EFFECT OF BILATERAL SOMATOSENSORY STIMULUS ON OSCILLATORY BRAIN ACTIVITY AND LONG TERM MEMORY

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Submitted by GİZEM GÖKTEPE in partial fulfillment of the requirements for the degree of **Master of Science in Health Informatics Department, Middle East Technical University** by,

Prof. Dr. Deniz Zeyrek Bozşahin
Director, **Graduate School of Informatics** ____________________

Assoc. Prof. Dr. Yeşim Aydın Son
Head of Department, **Health Informatics** ____________________

Assoc. Prof. Dr. Tolga Esat Özkurt
Supervisor, **Health Informatics Dept., METU** ____________________

Examining Committee Members:

Assoc. Prof. Dr. Yeşim Aydın Son
Health Informatics Dept., METU ____________________

Assoc. Prof. Dr. Tolga Esat Özkurt
Health Informatics Dept., METU ____________________

Assist. Prof. Dr. Aybar Can Acar
Health Informatics Dept., METU ____________________

Assist. Prof. Dr. Murat Perit Çakır
Cognitive Science Dept., METU ____________________

Assist. Prof. Dr. Tolga Çukur
Electrical and Electronics Engineering Dept., Bilkent University ____________________

Date: __________

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last name : Gizem Göktepe

Signature : ________________

ABSTRACT

EFFECT OF BILATERAL SOMATOSENSORY STIMULUS ON OSCILLATORY BRAIN ACTIVITY AND LONG TERM MEMORY

Göktepe, Gizem

MSc., Department of Medical Informatics

Supervisor: Assoc. Prof. Dr. Tolga Esat Özkurt

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A psychotherapy treatment called eye-movement desensitization and reprocessing (EMDR) is used to elicit traumatic memories in shorter time and decrease its negative effect by using bilateral saccadic eye-movements, auditory and tactile stimuli. As yet, there is no well-accepted result with regard to the effect of bilateral stimuli on long term memory. In this thesis, effect of bilateral somatosensory stimulus on oscillatory brain activity and long term memory was investigated. Accordingly, a novel face recognition paradigm was designed comprising two separate sessions of memory encoding and recognition. In the encoding session, 240 face images consisting of 3 ethnicities as asian, black and white were uniformly presented to 20 university students. In the recognition session, with and without somatosensory stimulus applied, totally 336 face images (240 old, 96 new) were presented to the subjects while they were asked whether they had seen them previously. EEG recording was performed only during the recognition session. Analysis showed that bilateral somatosensory stimulus increased alpha activity in the left parieto-occipital channels prior to the stimulus and in the right parieto-occipital channels during decision making. Furthermore, subjects, who increased long term memory performance, also had significantly greater alpha activity in the frontal channels when somatosensory stimulus was applied. Our study shows that bilateral stimulation may change the long term memory performance along with a modification in the oscillatory brain activity.

Keywords: long term memory, bilateral somatosensory stimulus, brain oscillations, face recognition, alpha band

ÖZ

İKİ TARAFLI SOMATASENSÖRİYEL UYARANLARIN SALINIMSAL BEYİN AKTİVİTE VE UZUN SÜRELİ HAFIZADAKİ ETKİSİ

Göktepe, Gizem

Yüksek Lisans, Tıp Bilişimi Bölümü

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Bir psikoterapi yöntemi olan göz hareketleriyle duyarsızlaştırma ve yeniden işleme (EMDR) yöntemi iki taraflı sakkadik göz hareketleri, işitsel ve dokunsal uyaranlar kullanarak travmatik anılara daha kısa sürede ulaşılması ve bu anıların olumsuz etkisinin azaltılmasında kullanılmaktadır. Şuana kadar yapılan araştırmalarda kullanılan iki taraflı uyaranların etkisine dair henüz kabul edilmiş bir sonuç bulunmamaktadır. Bu tez çalışmasında, iki taraflı somatosensöriyel uyaranların salınımsal beyin aktivite ve uzun süreli hafızadaki etkisi incelenmiştir. Bu doğrultuda, bellek kodlama ve bellek tanıma olmak üzere iki ayrı bölümlerden oluşan özgün yüz tanıma paradigması tasarlanmıştır. Bellek kodlama bölümünde; asyalı, siyahi ve beyaz olmak üzere 3 farklı etnisiteden oluşan eşit dağılımlı 240 yüz imgesi 20 üniversite öğrencisine gösterilmiştir. Bellek tanıma bölümünde, somatosensöriyel uyaran kullanıldığında ve kullanılmadığı sırada, deneklere toplamda 336 yüz imgesini (240 eski, 96 yeni) daha önceden görüp görmedikleri sorulmuştur. EEG kaydı sadece bellek tanıma işlemi esnasında alınmıştır. Analiz sonuçları, iki taraflı somatosensöriyel uyaranların bellek tanıma öncesi sol pariyetal-oksipital kanallarda ve karar verme sırasında sağ pariyetal-oksipital kanallarda alfa aktivitesini arttırdığını göstermiştir. Ayrıca, uzun süreli hafıza performansını arttıran deneklerde, iki taraflı somatosensöriyel uyaran kullanıldığında, frontal kanallarda alfa aktivitesinde önemli bir artış saptanmıştır. Bu çalışma, iki taraflı uyarımın salınımsal beyin aktivitesinin modifikasyonu ile uzun süreli bellek performansını değiştirebileceğini ortaya koymaktadır.

Anahtar Sözcükler: uzun süreli hafıza, iki taraflı somatosensöriyel uyaran, beyin salınımları, yüz tanıma, alfa bandı

To My Family and My Best Supporters

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CT	Computed tomography
EEG	Electroencephalography
EMDR	Eye-movement desensitization and reprocessing
EOG	Electrooculogram
ERD	Event-related desynchronization
ERS	Event-related synchronization
fMRI	Functional Magnetic Resonance Imaging
fNIRS	Functional Near-Infrared Spectroscopy
HZ	Hertz
LTM	Long Term Memory
MEG	Magnetoencephalography
MS	Milliseconds
PET	Positron Emission Tomography
PRS	Perceptual Representation System
PTSD	Post-traumatic stress disorder patients
RT	Response Time
STM	Short Term Memory

CHAPTER 1

INTRODUCTION

Information is a collection of facts or learned about something or someone which we encounter. Preserving and processing that information is not just easy as it is seen. There is a mechanism to store those facts and events or any related information in our mind. It is basically done by our memory. Memory is described as three fundamental functionality: collect (sense/encode) information, store, and process (retrieve/recall) information when needed. Since it has significant importance for our lives then it is important to understand the mechanism of the processing memory. How does it work? How is information stored and retrieved? The most crucial question: is there any way to improve it? When we find these answers, it will definitely affect our lives positively.

Most of the people encounter memory loss at some point. In other words, we can even forget about our precious memories from the past or any information that we memories a day ago. It is defined as short-term memory loss and long-term memory loss. For example; if you forgot what you drink 5 minutes ago, it is short-term memory loss. When you forget the name of school teacher 5 years ago, it is long-term memory loss. Memory has importance almost everything we face in life. Thus, studies on memory are still pursuing on how the mechanism is processing in real time. With respect to these studies, memory is categorized basically as short-term and long-term memory. Again, it is separated into the parts of a sub-memory system (Tulving, 1995). Information what we have is going through on firstly short-term memory, then if it is valuable to store, it is stored on long-term memory.

In that point, sometimes significant experiences from the past might be forgotten. Even people accept that they do not remember anymore, however, it affects people in a long period of time. One of these experiences called as traumatic memories. People usually encounter a bad experience which they do not want to remember from their childhood. Even if it was tried to forget, its negative effects can show up. These effects can be expressed itself as phobias, depression, fears or feeling insecure. To deal with that Shapiro (1989) has developed a technique that reaches these traumatic memories and reduces its negative effect in shorter time. It is called eye-movement desensitization and reprocessing (EMDR). In this technique, bilateral eye-movement, auditory and tapping methods are applied.

It is observed that eliciting long term memory had become quicker when bilateral stimuli were applied. Additionally, people are mostly saved from negative effects of their traumatic memories. To understand these effects on people, studies on mechanism underlying EMDR is still continuing.

Specifically, bilateral stimuli (saccadic eye-movement, bilateral auditory, and bilateral tapping) used in EMDR are given to the patients at the certain frequency. Frequency, volume, and intensity are not stable for each patient. Clinicians apply those stimuli according to his observation/decisions. Until now, there are various studies on the effect of EMDR in a clinical base. However, there is no well-accepted hypothesis on how the mechanism of EMDR effects long-term memory. Another critical question is: Does this effect valid for the healthy people? On the other hand, bilateral stimuli may cause oscillatory activity in the brain. As known, oscillatory activity is defined as the repeated activity of neurons in certain frequencies. Since given stimuli are repeated activity -as bilaterally-, it might have an effect on the brain. This study investigates bilateral somatosensory stimuli effects on long-term memory and oscillatory brain activity particularly in alpha frequency range using Electroencephalography (EEG) which is neuroimaging technique.

This study is based on measurement of electrical activity on the brain when the bilateral somatosensory stimulus is given to the subjects. In this study, an effect of the bilateral somatosensory stimulus on oscillatory brain activity and long-term memory performance was studied. Bilateral tapping was selected as bilateral somatosensory stimulus. In Chapter 2, a brief introduction for EMDR and memory types and mechanism was mentioned. In Chapter 3, methods and materials used in the study were explained in detail. In Chapter 4, behavioral and oscillatory results were indicated. Finally, conclusion and discussion with regard to this study can be found in Chapter 5.

CHAPTER 2

LİTERATURE REVIEW

2.1 EMDR

EMDR is a psychotherapy technique which is applied by bilateral eye movements to reduce traumatic effects by Shapiro (1989). After several studies on EMDR, two bilateral methods were added and now it has three methods: bilateral eye-movements, bilateral auditory and bilateral tapping stimuli. These methods were applied by clinicians usually to post-traumatic stress disorder patients (PTSD). It simply allows patients to elicit their long-term traumatic memories in a quicker way. There are studies on how bilateral stimuli effects people when eliciting memory. According to that, EMDR effect is explained on by five hypothesis: i) working memory principles (Andrade et al., 1997) ii) reciprocal inhibition (van den Hout et al., 2001) iii) interhemispheric relationship in brain (Christman et al., 2003) iv) orienting response (MacCulloch et al., 1996) v) neurobiological mechanism (Stickgold, 2002). However, there is still no widely accepted hypothesis from these alleged hypotheses.

From memory perspective, there are studies on working memory which uses counting (Kemps and Tiggemann, 2007), rhythmic tapping (van den Hout et al., 2001), visual noise (Kavanagh et al. 2001) to the PTSD patients. According to the studies, using EMDR’s bilateral stimuli has more effect to reach traumatic memory and reduce their negative effect compared to none. Unfortunately, there are limited studies on EEG for EMDR. Studies on EEG is usually based on an interhemispheric relationship for the brain. According to these studies, there is no evidence for interhemispheric connectivity which allows reaching memories in a quicker way (Samara et al., 2011; Propper et al., 2007).

2.2 Memory

Everything in what we see, what we hear, touch or any feeling in life makes a memory. Every single moment creates an experience starting from the birth to end of your life. It shapes and re-creates your thinking style, behaviors, and perceptions. It can be explained simply as three parts: encoding, storing and recalling information from the brain.

Mechanism of memory can be described as different categories such as short-term memory, long-term memory, episodic memory, semantic memory, procedural and declarative memories. All have a different type of mechanism for processing and retrieving information. According to the Tulving paper (1995), memory is separated into subsystems (see Table 1).

Table 1: Major components of the memory, adapted from Tulving (1995)

System	Other Terms	Subsystems	Retrieval
Procedural	Non-declarative	Motor skills Cognitive skills Simple conditioning Simple associative learning	Implicit
Perceptual Representation System (PRS)	Priming	Structural description Visual word form Auditory word form	Implicit
Semantic	Generic Factual Knowledge	Spatial Relational	Implicit
Primary	Working Short-term	Visual Auditory	Explicit
Episodic	Personal Autobiographical Event memory		Explicit

According to systems of memory, even all have a specific duty, they are mostly related to each other. This system is constituted in years and still developing. Yet, there is no strict separation between them. However, we can describe these categories as simply follows:

Short Term Memory (STM), has a limited capacity. It works as a brief storage and allows information to pass through the long-term memory.

Long-Term Memory (LTM), can be separated into two main groups: *explicit* which has conscious, *implicit* which has no conscious.

2.2.1 Long-Term Memory

Long-term memory can be separated into two major categories which are implicit (*procedural*) and explicit. Implicit memory is described as non-declarative. Unconsciously behaviors such as riding a bicycle, using pencil, tying shoes or brushing teeth. It is hard to verbally describe these 'natural' events. On the other hand, explicit memory is separated into two: semantic and episodic memory.

Semantic memory deals with meanings, facts and conceptual knowledge. Episodic memory constitutes from past experience of individuals. According to Tulving's theory of memory (1972), episodic memory differs from semantic memory as information that is stored. To clarify, episodic memory receives and stores information related to a temporal and spatial relationship between events or episodes. On the other hand, semantic memory has a memory which needs for using language.

2.2.2 Memory Information Process

According to Atkinson and Shiffrin (1968) the multistore model of memory, there are three linear stores which process information across them. These are a sensory memory, short-term memory, and long-term memory (see Figure 1). Sensory memory gets environmental input and transmits into short-term memory with attention. It means that attention makes sensory inputs memorable. Since short-term memory has limited capacity, if information needs to be stored for a long time, it needs to be rehearsed. After a number of rehearsals, information transferred into long-term memory. However, after criticism about a multistore model, Baddeley and Hitch (1974) developed working memory which replaces short-term memory in this model. Then, Baddeley enhanced this model with adding an episodic buffer (see Figure 2).

