SUPPRESSION OF SEMANTIC INTERFERENCE DURING AN AUDITORY WORKING MEMORY TASK: AN EEG STUDY

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ABSTRACT

SUPPRESSION OF SEMANTIC INTERFERENCE DURING AN AUDITORY WORKING MEMORY TASK: AN EEG STUDY

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Adequate performances in daily life tasks require avoidance of attentional failures and enhanced cognitive control mechanism. Brain oscillations are claimed to have an effect on memory protection and suppression of distractive input. In this thesis, an effect of semantic interference suppression is investigated in an auditory working memory Sternberg paradigm. Semantic interference is created by Deese-Roediger-McDermott lists, adapted to Turkish. This study seeks an answer to whether the suppression of internal distractive mechanisms is performed in a way, similar to the inhibition of external distractors. Further, the study compares the resolution of interference in trials with semantic interference to the ones without it. Moreover, instances of cognitive failures, errors of false memory, are further compared with instances of successful resolution of semantic interference. We suggest that effective synchronization and desynchronization of upper alpha power during the stimulus free delay period is vital for successful performance on the task, failure to do so could lead to the formation of false memory errors.

Keywords: auditory working memory, stimulus free delay period, attention, alpha band, synchronization

ÖZ

İŞİTSEL ÇALIŞMA BELLEĞİ GÖREVİ SIRASINDA ANLAMSAL KARMAŞANIN BASTIRIMI: BİR EEG ÇALIŞMASI

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Günlük işlerin başarılı bir şekilde tamamlanması için dikkat hatalarından kaçınılması ve gelişmiş bir zihinsel kontrol mekanizmasının olması gerekmektedir. Beyin salınımlarının, belleği korumakta ve dikkat dağıtıcı bilgilerin bastırılmasında önemli bir rol oynadığını görülmüştür. Bu tezde, anlamsal karmaşanın bastırılması modifiye edilmiş Sternberg kısa süreli işitsel çalışma bellek paradigması kullanılarak incelenmiştir. Anlamsal karmaşa Türkçe'ye uyarlanmış olan Deese-Roediger-McDermott kelime listeleri kullanılarak yaratılmıştır. Bu çalışma içsel dikkat dağıtıcı mekanizmaların bastırılmasının, dışsal dikkat dağıtıcı mekanizmaların bastırılmasına benzer olup olmadığı sorusuna cevap aramaktadır. Ayrıca bu çalışmada anlamsal karmaşanın çözümü, anlamsal karmaşayı içeren ve içermeyen kelime listeleri karşılaştırılarak incelenmektedir. Yanılsamalı bellek hatalarının oluşumu, hataların anlamsal karmaşası başarılı bir şekilde çözülmüş örneklerle karşılaştırılmasıyla incelmektedir. Sonuçlar yüksek alfa bandı değerlerinde gözlenen senkronizasyonun ve desenkronizasyonun uyaran olmadan bellekte tutma süresinde görevin başarılı bir şekilde tamamlanması için kritik öneme sahip olduğunu, başarısızlık durumunda da yanılsamalı bellek hatalarının oluşması ile ilişkilendiğini ortaya koymaktadır.

Anahtar Kelimeler: işitsel çalışma belleği, uyaran olmadan bellekte tutma süresi, dikkat, alfa bandı, senkronizasyon

This thesis is dedicated to my parents.

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ANOVA	Analysis of Variance
BAS	Backword Associative Strengths
DRM	Deese-Roediger-McDermott
EEG	Electroencephalography
fMRI	Functional Magnetic Resonance Imaging
fNIRS	Functional Near-Infrared Spectroscopy
Hz	Hertz
IAF	Individual Alpha Frequency
KHz	Kilohertz
MEG	Magnetoencephalography
PET	Positron Emission Tomography
RT	Response times
s	second(s)

CHAPTER 1

INTRODUCTION

The ability to carry day-to-day tasks successfully lies in efficient functioning of cognitive system. Everyone experience various failures of cognitive system, which can occur in form of attention lapses, mind wandering, memory and action failures during some times in their lives. While some of these failures just create minor inconveniences, others can result in deadly accidents (Robertson, 2003).

