeedback stimulation. All EEG signals that were collected throughout the entire sessions are processed to spectrum estimation for EEG features extraction, and food intake assessment was done by analysing the self-report questionnaire terms. All data were analysed and examined for variance at pre and post-stimulation.

1.4 Contribution of study

The main motivation of this study is to contribute to the growing literatures associate with EEG-NF in overweight and obesity cases. This technique is believed to have potential as a tool to modify the general symptoms of food intake behavior in some cases.

It also has the advantages of being non-invasive compared to other methods of neurofeedback. The effects are seen not only when the person's brain activity is being monitored and they are getting feedback in the form of auditory and visual displays on the computer but continues beyond that after enough stimulation has been performed.

The significance of the study is able to show and explain how PFC stimulation can be achieved in a non-invasive and painless way compared to other techniques (e.g tDCS and TMS) and also in studying and understanding the potential effects of stimulation on PFC neural functions through EEG signals assessment.

1.5 Thesis Outlines

Chapter 1 of this thesis explains the overview of study, problem statement, objectives, scope of study and motivation of study. Chapter 2 describes, the fundamentals of EEG brain activity, studies biomedical devices in food-intake behavior, reviews the studies of brain-stimulation systems and summary. Chapter 3 details the methodology of study including study design, data collection procedures, experiment materials and verification of hypothesis. Chapter 4 involves the results and discussion, which includes an explanation of the observed relationship between food intake behavior and brain activity. Chapter 5 concludes on the work done, analyses the advantages for this study, and explains the recommendation for future work.

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LIST OF PUBLICATIONS

Journal Article

Published: M. I. Al-hiyali, A. J. Ishak, H. Harun, S. A. Ahmad, and W. S. Wa, “A Review in Modification Food-Intake Behavior by Brain Stimulation : Excess Weight Cases,” Neuroquantology, vol. 16, no. 12, pp. 86–97, 2018.

In Progress: M. I. Al-hiyali, A. J. Ishak, H. Harun, S. A. Ahmad, and W. S. Wa, “Examination Of Prefrontal Cortex Activity After EEG-Neurofeedback Stimulation In Overweight Cases”International Journal of Integrated Engineering Vol. 0 No. 0

Conference Paper

Published with Best Paper Award: Mohammed I. Al-Hiyali, Asnor J. Ishak, Hafiz Harun, Siti A. Ahmad, W. A. Wan Sulaiman."Stimulation The Prefrontal Cortex By EEG Neurofeedback Training In High Body Mass Index Individuals", 2018 IEEE-EMBS Conference on Biomedical Engineering and Sciences (IECBES), 2018

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