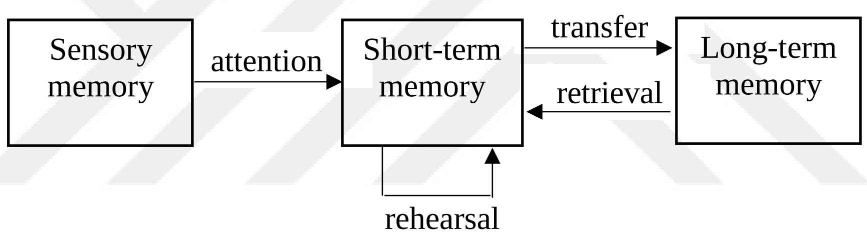

Figure 1: Multistore model of memory, adapted from Atkinson and Shiffrin (1968)

With Baddeley and Hithch (1986) and Baddeley (2000) working memory model, a short-term memory which is defined before from Atkinson and Shiffrin became insufficient. It is more than one simple storage (e.g. central executive loop, phonological loop etc.).

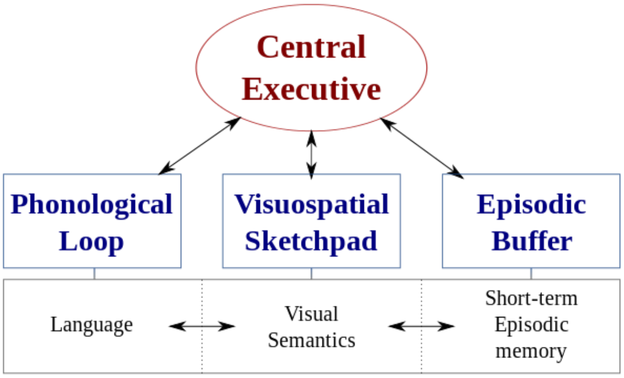

Figure 2: Working Memory Model, originally adapted from Baddeley (2000).

Learning and memory process is usually explained in three stages (Melton, 1963): *encoding*, *storage,* and *retrieval*. According to Melton (1963), *encoding* is the initial process of learning and perception. It is the first step for information processing. Since it is the first encountered events or perception, it does not mean that people encode everything that they perceived. It is selective which requires distinctiveness and attention to remember later (Hunt, 2003). *Storage* keeps information and maintains it. It stores information in short-term or long-term memory. *Retrieval* can be defined as gathering information from the storage. Tulving (1991) describes retrieval as “the key process in memory”. The reason why retrieval has significance is that when encoded or stored information is not gathered, it becomes redundant.

Recognition is a part of the retrieval process. It is categorized as a subcategory of declarative memory (Medina, 2008). According to Medina (2008), recognition is divided into two subcategories: *recollection* and *familiarity*. Recollection is basically "remembering" details of events which previously encountered. On the other hand, familiarity is "knowing" of an experienced event without trying to gather details of an event.

A recall is a type of retrieval which is basically re-accessing memory. It is different than recognition. Recognition has mostly been done after recall/retrieval processing. In this study, participants asked for a recognition test.

2.3 EEG and Brain Oscillations

2.3.1 Electroencephalography (EEG)

Electroencephalography is a measurement of electrophysiological brain activity. It is one of the brain-imaging techniques that allow researchers ability to understand brain activity. Other brain imaging techniques are magnetoencephalography (MEG), functional magnetic resonance imaging (fMRI), positron emission tomography (PET), computed tomography (CT), and functional near-infrared spectroscopy (fNIRS). Each imaging techniques has advantages and disadvantages in terms of spatial and temporal resolution, usability or feasibility. EEG has low spatial resolution compared to other imaging techniques. Therefore, it is usually hard to specify which region of the brain is activated exactly. However, EEG is most frequently used in studies since its ability for high temporal resolution. Thus, it is easy to detect neurons activity in time.

2.3.2 Neural Oscillation and Frequency Bands

Every single neuron creates electrophysiological activity in the brain. This electrical activity transmits its' activity to other neurons which creates action potential starting from a membrane. It is a potential change in the membrane when neurons are in communication (Hodgkin and Huxley, 1952). Neural oscillation is a repetitive electrical activity generated spontaneously from central nervous system (Başar, 2013). It is founded firstly by Hans Berger (1929) who able to record the electrical activity of the brain. Neural oscillations can be defined by frequency, amplitude, and phase. It is usually grouped by its frequency band interval. Frequency is repetitive events which occur in a specific time interval. It is measured in Hertz (Hz) and separated into five groups: delta band 1-3 Hz, theta band 4-7 Hz, alpha band 8-12 Hz, the beta band 13-30 Hz and gamma band 30-100 Hz. There is also study considering very low frequency (< 1 Hz) (Steriade et al., 1993).

According to the studies, delta band is related to autonomic functions (Knyazev, 2012). It is observed more in sleeping state. Alpha wave is observed first in awake and relaxed states (Anderson, 1968). It can be seen clearly when the eye is closed with an awake state. However, it is generally related to inhibitory functions (see *section 2.3.3*). Beta is usually related with motor functions (Kilavik, 2013). Teta and gamma band is associated with memory encoding functions (Nyhus et al., 2010). In general, it can be said that neural oscillation is mostly related with cortical behaviors. There are various studies which confirm oscillations has a specific role in behaviors (Başar et al., 2001). Still, there is no strict distinction between oscillation and behaviors. However, it is possible to categorize them from previous studies based on functional and anatomical features (see Table 2). It should be noted that this is not a totally accepted version for a relationship between oscillation and functions.

Table 2: Cortical Networks and Oscillations, adapted from Uhhlaas, 2012

	Delta (1-3 Hz)	**Theta (4-7 Hz)**	**Alpha (8-12 Hz)**	**Beta (13-30 Hz)**	**Gamma (30-200 Hz)**
Anatomy	thalamus, neocortex	hippocampus, sensory cortex, prefrontal cortex	thalamus, hippocampus, reticular formation, sensory cortex, motor cortex	all cortical structures, sub-thalamic nucleus, basal ganglia and olfactory bulb	all brain structures, retina, and olfactory bulb
Function	memory, synaptic plasticity	memory, synaptic plasticity, top-down control and long-range synchronization	inhibition, attention, consciousness, top-down control and long-range synchronization	sensory gating, attention, motor control and long-range synchronization	perception, attention, memory, consciousness and synaptic plasticity

In this study, alpha band activity (8-12 Hz) is observed for detailed research.

2.3.3 Alpha Band and Inhibition-Timing Hypothesis

Alpha frequency is accepted as one of the fundamental blocks for central nervous system (Başar and Shürmann, 1997). Alpha is firstly assumed as noise in the brain since it is spontaneously occurring when eyes closed and awake state (Başar and Shürmann, 1997). This case brings the mind to question that alpha is only a noise in central nervous system or not. Therefore, studies on alpha are deeply researched. Recent studies show that alpha is not a noise, however, it has a functional role in cognitive behavior and process such as attention (Thut, 2006) and memory (Klimesch, 2012).

There are various studies with respect to the functional role of alpha frequency. One fundamental role of alpha frequency is defined with the inhibition-timing hypothesis by Klimesch (2007). According to Klimesch, a basic principle of the inhibition-timing hypothesis can be explained in terms of excitation level of excitatory neurons in oscillatory activity. Firing of a cell is occurs usually in two conditions: i) cell fires if excitation level is high to be able to suppress inhibition effect ii) cell fires if oscillation amplitude is high or excitation level is low (Klimesch, 2007). In simply, alpha synchronization is associated with low excitation level. On the other hand, alpha desynchronization is associated with high excitation. It suggests that neurons are desynchronized when the task requires cognitive activity.

Alpha desynchronization usually called as event-related desynchronization (ERD). Studies on ERD suggest that activation of cortical area cause alpha desynchronization (Pfurtscheller and Klimesch, 1991). It means that a complexity of cognitive activity causes more desynchronization in neurons (Van Winsum et al., 1984). For example, a visual study which requires attention is reflected ERD (Worden et al., 2000). Another planning task reflected ERD over motor areas (Pfurtscheller, 2003). Thus, results show that ERD has an important role in information processing.

Alpha synchronization called as event-related synchronization (ERS) is represented as increasing power amplitude of alpha. It is defined when there is no active cognitive process (Pfurtscheller and Klimesch, 1991). According to them, when ERD implies cortical activity ERS should reflect "idling system" in the brain. Idling system is described as "no information process in a cortical area" by Adrian and Matthews (1934). In that sense, a cortical idling area is defined by Chase and Harper (1971) which indicates localized idling rhythm in specified cortical areas. For example, occipital ERS for visual stimulus can be accepted as cortical idling area. On the other hand, there are studies which show ERS before the stimulus is presenting (Başar et al., 1989). This means that alpha power increase reflects subject's expectation to expected stimuli. Another study of Klimesch (1992) reported that increase in alpha power before stimulus may be related with judgment task. Moreover, he indicates that alpha power increase has an effect on memory performance (Klimesch, 1992). At last, Klimesch (1995) speculated that ERS during "idling" has an important role on inhibition as "to block memory for avoiding irrelevant parts of neural networks". To be clear, ERS has contradictory result in terms of its definition of "idling rhythms". It can be said that ERS is not just an idling rhythm which is "mentally inactive" but also have significance on cognitive states.

2.4 Research Question

It seems that EMDR has an effect on eliciting traumatic memory. Thus, this effect can be valid for not only in traumatic memories but also enhancing long-term memory performance with respect to bilateral stimuli that is used. Since bilateral stimuli have an ability to create oscillatory brain activity, this may affect long-term memory in terms of response time and increasing memory performance. Furthermore, it is important to understand how bilateral stimuli affect oscillatory brain activity on the specific frequency range. Thus, this study aims to investigate bilateral somatosensory stimuli effects on long-term memory and oscillatory brain activity, particularly in an alpha frequency range.

CHAPTER 3

MATERIALS AND METHODS

3.1 Participants

The 20 university student with age range in 18-30 were attended to the experiment (mean age = 23.45 ± 1.39). All participants were selected strongly right-handed, have normal eyesight and no psychological illness background. An experiment was carried out the one person with no interference of other. Participants were warned to not drink any alcohol, coffee, or any drinking which may contain caffeine or drug effect. Each one was signed a consent form to admit they are engaging study as a volunteer. Experimental design was approved by ethical committee of Middle East Technical University.

3.2 Experiment Design

3.2.1 Database Preparation

One of the goals of the experiment was creating visual memory for participants. Therefore, human faces were selected to use as visual stimuli. In total, randomly constituted 336 neutral human faces from three kinds of ethnicity – asian, black and white - were taken from Chicago face database (Ma, Correll, & Wittenbrink, 2015). Ethnicities and genders were separated equally for each experimental blocks. All images were placed onto a white background and centered to the screen with high resolution (*2444 pixels (wide) ×1718 pixels (high)*) (see Figure 3).

Figure 3: Sample visual stimuli from Chicago face database

3.2.2 Condition Preparation

EMDR uses Neuro*Tek* Tac/AudioScan[1] for creating somatosensory stimuli as bilateral auditory or tapping. In this experiment, two conditions were applied to subjects. These are; tapping and control condition. In tapping condition; tapping type of NeuroTec Tac/AudioScan device was used as bilateral somatosensory stimulus. In control condition, no stimuli were used for subjects. All conditions were applied randomly to the subjects.

3.2.3 Experimental Paradigm

Experimental paradigm consists of two blocks: Encoding and Recognition session. Each block was implemented in *Matlab R2014a Psychophysics Toolbox Version 3* (Brainard, 1997; Pelli, 1997; Kleiner et.al, 2007). All answers were collected from gamepad (*Logitech Wireless Gamepad F710*). Subjects were sitting in front of the computer from 90 cm distance. All visual stimuli were presented from 21-inch computer screen.

3.2.3.1 Encoding Session

In this session, randomly constituted 240 human face images from three kinds of ethnicity (asian, black and white) was used for encoding procedure. All subjects were asked to pay attention to the faces since they were asked later from these shown pictures.

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[1] http://neurotekcorp.com/tac-audioscan/

Each trial consist of: (i) 1 second of fixation cross, (ii) 4 second of face image presentation, (iii) 4 second of cue question to identify the ethnicity of faces, (iv) 4 second of math quiz to reduce recency effect and increase cognitive load. Cue question was simply asked "What is the ethnicity of face image just you have seen?" to the subjects. Math quiz was consist of simple arithmetic calculation as randomly generated one-digit numbers (1 - 9) and operators ('+', '-', '*', '/'). Question format can be described as following: (a ± b) * c or (a ± b) / d.

Subjects were asked to answer math quiz if the generated equation resulted as "correct" or "wrong". Encoding session paradigm is illustrated below (see Figure 4).