Cognitive failures can be grouped into three broad categories: attention failures, retrospective memory failures, and prospective memory failures. Attentional failures occur as a failure to maintain or sustain attention resulting in a momentary lapse. External (e.g., loud noises) or internal (e.g., thoughts, daydreaming or absent-mindedness) distractions can cause these failures. Retrospective memory failures arise from inability to retrieve previously stored information. These memory failures occur in various contexts over short-term memory (e.g., forgetting the time of a just settled meeting), autobiographical or personal memory (e.g., forgetting your telephone number), or fact-based semantic memory (e.g., forgetting the name of a river in the city). Forgetting to fulfill some tasks in future refers to as prospective memory failures. Forgetting to perform a part of a task (e.g., forgetting to buy milk while at a shop), forgetting the time of the task (e.g., forgetting the time of a presentation), or forgetting an event itself (e.g., forgetting to attend a birthday party) can be seen as examples of prospective memory errors (Unsworth et al., 2012).

Some cognitive failures are attributed as resulting from failures of cognitive control system, responsible for guiding processing and actions to perform goal-directed actions (Unsworth et al., 2012). Study of these failures can provide a better understanding of the functioning of cognitive system, how cognitive failures occur, and in which conditions individuals will be more prone to these failures. One way to understand these processes is through extensive study of memory and attentional processes.

Cognitive processes are studied by various paradigms involving different experimental measurements and techniques, and different populations. Taking in mind that cognitive processes operate on a level of seconds and milliseconds, it is important to use appropriate recording tools to capture them.

Electroencephalography (EEG) is one of central tools employed by cognitive electrophysiology – a field which studies direction of electrical activity flow produced by populations of neurons while assisting a cognitive task (Cohen, 2014). One of the main goals of cognitive electrophysiology is to “dissect and understand cognitive components of behavior” (Cohen, 2014). Non-invasive EEG is advantageous because it can capture high temporary resolution data.

Although the relationship between cognitive processes and electrical fields is still not clearly understood, growing evidence suggests a link between them. In vitro studies, for example, indicate an interaction between local field potentials and synaptic events that can indicate learning and memory. In addition to this, timing of action potentials and the phase of local field potentials might have a relation (Cohen, 2014). This account suggests that although being still in development, cognitive electrophysiology can be applied to study of cognitive processes successfully.

As it was mentioned before, attentional failures are created by internal and external distractions. Studies of brain oscillations report that top-down attentional modulations suppress external distractive information in various tasks: somatosensory (Haegens et al., 2012), auditory (Banerjee et al., 2011; Bastiaansen and Brunia, 2001; Muller and Weisz, 2012; Mazaheri et al., 2014), visual (Jensen et al., 2002), and in challenging listening situations (such as adverse listening conditions (Obleser et al., 2012; Wilsch et al., 2014)). However, it is not yet understood whether they suppress internal distractions similarly to the external ones. In this study we model internal distraction by using semantically related auditory sets of words creating semantic interference and compare modulations of power in a context of semantic interference with a context where no semantic interference occur.

Semantic interference paradigm can lead to creation of associative memory errors, false memories – recalling a novel item, which has associative relations to the items in set (Schacter et al., 2011). In this experiment, resolution of semantic interference is further compared with false memory instances.

The remainder of this thesis will continue with a literature review (Chapter 2). It starts by a broad introduction to memory and working memory concepts, continues with models of semantic processing, provides an introduction to EEG and oscillatory studies. In chapter 3, the methods and materials are introduced. In chapter 4, the behavioral and electrophysiological results are presented. Finally, a general discussion of the results, limitations of the study and conclusion are provided in chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 Memory

A summary of one's past personal memories, knowledge about the world, how to perform things and many other experiences can be attributed to "memory" in a general sense. For decades psychologist are trying to understand this system providing new models and explanations, looking at the phenomenon from different angles through implementation of different paradigms. In order to understand the memory system better, Tulving (1984) suggests introducing multicomponent systems, breaking the whole system into smaller components.