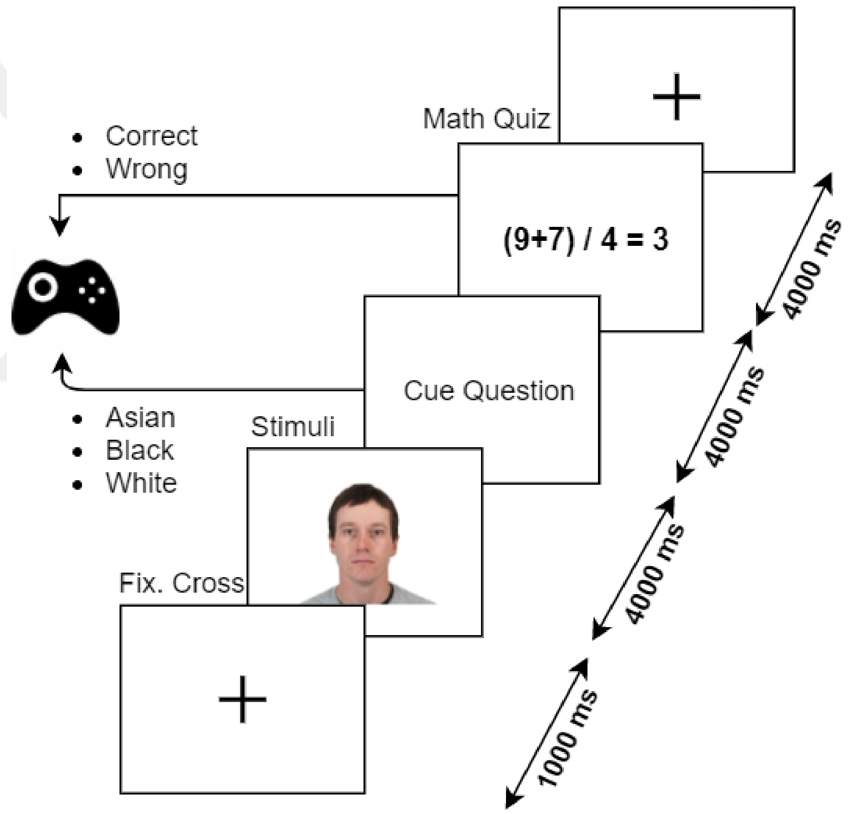

Figure 4: Schematic representation of an encoding session trial. Each trial consists of: (i) 1 second of fixation cross, (ii) 4 second of face image presentation, (iii) 4 second of cue question to identify the ethnicity of faces, (iv) 4 second of math quiz.

Each trial takes 10 seconds. All subjects have limited time (4 seconds) for answering questions. If they were not able to answer questions in time, it passes another trial automatically.

3.2.3.2 Recognition Session

After an hour break, one-minute EEG recording was taken to create a baseline for each subject. This baseline recording provides to get spontaneous background activity of subjects for detecting subject specific bias to not affect group data outputs. Additionally, it helps to eliminate subject-specific physiological noises when analyzing data. Neuro*Tek* Tac/AudioScan was used as a bilateral somatosensory stimulus in this session.

In this session, 240 (old) + 96 new faces (not shown in encoding session) were presented to the subjects. Bilateral somatosensory stimulus to hands was sent, while subjects were questioned on whether they had seen the face images previously. Additionally, control condition without any somatosensory stimuli was also accomplished.

Recognition session was processed as follows: (i) 1 second of fixation cross, (ii) 4 second of face image presentation, (iii) 4 second of question which asks “Have you seen this person before?” to the subjects. Recognition session paradigm was represented below (see Figure 5).

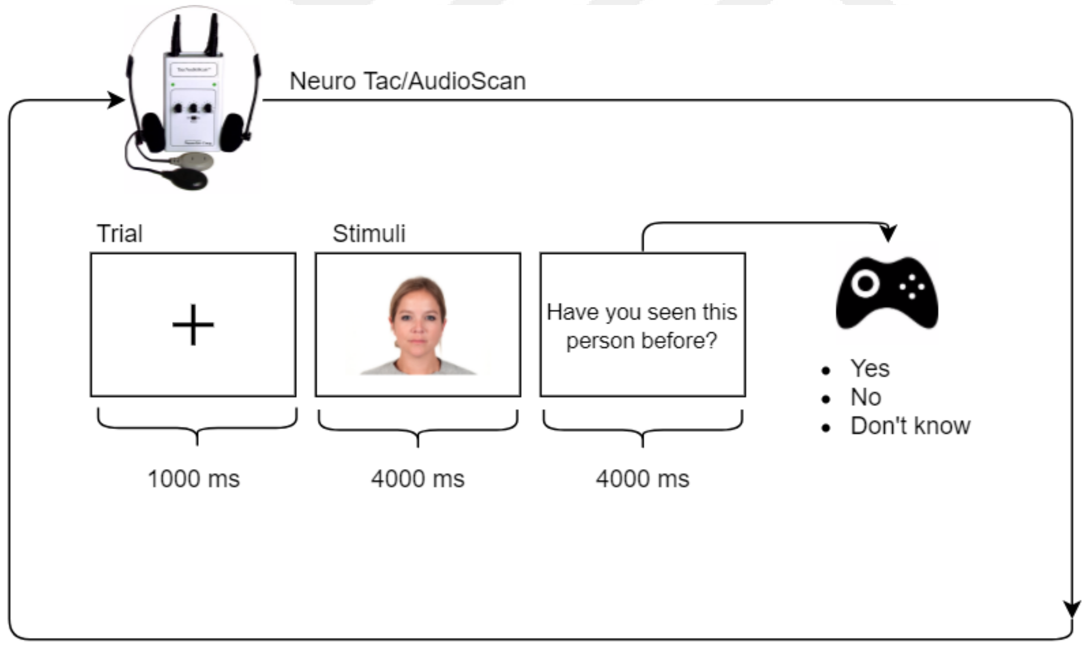

Figure 5: Schematic representation of recognition session trial. Each trial consisted of: (i) 1 second of fixation cross, (ii) 4 second of face image presentation, (iii) 4 second of a question for subjects whether they had seen face images previously.

In this session, trials take 9 seconds. All subjects have limited time (4 seconds) for answering question. If they were not able to answer questions in time, it passes another trial automatically like as encoding session.

3.3 EEG Preparation and Procedure

3.3.1 Electrode Preparation

Easy cap 32 Channel Standard EEG Recording Cap[2] was used for the experimental process. During the preparation process, electrodes were located according to “Easy Cap Installation” guide (see Figure 6). According to the installation guide, preparation follows 3 stages which were cap fitting, electrode locating and impedance level minimization. First, capsize was selected for subjects head scale. Center electrode “Cz” was selected as the middle of the head and it was fixed while the cap is mounting. After cap mounting, electrodes location were cleaned with alcohol. Electrodes were placed according to the 10/20 universal placement system (see Figure 6). Then, impedance level of each electrode was decreased with *chloride-free*, abrasive electrolyte gel (*Abralyt 2000*) which helps to minimize impedance level.

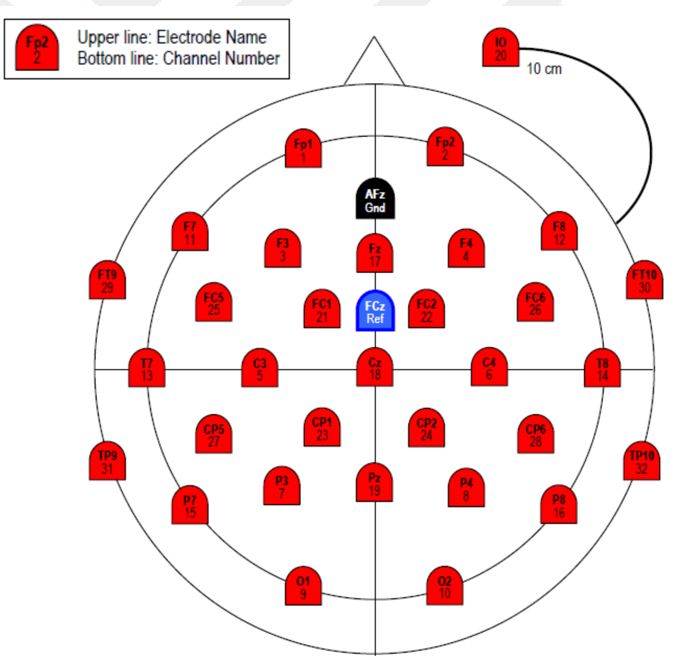

Figure 6: Easy cap 32 Channel Standard EEG Recording Cap: Electrodes with 6 mm central opening, extended 10/20-System placement.

[2] http://www.easycap.de/e/products/products.htm

3.3.2 Data Acquisition

During the EEG recording, electromagnetic and acoustic insulated Faraday cage was used. EEG recording was performed with 32-channel (Ag/AgCl) Brain Amp System (*BrainProducts, Münih, Germany*) 10/20 universal system placement with a sampling frequency of 1000 Hz. Impedance level was minimized to under 10 kΩ. Electrooculogram (EOG) was recorded with two electrodes placed for the vertical and horizontal eye movement. Two electrodes placed for earlobes, two of them placed for mastoids as a reference. EEG recording was performed only in recognition session.

3.3.3 Experimental Procedure

The experimental procedure was simply followed by these steps:

- Subjects were taken to the experiment place (*faraday cage*). 1-minute training session was applied to subjects.
- Encoding session was processed. 240 visual stimuli (face images) were presented to the subjects. All answers were collected via the gamepad.
- After encoding session was finished, subjects have taken a 1-hour break.
- During break time, EEG preparation processes were followed.
- After one hour break, one-minute baseline EEG recording was performed
- Recognition session was followed. During recognition, EEG recording was performed. All answers were collected via gamepad.
- After recognition session was finished, all equipment of EEG device was released from the subjects. Then, experimental process was finished.

3.4 Data Analysis

3.4.1 Behavioral Analysis

Behavioral data was analyzed with IBM SPSS 16 (*IBM, Armok, NY*) predictive analytics software which provides statistical analysis/reporting, analysis tool. Memory performance and response times were collected from subjects and analyzed by using two-tailed paired t-test for independent measures. Memory performance was analyzed only for correct trials.

3.4.2 EEG Analysis

EEG data was analyzed by using *Fieldtrip* which is *Matlab Software Toolbox* (Oostenwald et.al., 2011). Since the noises occurred in 7 subjects EEG data, 13 subjects out of 20 were used for analysis.

3.4.2.1 Preprocessing and Time-Frequency Analysis

EEG raw data was bandpass filtered in 0.2-100 Hz using 4^{th} order Butterworth filter. After trial separation, data was demeaned. To remove artifact of eye movements and eye blinks, independent component analysis (fast ICA) was applied to demeaned data. Then, trials were grouped with respect to condition type: tapping or control condition. Since the EOG cause noise and artifact, it was removed by using Fieldtrip function *ft_databrowser* and *ft_rejectvisual* which allows to see all trials and channels of preprocessed data visually and reject them.

After trial removing, a time-frequency analysis was done with using fast Fourier Transform by using *ft_freqanalysis* fieldtrip function. It was performed by using 500 ms Hanning window with 50 ms shifting for 2-40 Hz incrementing by 2 Hz. Baseline normalization was done according to relative change for subject and condition-specific using the following formula:

$$Pow(N) = \frac{Pow(A) - Pow(B)}{Pow(B)}$$

Pow(N) represents baseline normalized power value, Pow(A) represents average power of all channels and trials, Pow(B) is average power of specific time interval which is [-1 - -0.3] taken as a baseline reference.

3.4.2.2 Statistical Analysis Method for EEG Analysis

For statistical analysis, cluster-based permutation test was used. It compares conditions by means of t-values for every channel-time or channel, frequency and time. Calculation was done with *ft_statfun_indepsamplesT* function which allows comparing means with different measures. Selection of sample was processed with respect to a threshold for t-value which is defined in *cfg.clusteralpha.* In this study, cluster alpha selected 0.05 as threshold for two-tailed test, t-values were taken for channel, frequency and time pair. After cluster selection, cluster-based statistics was performed according to a max sum of cluster t-value.

A comparison was done within four conditions: tapping and control condition trials for pre and on-stimulus, tapping correct and wrong trials, and control correct and wrong trials. Grand average power was used within 10000 iterations. Cluster alpha was selected significant when the alpha value is 0.025 for each tail. All permutation test was done in the alpha range 8-12 Hz. Channels were selected and averaged according to the observed change in the alpha band.

CHAPTER 4

RESULTS

4.1 Behavioral Results

4.1.1 Memory Performance

In the recognition session, subjects were asked to whether they had seen face image stimuli previously. Their answers were recorded and categorized as correctly or wrongly recognized. According to the statistical analysis, there was no significant change for tapping and control condition between correct trials. A number of correctly recognized faces in recognition session was demonstrated (see Figure 7).

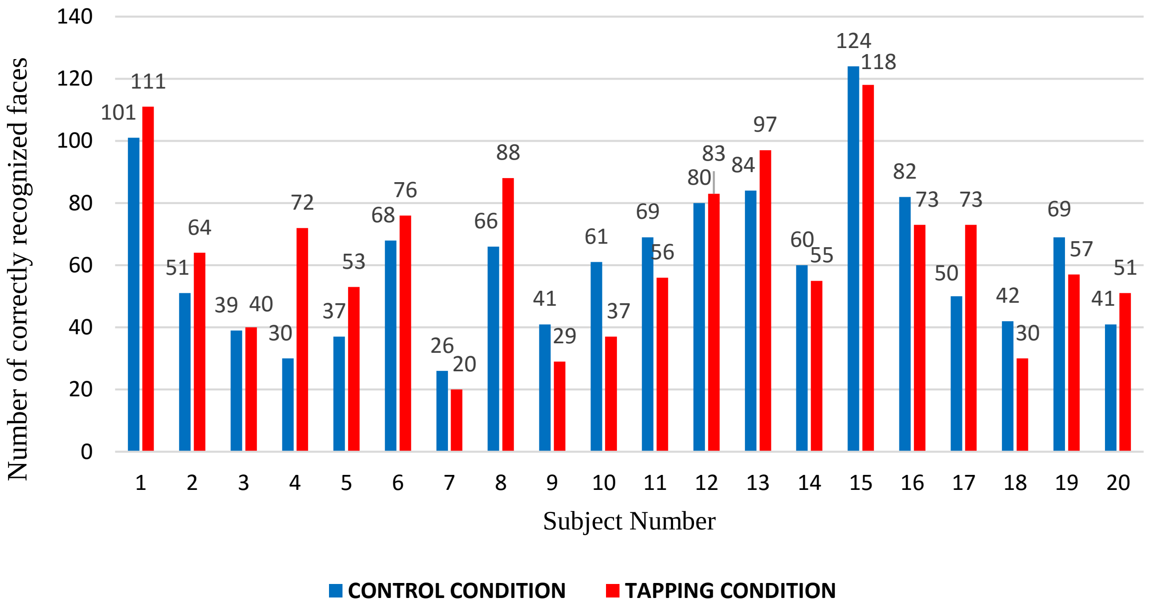

Figure 7: Number of correctly recognized faces in recognition session. Answers were recorded for each tapping and control condition.

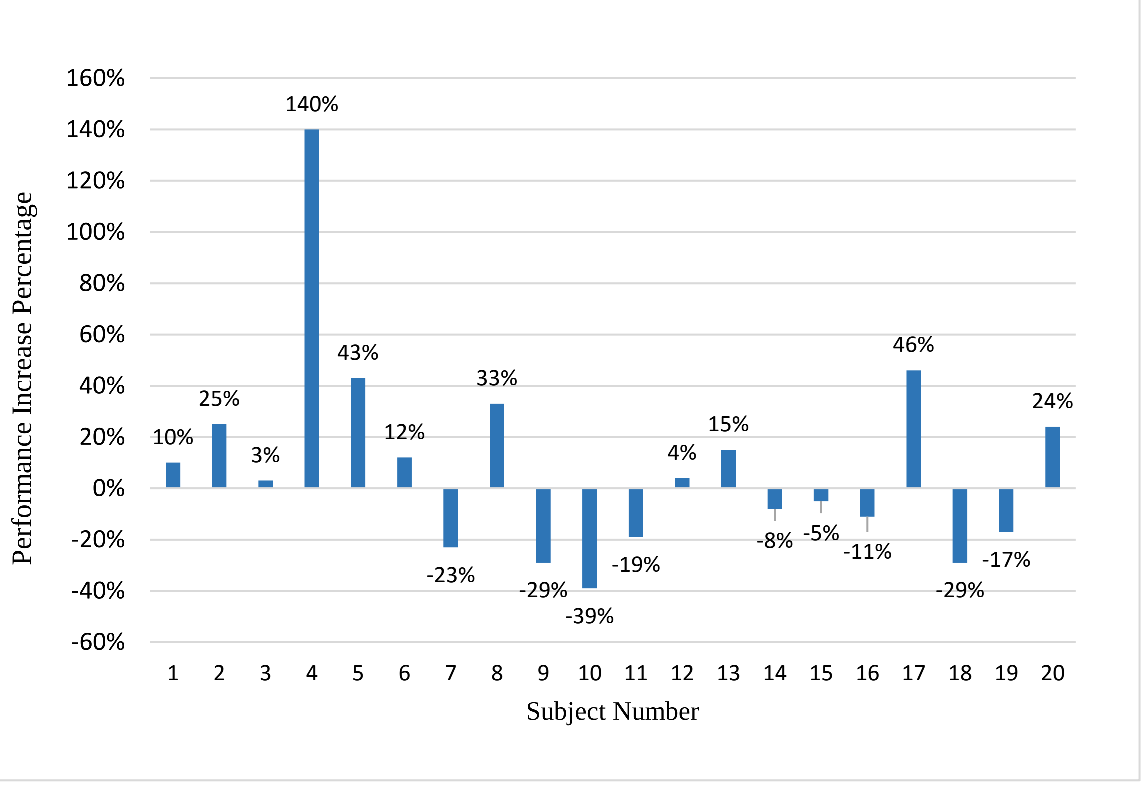

Figure 8: Performance increase percentage of subjects. Performance increase was calculated based on control condition.

Table 3: Descriptive statistics of memory performance

	N	Mean	Std. Deviation	Std. Error
Control Condition	20	61.05	24.8479	5.556
Tapping Condition	20	64.15	26.7803	5.988

4.1.2 Response Time

Response times (RT) were calculated for the time interval between the presented faces stimuli were disappeared and the answer was given. It was saved for each condition. According to the statistical analysis, there was no significant difference between all trials for tapping and control condition (see Table 4 and Table 5).

Table 4: Descriptive statistics for response times of control condition

Control Condition	N	Mean	Std. Error	Std. Deviation
All Trials	19	0.5583	0.06499	0.28329
Correct Trials	19	0.5607	0.06827	0.29756
Wrong Trials	19	0.5560	0.06292	0.27424

Table 5: Descriptive statistics for response times of tapping condition

Tapping Condition	N	Mean	Std. Error	Std. Deviation
All Trials	19	0.5571	0.04668	0.20349
Correct Trials	19	0.5666	0.04489	0.19566
Wrong Trials	19	0.5476	0.04968	0.21657

Subjects' answers were faster for control condition correct trials than tapping correct trials. Additionally, wrong trials answered faster for tapping condition than the control condition. Response time comparison between conditions was demonstrated (see Figure 9).

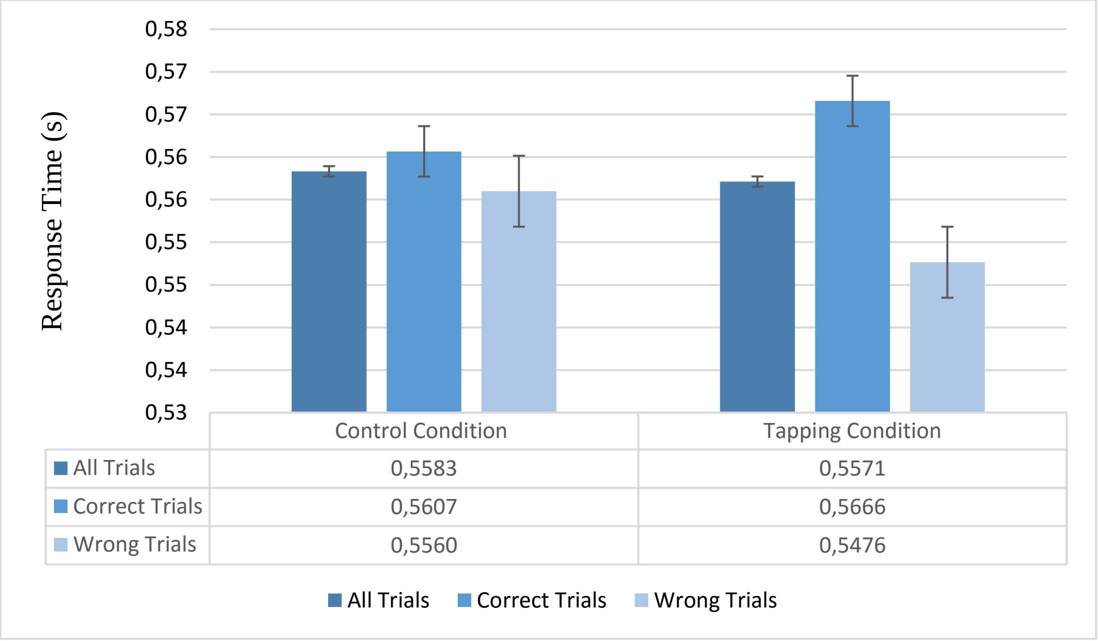

Figure 9: Response time comparison between control condition and tapping condition for all correct and wrong trials.

4.2 EEG Results

4.2.1 Task Related Time-Frequency Analysis

The task was considered with respect to the timing of visual stimuli presentation. It was categorized as prior to visual stimulus and during visual stimuli presentation. In the analysis, pre-stimulus refers time interval of [-0.3s - 0s] and on-stimulus refers time interval of [0s - 4s]. During the two parts of the task, grand average power spectrum was calculated within all subjects independent from the conditions. Average alpha power indicates that there was an alpha synchronization (i.e. alpha power increase) in both pre-stimulus and on-stimulus time interval. Localization of alpha activity was appeared mostly in left parieto-occipital channels for pre-stimulus and right parieto-occipital channels for on-stimulus time interval (see Figure 10).

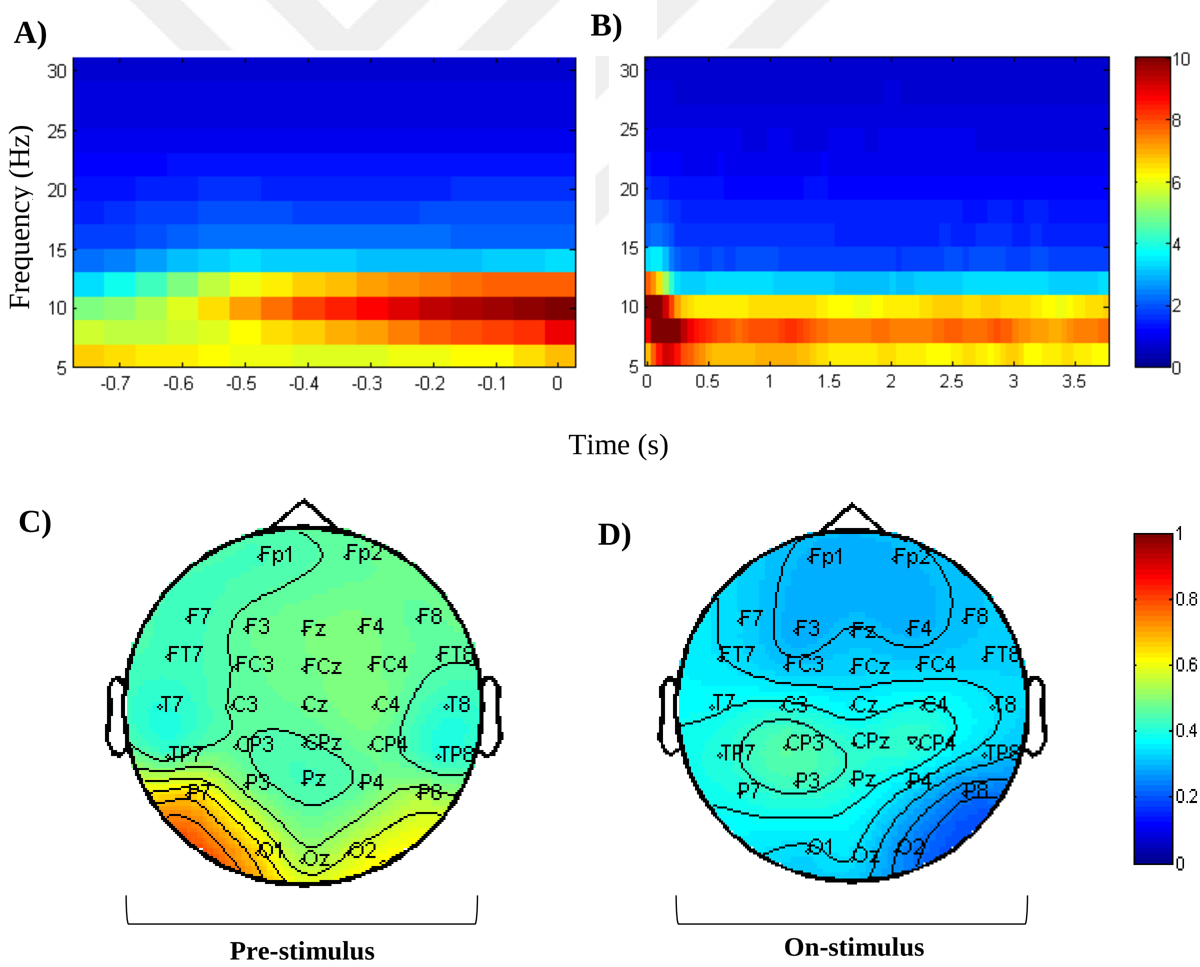

Figure 11: Grand average power spectrum for A) pre-stimulus [-0.3s-0s] time interval and B) on-stimulus [0s-4s] time interval. Topoplot representation for C) pre-stimulus D) on-stimulus time interval in alpha range.

4.2.2 Statistical Analysis

4.2.2.1 Channel Selection

For analysis, channel selection was processed as follows:

- Time-frequency analysis was performed according to two different conditions: control and tapping condition. Alpha activity was specifically analyzed within two conditions at 8-12 Hz range.

- For each condition, the task was analyzed with respect to a time interval as prior to visual stimuli and during the visual stimuli. Additionally, analysis was performed with taking into account of the trials as being correct or wrong.

- Alpha power spectrum for specified condition and time-interval were calculated and presented separately.

- Accordingly, channels were selected with regard to alpha power changes in those conditions and time-periods. In addition to that, since the alpha power change observed in left parieto-occipital and right parieto-occipital channels for the whole task, those channels were selected for every condition. Additional channels were selected according to alpha power change in channels which were not part of the left parieto-occipital and right parieto-occipital region.

In brief, conditions were compared with respect to three cases. These are; correct trials comparison of control and tapping condition, correct and wrong trials of tapping condition, and correct and wrong trials of control condition. All trials were averaged across all subjects.

i) Tapping Condition vs Control Condition

In this case, correct trials were selected to make an analysis on control and tapping condition. Alpha activity and alpha power difference between two conditions were presented for the pre-stimulus interval. According to the pre-stimulus time interval, alpha power changes between conditions were mostly appeared in left and right parieto-occipital channels (see Figure 11). On the other hand, there was alpha power change in central-left temporal and right parieto-occipital channel within on-stimulus time interval (see Figure 12). Thus, these channels were selected for the statistical analysis.