Tulving notices that generalizations of memory can be easily made about particular kinds of memory, but not about memory as a whole. Moreover, the evolutionary processes that had an impact on many other systems should have also had an influence on the memory; as a result, the memory system is far from perfect. Even if it was firstly originated as a whole at the beginning, with time, deviations in the system should be expected. Furthermore, Tulving suggests that some processes may just appear to work as proposed only due to the lack of contrary scientific evidence. In addition, Tulving propose that development of knowledge may provide better theories about mental processes and replace currently existing ones. Finally, Tulving emphasize a "kind of failure of imagination", so that "if we reflect on the limits of generalizations about memory, we might be ready to imagine the possibility that memory consists of a number of interrelated systems" (Tulving, 1984).

In the recent years various classifications of memory system has been created and tested. One frequently adopted classification is Atkinson's and Shiffrin's model, which classified memory into three large components: sensory, short-term, and long-term stores. Information is firstly registered according to the relevant sensory dimension into a sensory memory. Sensory information is then proceeded to short-term or subject's "working memory". Information in this system decays shortly if it is not recorded to the long-term storage. Terry (2009) further summarizes the widely accepted existing decomposition views (Table 1). Based on this, the memory system can be defined as following: a multi-dimensional and multi-level theoretical concept, which aids in encoding, storage, and retrieval of various (semantic, procedural, or episodic) types of information over variable (short or long) time, by using different levels of encoding.

As the main focus of this work is about memory composition over short time, the following sections will focus on memory in terms of subdivision of short term memory system – *working memory*.

Table 1 Approaches to memory, adapted from Terry (2009)

Memory composition	Stages of Memory	Processes of Memory
Short-term Memory	Encoding into memory	Depth of processing
Long-term Memory	Storage in memory	Shallow rehearsal
Episodic	Retrieval from memory	Elaborative rehearsal
Semantic		Transfer-appropriate processing
Procedural		
Priming		

2.1.1 Definition of Working Memory

Working memory (WM) is usually referred to as a limited-capacity system which supports active manipulation (i.e., encoding, storage, and retrieval) of information over a short time period. WM should be distinguished from short term memory which is referred as a system responsible for temporary storage of information (Baddeley, 2012). Being essential theoretical concept in psychology and cognitive neuroscience research, WM has a central role in many everyday complex cognitive tasks (Shah & Miyake, 1999).

For the past 40 year, vast number of theories was developed to provide an explanation to functions and structure of WM. A number of most influential theories - multiple-component theory, embedded-processes model, and “controlled attention” framework - will be outlined in the next section

2.1.2 Theoretical Approaches to WM

With lack of consensus on the functions and components of working memory system, it is important to provide an evaluation to the existing memory models.

Baddeley’s and Hitch’s multi-component model (1974) describes WM as a system with three components: a central executive component and two “slave”, subsystems, the phonological loop (a system for temporary storage of phonological based information) and the visuospatial sketchpad (a system for temporary storage of visual and spatial information (Baddeley & Logie, 1999). This theoretical model was later extended by adding an episodic buffer component which links central executive component and long term memory (Baddeley, 2000).

Cowan’s embedded-processes model (1997) links working memory and attention. The model consists of long-term memory, currently activated subset of long-term memory, and currently attended/focused subset of working memory. The system embedded processes in one another such that the long-term memory comprises the active memory which in turn comprises the focus of attention. The focus of attention is controlled by the central executive and automatic recruitment components.

Controlled attention framework (Engle, 1999) is a model which proposes a domain-free, limited-capacity controlled attention. This model comprises storage of a threshold-activated long-term memory trace, a number of processes guiding start and maintaining this activation, and controlled attention system.

In general, although the models differ greatly in details, they have a number of similar notions. For example, almost all models stress a component that requires the modulation of cognitive control. In addition to this, there are components that process perceptional information. Moreover, models usually state an importance of link between short-term and long term memories.

In this work, the Baddeley’s and Hitch’s (Baddeley and Hitch, 1974; Baddeley, 2012) multicomponent model will be taken as the main framework because it incorporates all of the mostly needed components in itself to some extent. For instance, it states the importance of central executive component, a system for monitoring, maintenance, and manipulation of the task-relevant information. This component is an important theoretical assumption about cognitive control system – which has a central role in this study.

2.2 Semantic Memory and Semantic Interference

Tulving refers to semantic memory as a “mental thesaurus”, containing the vocabulary items, their meanings and relation between them (1972). It is an essential component involved in language usage which registers cognitive reference of input signals. The example of a semantic memory would be a sentence like “I remember that the formula of water is H_2O”. A remember/know statement suggests that the information was registered into semantic memory earlier. This information refers to a linguistic translation of general concepts and their interrelations (Tulving, 1972).

2.2.1 Semantic Memory Models

A variety of models were proposed to understand the mechanisms of semantic memory formation (Jones et al., 2015). Four of them will be briefly introduced. The first one is semantic networks models. This network, originally proposed by Collins and Quillian (1969), represents a hierarchical structure of superordinate and sub- categories, and individual exemplars of the subcategories. Superordinate domains represent the large categories of general concepts, like “food” or “animal beings” (Garrard et al., 2001). Subcategories refer to a more detailed explanation of a category such as “fruit” or “vegetable”. At the exemplar level, instances like “apple” and “orange” are placed.

The second one is feature-list models. This model of Rips et al. (1973) proposes that the meaning of words is composed of binary descriptive features, which reflect the word’s perceptual referent (Jones et al., 2015). The <has_wings> feature, for instance, would be “turned on” for a bird, but off for a dog. The account for features was future developed to distinguish features of two types – features that are present in all cases, and the typical features that are common but not mandatory. For example, <has_wings> feature are present for all birds, but <can_fly> feature is typical but not common for all (Jones et al., 2015).

The third one is spatial models. Spatial models are based on the empirically derived semantic features from semantic differential ratings. In the empirical studies participants are asked to rate words on a likert scale against a set of polar features. Later, each word’s meaning is computed as a coordinate in a multidimensional space (Jones et al., 2015).

Finally, trying to explain how semantic knowledge is retrieved and processed, spreading-activation theory proposes that the semantic content is organized in terms of interconnected semantic networks. In other words, the theory suggests schematic representation of items such that the more related items are, the closer they are located and, as a result, the faster they are primed (Anderson, 1983; Collins & Loftus, 1975).

Due to the fact that the classical theories are mostly based on the predefined gratings, do not involve any learning mechanism, and are not based on specified cognitive mechanisms (Jones et al., 2015). They highlight an importance of relation between words on different scales: directional flow from a larger concept to specific instances and interrelation between the semantically close instances. Close relation between items result in an occurrence of errors.

2.2.2 Associative Memory Errors and DRM paradigm

Schacter et al. (2012) report that associative memory errors domain is one of the domains of errors in human memory system. Associative memory errors occur when a novel item is falsely recognized because of being closely related to a previously presented item (Gallo, 2006). These errors are easily induced by so-called 'Deese–Roediger–McDermott (DRM) paradigm' (Deese, 1959; Roediger & McDermott, 1995). DRM paradigm provides a simple way to demonstrate *false memories*, the recollection of something that did not happen (Gallo, 2010). In classic DRM paradigm participants are presented with study sets of associated words. After words presentation participants take a free recall or a recognition memory test (Gallo, 2010).

Although memory is agreed to have a constructive nature, the components which DRM reflects are still under debate. Some researchers suggest that DRM exposes adaptive features that obviate to the limits of the information processing system – e.g. the meaning or associations of presented materials are remembered, the remaining is reconstructed through references. Alternatively, it is hypothesized that the DRM paradigm exhibits all constructive processes of memory (Gallo, 2010).

According to Gallo (2010), current research can provide evidence about the success of the DRM. First of all, DRM paradigm proves itself as being robust to a variety of manipulations. Relatedness effect measurement – the probability of false recall of the unstudied item – is used to determine the size of the illusion. This evidence suggests the importance of associative processes in memory. Additionally, the evidence suggests that DRM paradigm do induce false memories.

Alternatively, it is suggested that DRM illusion may be based on guessing strategies related to the associative processes; however, this evidence is not supported by current findings in the literature.

1) It is subjective judgment that leads participants to remember the related lure from the presented list.
2) Evidence suggests that explicit warning to avoid illusions do not eliminate the illusion.
3) Modeling procedures estimate an illusory subjective experience.
4) Participants experience similar difficulties in choosing between words in the list and related lure on forced-choice tests.
5) Implicit memory test, which do not address illusory phenomenon, also elicit significant priming effect of the related lure (Gallo, 2010).