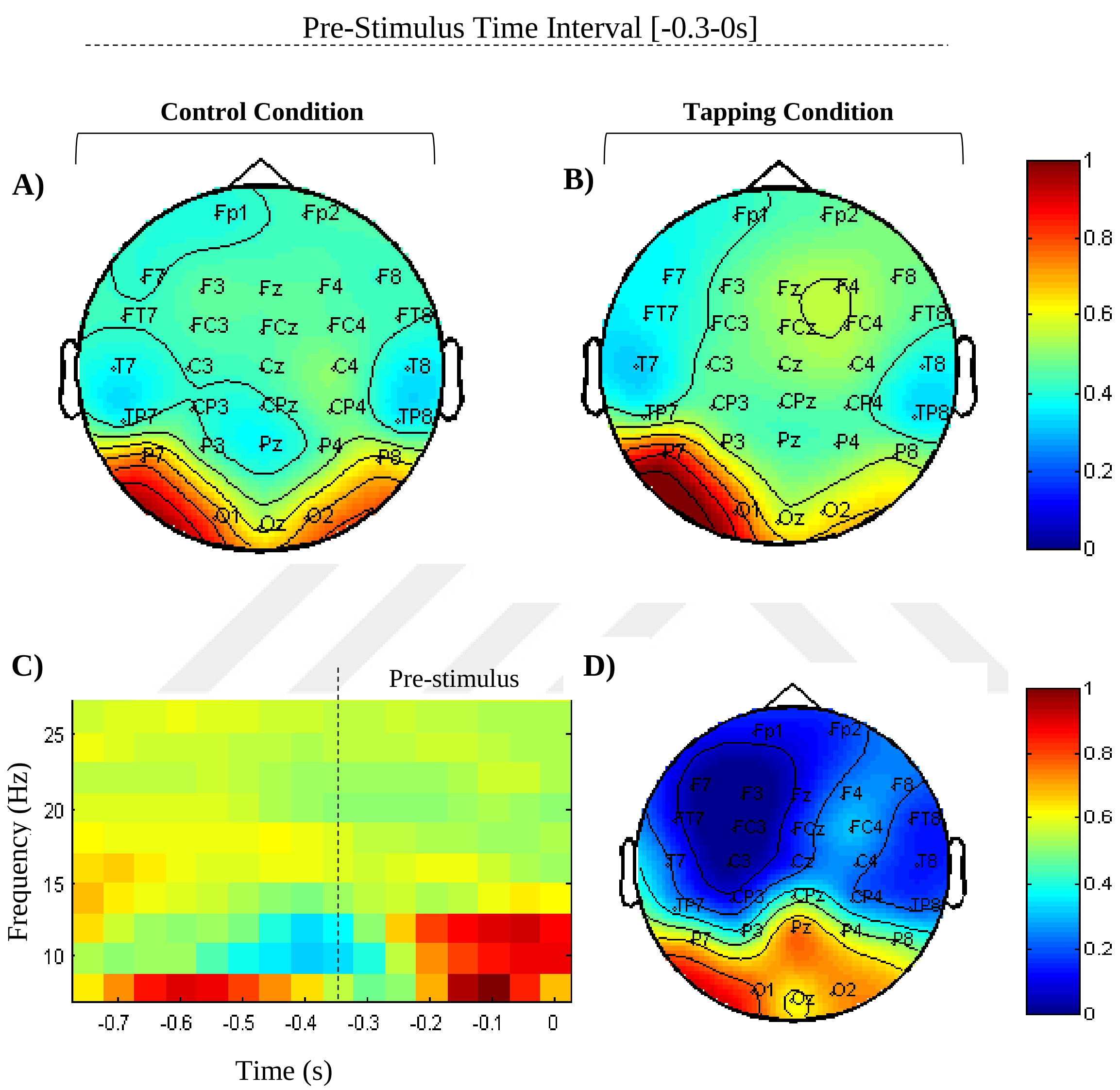

Figure 13: Power spectrum of conditions on pre-stimulus time interval [-0.3-0s]. A) Control condition. B) Tapping Condition. C) Difference power spectrum between conditions. D) Topoplot representation of difference power spectrum of conditions in the alpha range [8-12] Hz.

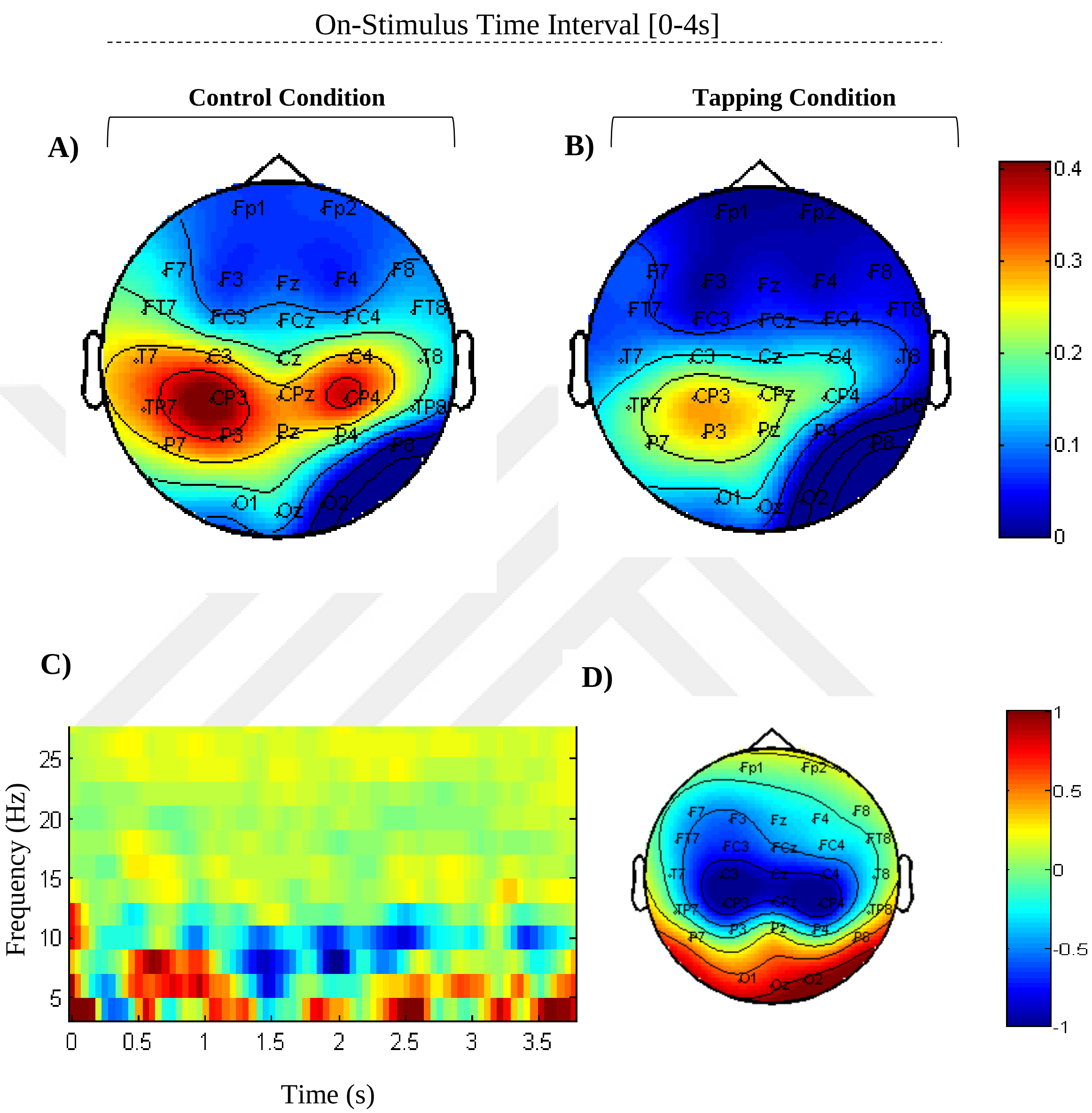

Figure 14: Power spectrum of conditions within on-stimulus time interval [0s-4s]. A) Control condition. B) Tapping Condition. C) Difference power spectrum between conditions. D) Topoplot representation of difference power spectrum of conditions in the alpha range [8-12] Hz.

ii) Control Condition Correct vs Wrong

In this case, alpha power change within correct and wrong trials was calculated across on-stimulus time interval due to pre-stimulus parts are same for both trials. According to the power spectrum change between correct and wrong trials, there was alpha power change in central parietal and left temporal parietal channels (see Figure 13). Thus, those channels were selected for statistical analysis.

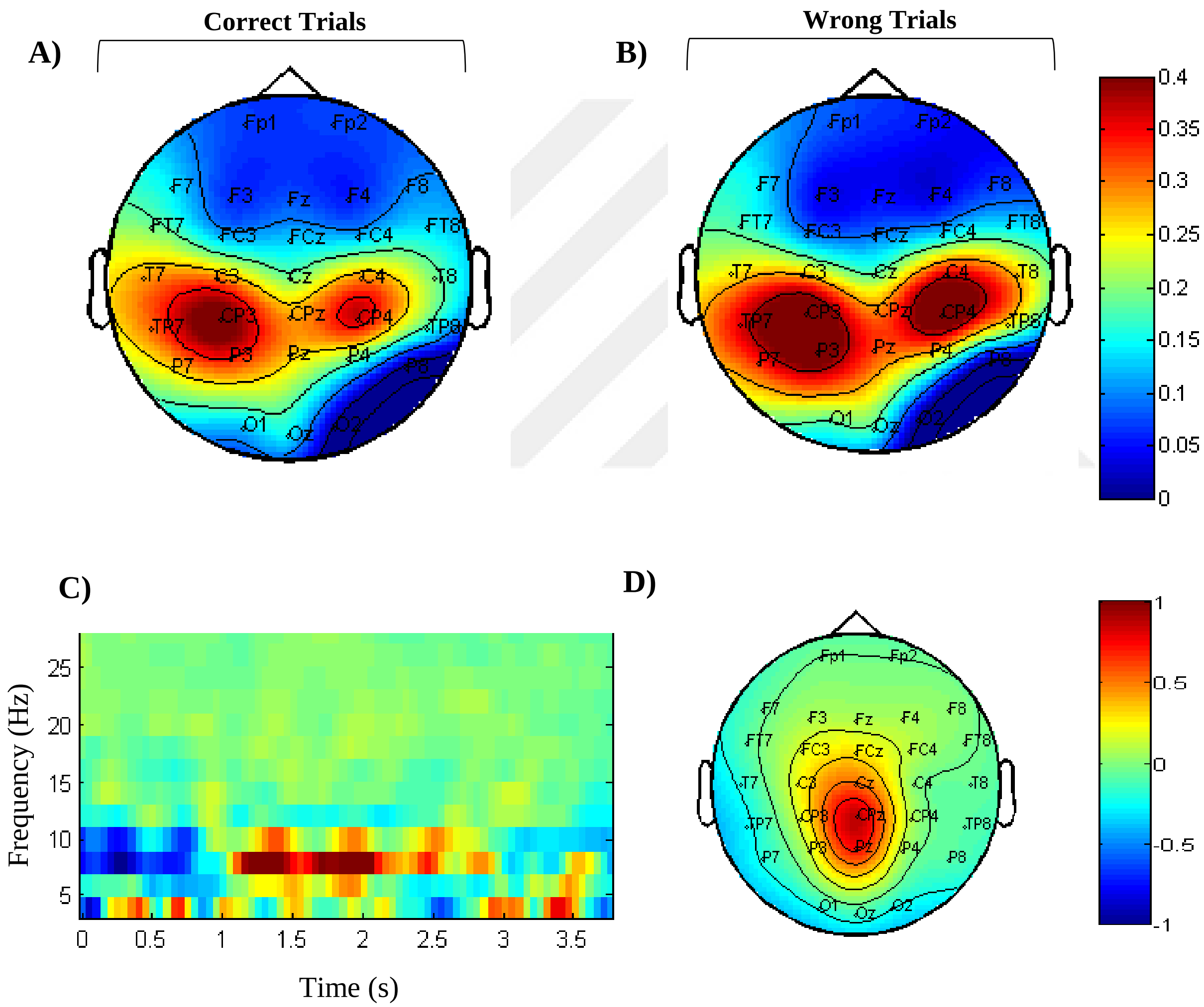

Figure 15: Power spectrum of control condition within on-stimulus time interval [0s-4s]. A) Correct trials B) Wrong trials. C) Difference between correct and wrong trials. D) Topoplot representation of the difference between correct and wrong trials.

iii) Tapping Condition Correct vs Wrong

In this case, similar to control condition case, only on-stimulus time interval power changes within correct and wrong trials were calculated. According to alpha power changes, the difference was mostly appeared in central-parietal and parietal channels (see Figure 14). Therefore, these channels were selected for statistical analysis.

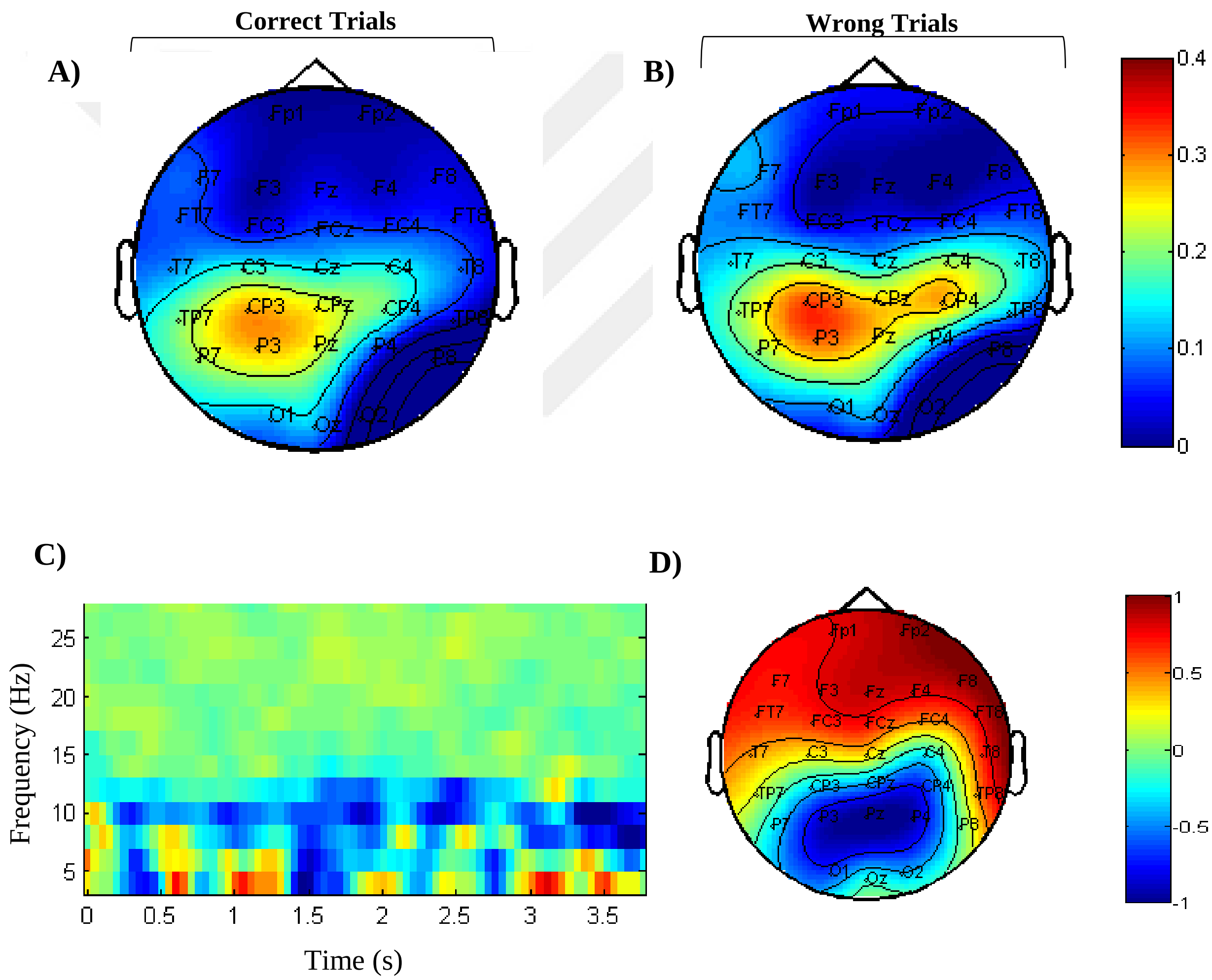

Figure 16: Power spectrum of tapping condition within on-stimulus time interval [0s-4s]. A) Correct trials B) Wrong trials. C) Difference between correct and wrong trials. D) Topoplot representation of the difference between correct and wrong trials.

4.2.2.2 Cluster-based permutation test results

Non-parametric cluster based permutation test was performed for three cases according to selected channels. Here are the three cases:

- Tapping correct vs Control correct –Pre/On-Stimulus
- Tapping correct vs Tapping wrong
- Control correct vs Control wrong

a) Tapping correct vs Control correct

- **Pre-Stimulus Cluster Analysis**

  In pre-stimulus time interval, there was significant alpha activity increase in left parieto-occipital channels (specifically O1 and P7 channels) for tapping condition compared to control condition ($p < 0.05$) in time interval [-0.25s- -0.20s] (see Figure 15).

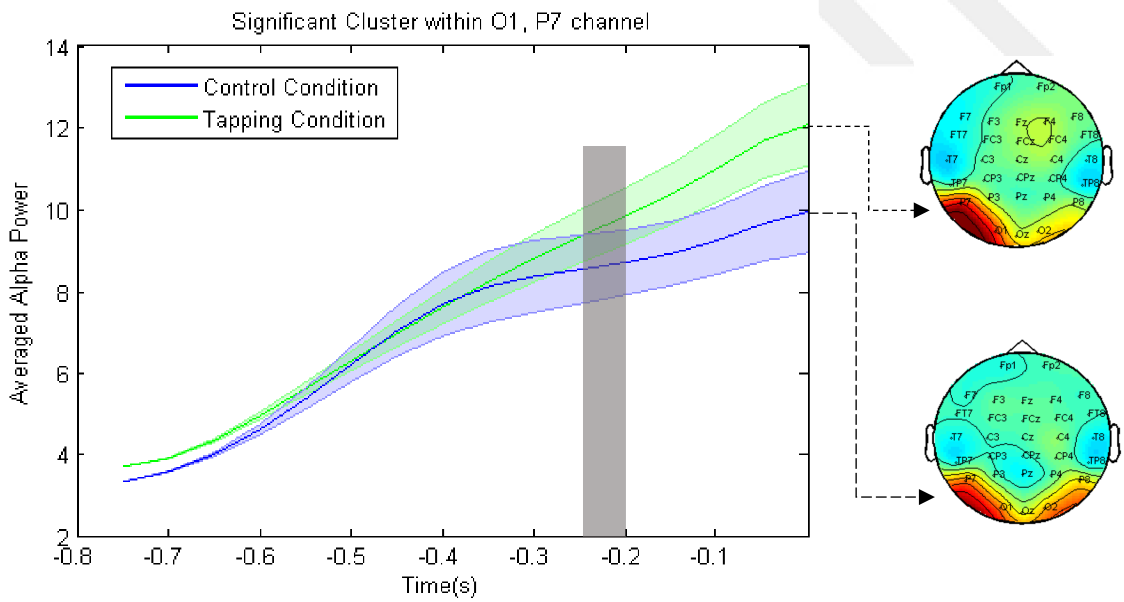

Figure 17: Averaged power-spectrum plot within significant cluster O1 and P7 channels ($p < 0.05$). The shaded area shows significant time interval [-0.25 - -0.20s].

- **On-Stimulus Cluster Analysis**

During face image stimuli presentation, alpha activity was significantly stronger ($p < 0.05$) in only in right parieto-occipital channels (specifically O2 and P8 channels) for tapping condition than control condition in time interval [0.3s-0.85s] (see Figure 16).

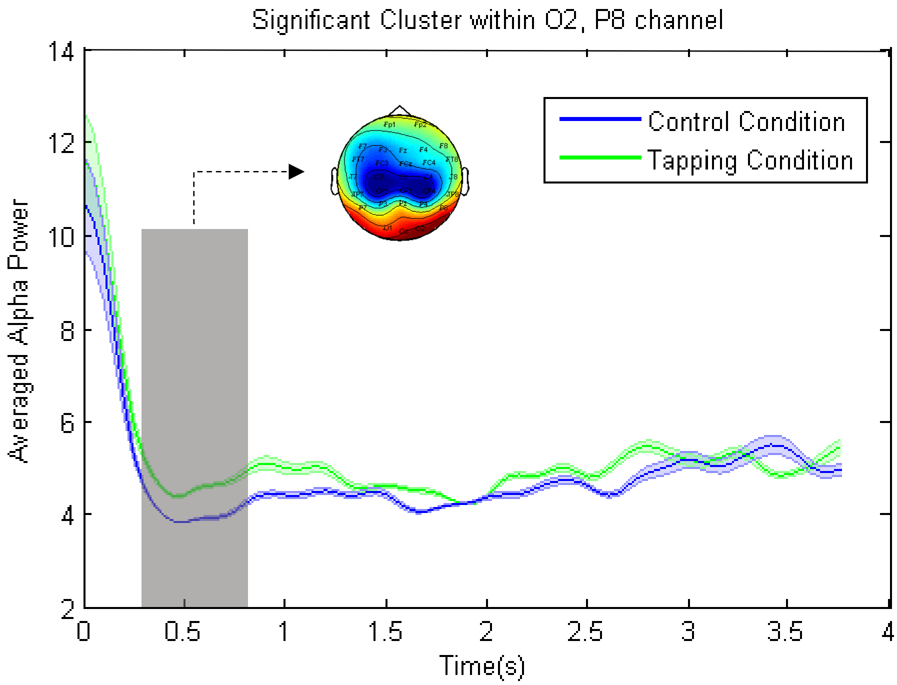

Figure 18: Averaged alpha power plot within significant cluster O2 and P8 channels ($p < 0.05$). The shaded area shows significant time interval [0.3-0.85s].

b) Tapping correct vs Tapping wrong

For comparison of correct and wrong trials, alpha activity was significantly stronger ($p < 0.05$) when subject was not correctly recognized in time interval [1.45s-1.8s]. Correct trials had lower alpha activity in left central-parietal and temporal-parietal channels which were specifically CP3, P3, TP7, T7 channels (see Figure 17).

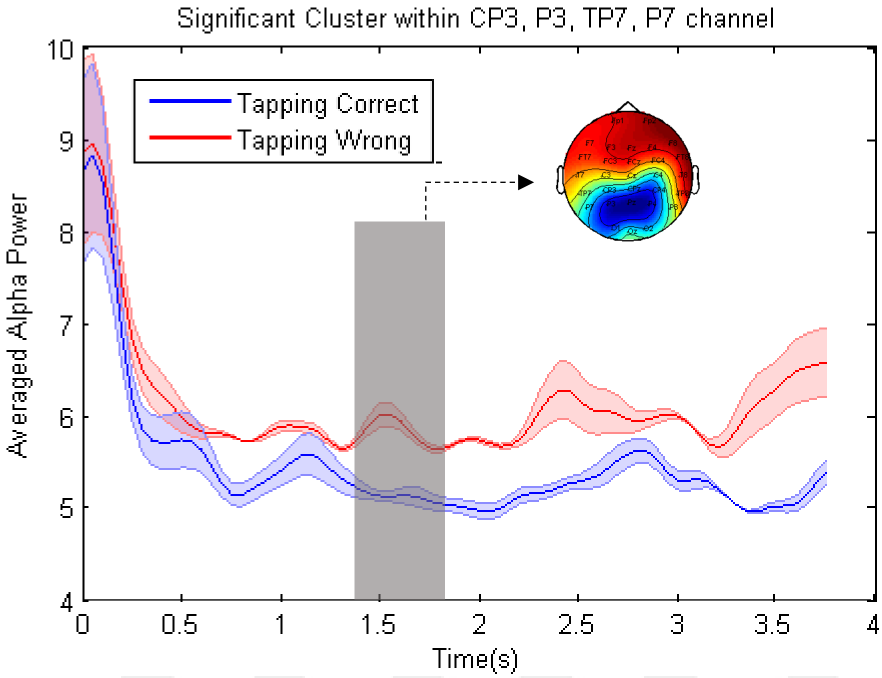

Figure 19: Averaged alpha power plot within significant cluster CP3, P3, TP7, P7 channels ($p < 0.05$). The shaded area shows significant time interval [1.45-1.8s].

c) Control correct vs Control wrong

Statistical analysis was done with selected channels for control condition correct and wrong trials. According to analysis, there was no significant alpha power change in selected channels.

4.2.2.3 Alpha power and memory performance relation

According to the behavioral results, 55% of subjects were increased their memory performance when the bilateral somatosensory stimulus was applied (see Figure 7). Due to figure out whether bilateral somatosensory stimulus has an effect on long-term memory performance with regard to oscillatory brain activity, subjects were divided with respect to their memory performance. These were; subjects who increased memory performance and subjects who decreased memory performance when a somatosensory stimulus was applied (i.e. tapping condition). Analysis also performed with these subjects forthe control condition.

a. Alpha power changes within increased vs decreased memory performance

Subjects who increased their memory performance has significant alpha power enhancement within frontal channels in comparison to subjects who decreased their memory performance when bilateral somatosensory stimulus was used (see Figure 18). On the other hand, there was no significant change in alpha activity for control condition (see Figure 19).

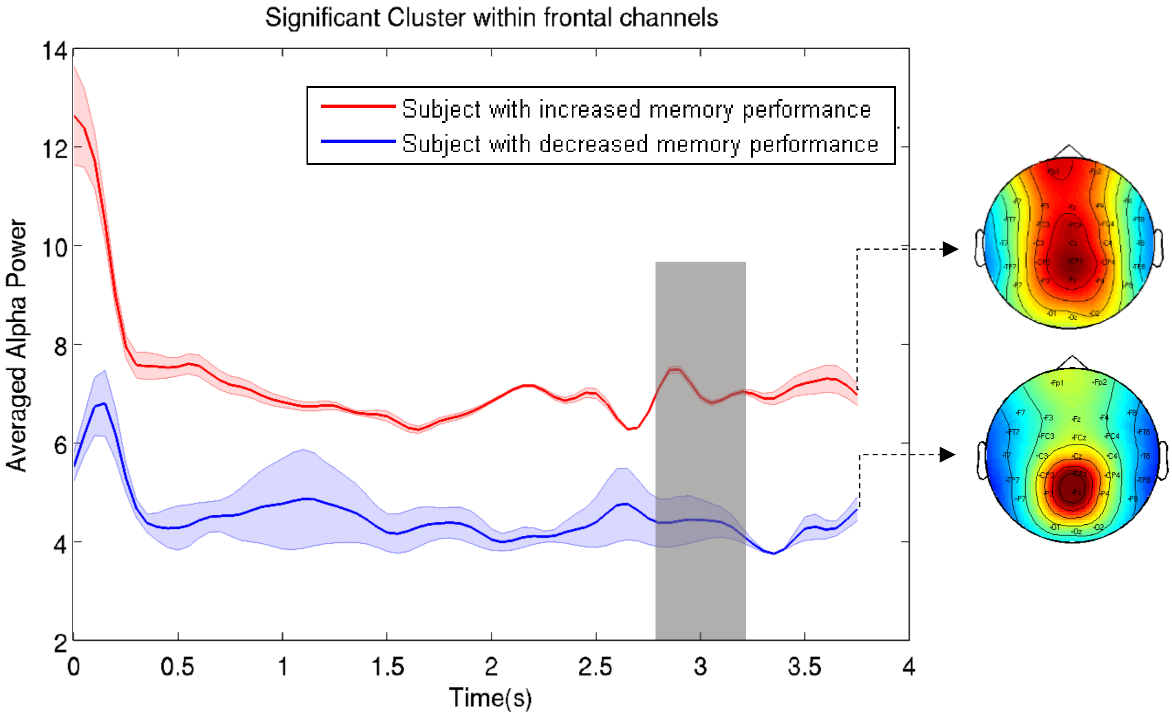

Figure 20: Average alpha power with respect to subjects which have increased and decreased memory performance for tapping condition. Shaded area shows significant cluster ($p < 0.05$) within frontal channels at time [2.7-3.3s].

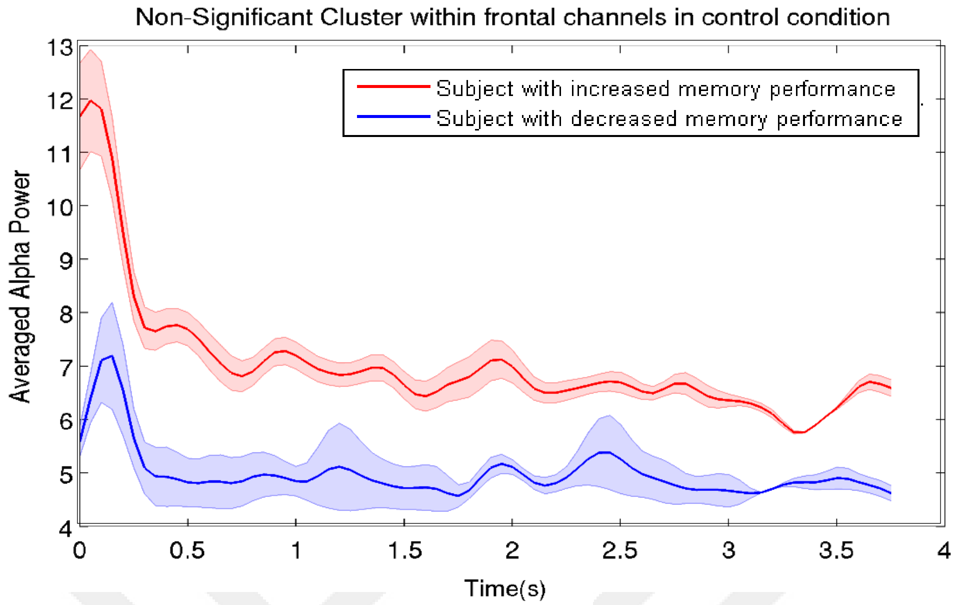

Figure 21: Average alpha power with respect to subjects which have increased and decreased memory performance for the control condition.

b. Alpha power changes within averagely high vs low memory performance

Subjects who averagely have averagely higher memory performance for the whole task were also analyzed. Subjects were divided with respect to mean of a total number of stimuli they had recognized. According to that, there was no significant alpha activity change when somatosensory was applied for both conditions (see Figure 20 and 21).

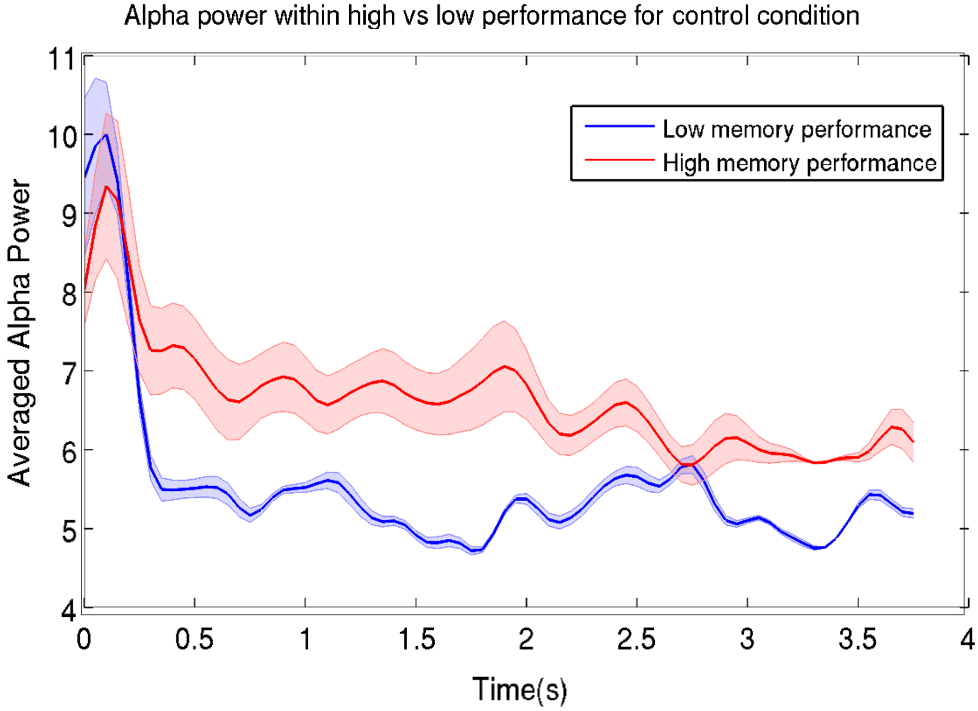

Figure 23: Average alpha power with respect to average memory performance within subjects for the control condition.

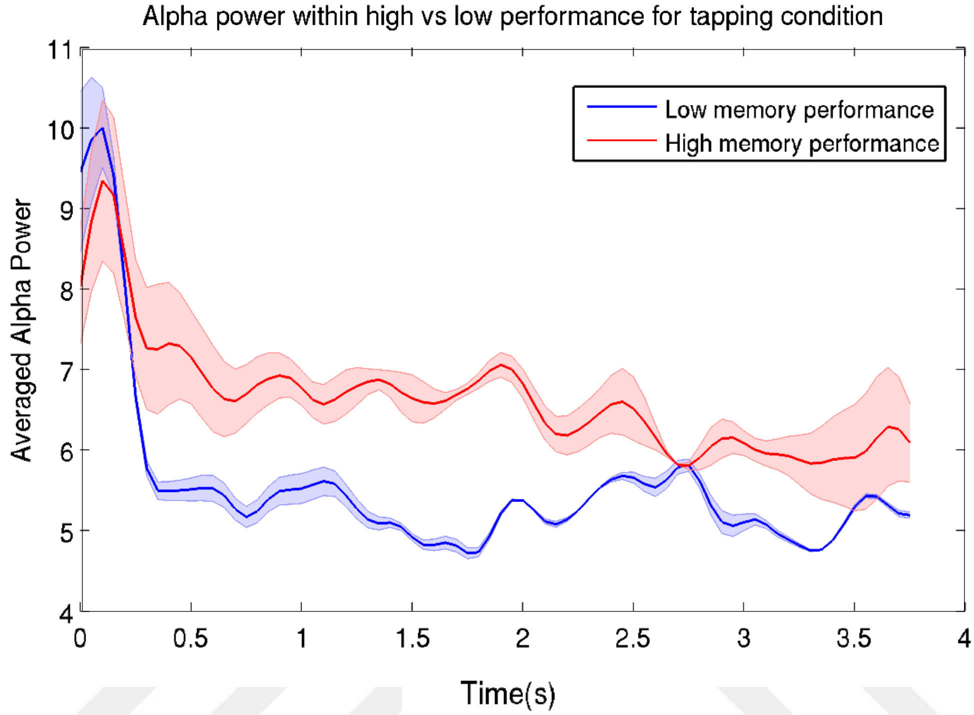

Figure 24: Average alpha power with respect to average memory performance within subjects for tapping condition.

Accordingly, there were no significant alpha power changes with respect to subjects who have averagely high or low performance. Alpha power changes in frontal channels were not related with memory performance level. Thereby, it can be associated with the bilateral somatosensory effect.

CHAPTER 5

DISCUSSION AND CONCLUSION

5.1 DISCUSSION

Analysis indicated that subjects had strong alpha synchronization before image presentation whereas alpha desynchronization was observed during image presentation independent from conditions. It was expected with respect to studies on alpha change on the cognitive task (Klimesch et al., 2007; Pfurtscheller and Klimesch, 1991). According to Klimesch et al. (2007), alpha synchronization (i.e. alpha power increase) indicates low excitation level of neurons, on the other hand, alpha desynchronization (i.e. alpha power decrease) indicates high excitation level. It means that when subjects encounter with high cognitive functions (visual recognition in this study), their alpha power level should be decreased.

From the conditions perspectives, bilateral somatosensory stimulus was applied in tapping condition whereas control condition has no somatosensory stimulus during image presentation. According to that, in pre-stimulus time interval, alpha synchronization was lower for the control condition. Moreover, alpha power was higher in tapping condition compared to control condition during face image presentation. However, level of decrease was higher rather than the control condition. It suggests that bilateral somatosensory stimulus might cause more cognitive load process for subjects. On the other hand, studies on alpha power before stimulus shows that increasing alpha power in pre-stimulus time interval can show increasing subjects' expectation level (Başar et al., 1989). Furthermore, Klimesch (1992) speculated that alpha power increase before stimulus may effect on memory performance in a positive way. Thereby, increasing alpha synchronization before stimulus might be related with increasing subjects' expectation for stimuli or has a role for memory performance in general. In this study, bilateral somatosensory stimulus increased alpha activity before stimulus which may be explained by expectation hypothesis. Beyond that, alpha desynchronization studies usually suggest that increasing complexity of cognitive functions causes more desynchronization (Van Winsum et al., 1984). Therefore, bilateral somatosensory stimulus might cause increases in cognitive load with decreasing level of alpha power during face image presentation. To understand the effect of bilateral stimuli on cognitive load, correct and wrong trials of tapping conditions were analyzed.

According to that, correct trials of tapping conditions has lower alpha compared to wrong trials. It indicates that when subject processed more cognitive activity their alpha power is lower than when they process lower cognitive activity. It might be speculated that decreasing level of alpha for central and parietal channels might cause correct results for the task.

According to behavioral results, more than half of the subjects were increased their long-term memory performance. Oscillatory results showed that subjects who increased their memory performance has significantly higher alpha power in frontal channels than subjects who decreased their memory performance. There was no significant change in the control condition in that sense. Inhibition-timing hypothesis indicates that increases in alpha power usually reflects mental inactivity or low excitation level (Klimesch et al., 2007). Studies on alpha power increase in frontal regions are accepted as suppression of analytic thinking mechanism (Fink and Neubauer, 2006). On the contrary, recent studies on frontal alpha power increase showed that alpha power increase reflects creative cognitive task rather than mental inactivity (Fink, 2012). In a relationship with our study, Sauseng et al. (2005) indicated that alpha power increase in prefrontal regions was coupled with occipital channels during a visual working memory task. Thereby, he implies that alpha power increasing in frontal regions might be an indicator for visual memory process for the brain. Subjects had a higher alpha increase when the time close to end of visual stimulation. Thereby, it is possible that frontal alpha increase might be the indicator for decision-making process for visual memory task.

5.2 LIMITATION

In this study, there were several limitations as well. One of these was limited sample size for the experiment. There were totally 20 subjects for the whole experiment, however, 7 were discarded with respect to the number of correct trials for each condition. A limited number of subjects can affect for reaching consistent results. Thereby, it is necessary to increase the number of subjects to test hypothesis results' validity.

Additionally, randomly applied conditions have positive and negative aspects. Randomizations were necessary to observe bilateral somatosensory effect in time course independent from ordering. It means that effect should be noticeable when bilateral somatosensory stimulus was applied. On the other hand, due to the duration of somatosensory effect was not precise, it is hard to estimate somatosensory effect is still affecting when control condition was applying to the subjects. When tapping condition applied first, there is a possibility to somatosensory effect is still continue. Moreover, it is important to consider disturbance of somatosensory stimulus. Somatosensory stimulus was applied bilaterally as tapping to the subjects. It means that subjects were exposed to tapping for a long time period. Therefore, it is possible for a couple of subjects might have been affected in terms of their stress level in a negative way.

Finally, due to each person have an individual alpha frequency, observing alpha power in 8-12 Hz might cause losing significant change in subject-specific level. Therefore, each subject should be analyzed with respect to their individual alpha frequency. In addition to this, subjects can be re-tested for recognition task to identify whether somatosensory effect was valid for a long time period.

5.3 CONCLUSION

In conclusion, this study shows that bilateral somatosensory stimulus has a role on alpha power synchronization/desynchronization in source level. It means that bilateral somatosensory stimulus increased alpha power prior to visual stimuli presentation. On the other hand, alpha power was decreased during visual stimuli presentation. In addition to that, alpha power change in left central-parietal and temporal-parietal channels were lower at correct trials. Thus, it may reflect the alpha power and correctness of recognition were related when bilateral somatosensory stimulus was applied. Moreover, increasing memory performance was related to increasing frontal activity when bilateral somatosensory stimuli applied. It indicates that when bilateral somatosensory were applied to the subject, their frontal activity was increased with respect to memory performance in a positive way. As a result, this study suggests that bilateral somatosensory stimuli may change long-term memory performance with modification of oscillatory activity in the brain.

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APPENDICES

APPENDIX A

SUBJECTS INFORMATION

Subject Number	Age	Gender
1	27	F
2	23	M
3	22	M
4	22	F
5	23	M
6	24	F
7	23	M
8	24	F
9	23	F
10	22	F
11	24	F
12	23	M
13	24	F
14	22	F
15	22	M
16	24	M
17	23	M
18	23	M
19	27	M
20	24	F

Table 6: Participant information: subject ids, age, gender (M = male, F = female) are presented.

APPENDIX B

PERFORMANCE ANALYSIS OF SUBJECTS

Subject Number	Control Condition	Tapping Condition	Memory Performance*	Performance Percentage	Condition Arrangement**
1	101	111	Increased	10%	C
2	51	64	Increased	25%	T
3	39	40	Increased	3%	C
4	30	72	Increased	140%	T
5	37	53	Increased	43%	C
6	68	76	Increased	12%	T
7	26	20	Decreased	-23%	C
8	66	88	Increased	33%	T
9	41	29	Decreased	-29%	C
10	61	37	Decreased	-39%	C
11	69	56	Decreased	-19%	C
12	80	83	Increased	4%	T
13	84	97	Increased	15%	C
14	60	55	Decreased	-8%	T
15	124	118	Decreased	-5%	T
16	82	73	Decreased	-11%	C
17	50	73	Increased	46%	C
18	42	30	Decreased	-29%	T
19	69	57	Decreased	-17%	T
20	41	51	Increased	24%	C

Table 7: Performance analysis of subjects. Subject ids, number of correctly recognized faces for each condition, memory performance, percentage of memory performance (out of 100), and condition arrangement are presented.

***Memory Performance : Memory performance were defined as increased/decreased based on control condition.**
****Condition Arrangement: C = Control condition was performed first**
T = Tapping condition was performed first

APPENDIX C

DISTIRIBUTION OF TRIALS FOR CONDITIONS

	Control Condition			Tapping Condition		
Subject Number	**Correct Trials**	**Wrong Trials**	**Don't know Trials**	**Correct Trials**	**Wrong Trials**	**Don't know Trials**
1	101	65	2	111	56	1
2	51	33	84	64	60	44
3	39	82	47	40	82	46
4	30	130	8	72	71	25
5	37	129	2	53	107	6
6	68	100	0	76	90	2
7	26	32	110	20	30	118
8	66	82	20	88	65	15
9	41	125	2	29	134	5
10	61	107	0	37	130	1
11	69	94	5	56	105	7
12	80	69	19	83	77	8
13	84	84	0	97	71	0
14	60	106	2	55	99	14
15	124	43	1	118	49	1
16	82	82	4	73	94	1
17	50	102	16	73	77	18
18	42	115	11	30	122	16
19	69	99	0	57	111	0
20	41	115	12	51	97	20

Table 8: Distribution of trials for control and tapping condition. Conditions have totally 168 trials per each.

APPENDIX D

RESPONSE TIMES (SECONDS)

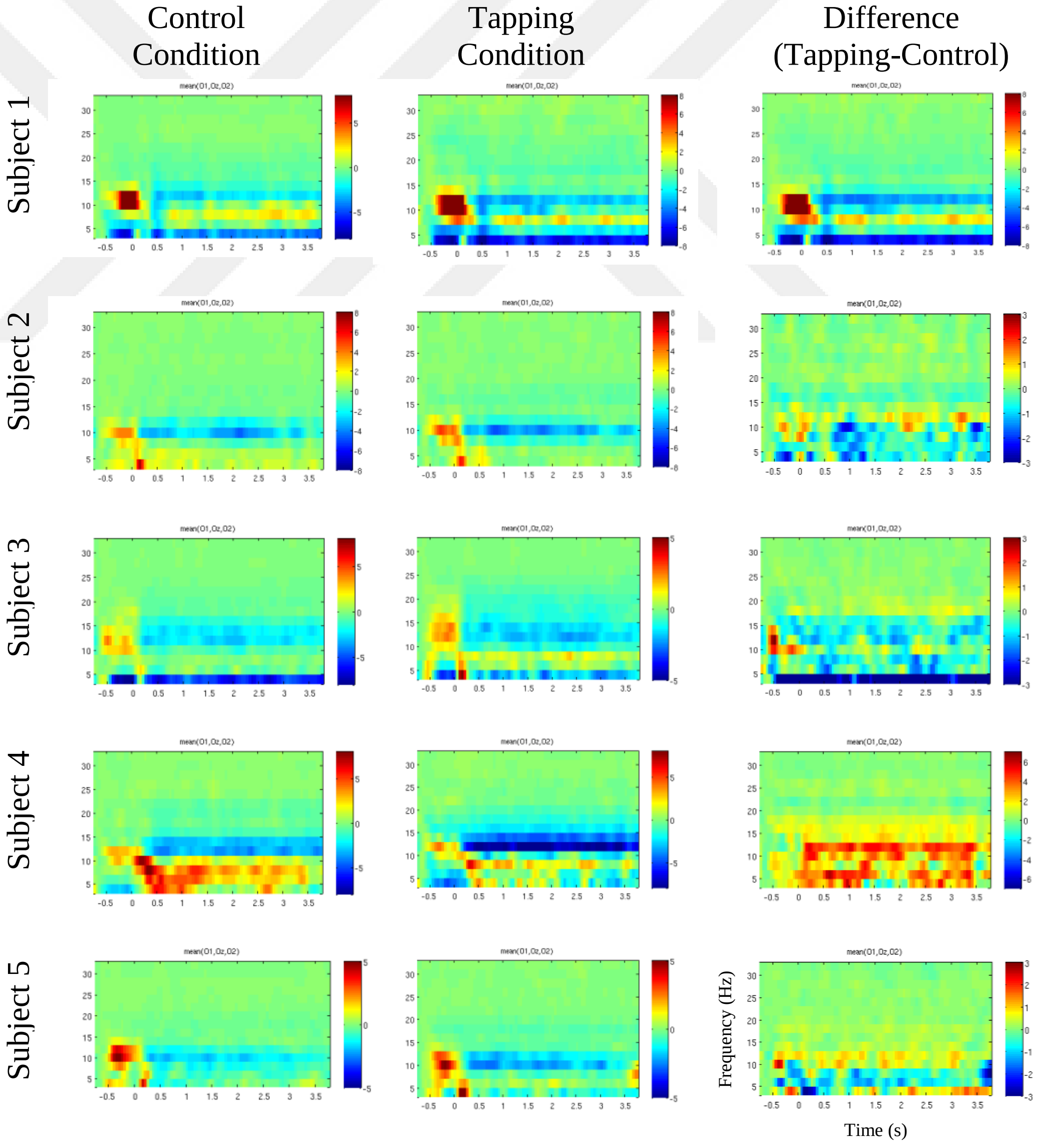
Subject Number	Control Condition			Tapping Condition		
	All Trials	Correct Trials	Wrong Trials	All Trials	Correct Trials	Wrong Trials
1	0,50533	0,500739	0,509929	0,511974	0,540733	0,483215
2	0,37114	0,353438	0,388833	0,484818	0,519	0,450636
3	1,30082	1,355075	1,246561	1,152208	1,179513	1,124902
4	0,36153	0,379431	0,34362	0,431817	0,434633	0,429
5	0,45733	0,408528	0,506131	0,64103	0,645649	0,636411
6	0,24726	0,233053	0,261467	0,359891	0,375632	0,34415
7	0,82571	0,85595	0,795467	0,637932	0,635269	0,640594
8	N/A	N/A	N/A	N/A	N/A	N/A
9	0,34690	0,339931	0,353873	0,499974	0,468171	0,531776
10	0,56463	0,551	0,578269	0,566787	0,548639	0,584935
11	1,12136	1,184839	1,057886	0,869556	0,773377	0,965734
12	0,81186	0,760725	0,862987	0,510284	0,55106	0,469507
13	0,59336	0,585893	0,600833	0,555504	0,601515	0,509493
14	0,34734	0,342309	0,352364	0,399683	0,42295	0,376415
15	0,28645	0,313975	0,258918	0,332543	0,346202	0,318884
16	0,39422	0,401397	0,387043	0,330762	0,345768	0,315756
17	0,66944	0,57934	0,759539	0,654743	0,691836	0,617649
18	0,38626	0.422600	0.349926	0,77397	0.756905	0.791035
19	0,40873	0.414474	0.402982	0,425762	0.480493	0.371030
20	0,60841	0.669829	0.546983	0,445922	0.447627	0.444216

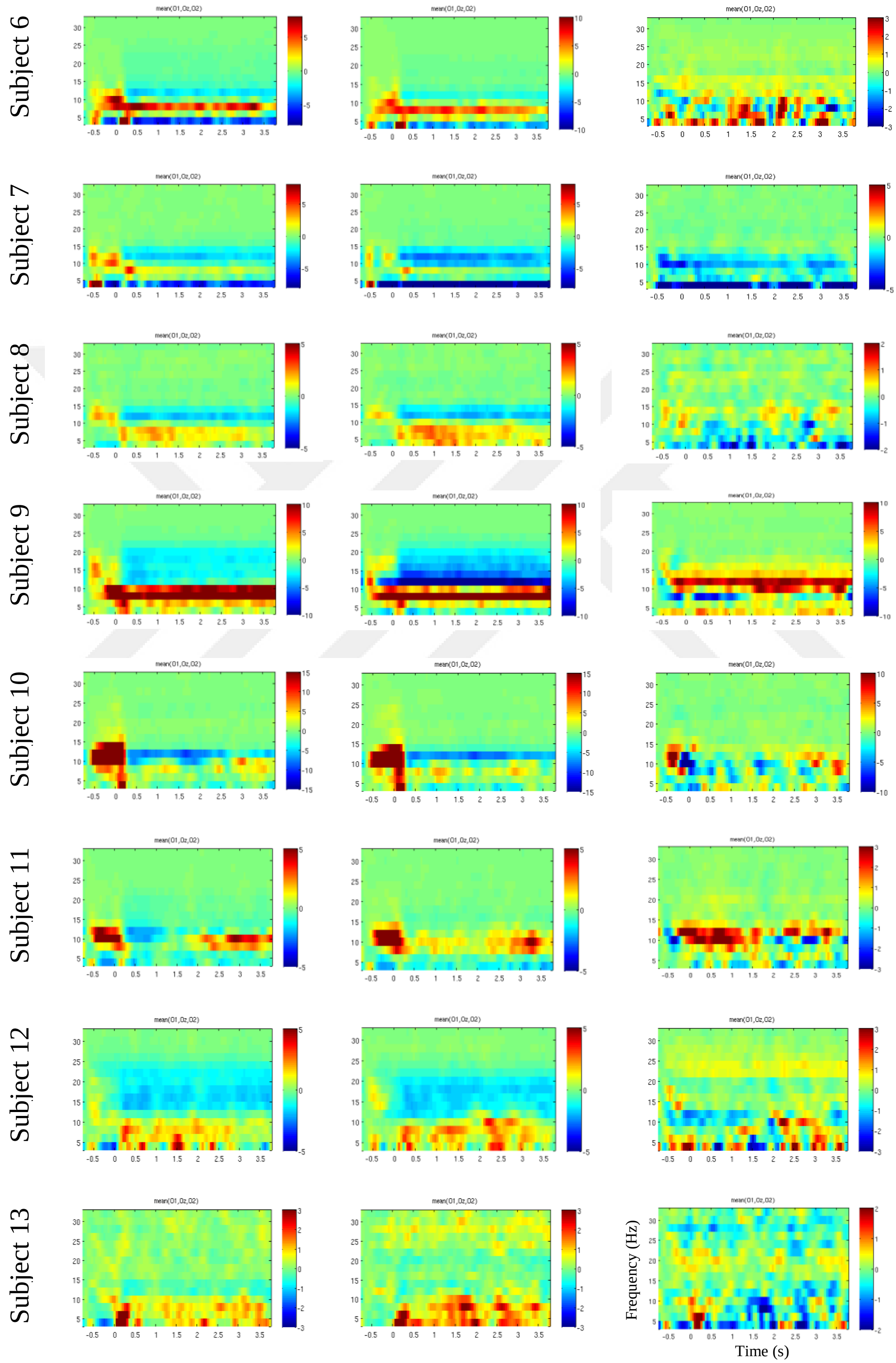
***This subject's response time was not recorded due to technical problems.**

APPENDIX E

SUBJECT SPECIFIC TIME-FREQUENCY REPRESENTATIONS

Figure 18: Subject-specific time-frequency plot for correct trials of control and tapping condition. Only 13 subjects (out of 20) were represented. Occipital channels were selected as representative channels. Pre-stimulus [-0.3s-0s] and on-stimulus [0s-4s] time interval can be seen in the same plot.




Subject 6
Subject 7
Subject 8
Subject 9
Subject 10
Subject 11
Subject 12
Subject 13
mean(O1,Oz,O2)
Frequency (Hz)
Time (s)

TEZ FOTOKOPİ İZİN FORMU

ENSTİTÜ

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Uygulamalı Matematik Enstitüsü ☐

Enformatik Enstitüsü ■

Deniz Bilimleri Enstitüsü ☐

YAZARIN

Soyadı : Göktepe
Adı : Gizem
Bölümü : Tıp Bilişimi

TEZİN ADI (İngilizce) :
EFFECT OF BILATERAL SOMATOSENSORY STIMULUS ON OSCILLATORY BRAIN ACTIVITY AND LONG TERM MEMORY

TEZİN TÜRÜ : Yüksek Lisans ■ Doktora ☐

1. Tezimin tamamı dünya çapında erişime açılsın ve kaynak gösterilmek şartıyla tezimin bir kısmı veya tamamının fotokopisi alınsın. ■

2. Tezimin tamamı yalnızca Orta Doğu Teknik Üniversitesi kullanıcılarının erişimine açılsın. (Bu seçenekle tezinizin fotokopisi ya da elektronik kopyası Kütüphane aracılığı ile ODTÜ dışına dağıtılmayacaktır.) ☐

3. Tezim bir (1) yıl süreyle erişime kapalı olsun. (Bu seçenekle tezinizin fotokopisi ya da elektronik kopyası Kütüphane aracılığı ile ODTÜ dışına dağıtılmayacaktır.) ☐

Yazarın imzası .... Tarih ....