2.2.3 False Memory Formation

Cann et al. (2011) summarizes two accounts of false memory formation in DRM paradigm. The first one is an activation/monitoring framework of

Roediger and colleagues (e.g., Gallo & Roediger, 2002; Roediger et al., 2001). This framework is built on the assumption that information, even though not presented during the encoding, can be inferentially activated and processed. Activation produced during the encoding of word lists spreads in a lexical-semantic system and may result in creation of an implicit associative response. Failure to reject the lure as internally generated may lead to “remembering” of the generated word as previously observed. In this view, false memory is defined as a function of the likelihood that an implicit associative response is activated such that the stronger the likelihood, the more likely the lure word will be remembered falsely (Cann et al., 2011).

The second framework is the fuzzy-trace theory. This framework is based on the assumption that a surface form, a verbatim trace, and its semantic content, a gist trace, result from encoding experience and occur in parallel (Brainerd & Reyna, 2002). False memories/ false recall originate from gist extraction or episodic interpretation of the gist, semantic, information, whereas correct recall is attributed to verbatim traces. Gist interference, at the same time, can be suppressed through verbatim trace-based recollection rejection processes (Cann et al., 2011).

2.2.4 False Memories in Short Term/WM paradigm

False memories research was first rooted in trying to distinguish false memories of childhood abuse from real one and, as a result, distinguish between the ones who have actually committed crime with the ones who did not.

Although being firstly treated solely as an episodic memory phenomenon, false memories can be induced in short-term memory as well (Coane et al., 2007; Atkins and Reuter-Lorenz, 2008). Atkins and Reuter-Lorenz (2011), in a fMRI study, suggested that false memory originate due to a failure of cognitive control system being unable to support accurate mnemonic retrieval to judge the semantic familiarity. As one of the hypothesis in relation to false memories events could be the failure of cognitive control, we hypothesize that it would be possible capture a reflection of it through attentional alpha modulations.

2.3 Cortical Oscillations and EEG

2.3.1 Electroencephalography

Human beings have had an interest in understanding of brain and body functions for a long time. Recent advances in technology lead to the development of various neuroimaging techniques. Measurements rooted in hemodynamic response (PET, fMRI, fNIRS) and neuron generated electric or magnetic activity (EEG, MEG) are now among frequently used functional imaging methods (Hagoort, 2003).

EEG measurements have a long history since Hans Berger's first attempts to measure human EEG recordings in early 20th century (Millett, 2001). Surface postsynaptic electric activity of a number of firing neurons produced as a response to a stimulus is recorded by EEG. This makes it possible to record signal at high temporal resolution (on the order of milliseconds). Hemodynamic-based response techniques, on the other hand, provide excellent spatial resolution in the expense of temporal resolution (Mehta & Parasuraman, 2013). Taking this into consideration, studies that require precise understanding of activation dynamics over a short period of time can be best studied using EEG while the studies trying to reveal precise activation location should be studied using hemodynamic measurements. With assumption that cognitive processes are fast and appear on millisecond range, methods with high temporal precision can be serving best to capture the process. Oscillations recorded by the EEG are reflections of neural oscillations of the cortex. EEG comprises a multidimensional (time, space, frequency, power, and phase) signal making it possible to extract information of various dimensions (Cohen, 2014). In addition, EEG systems are cheaper compared to many other methods.

2.3.2 Methods to study EEG signal: Event-Related Potentials and Time-Frequency Decomposition

EEG signal can be studied by evaluating event-related potentials or by applying time-frequency decomposition methods. In the upcoming section, a brief introduction to these two methods will be provided.

Event-related potentials (ERP) analysis used to be more commonly used in the second half of 20th century. ERPs are calculated by averaging trials into a single time-voltage graph of a channel or a set of channels. Despite having a number of advantages, like fast computations, high temporal precision and accuracy, and extensive previous research, ERPs can lose information due to averaging as well as provide a loose link to physiological mechanisms (Pfurscheller & Lopes da Silva, 1999; Cohen, 2014).

Spectral analysis can help identifying oscillatory components, dependences of oscillations in different brain areas, and dependences between different oscillations (Gross, 2014). Spectral analysis is based on transformation of recorded data (i.e., time series) into the frequency domain. Fourier, wavelet, and Hilbert transforms are among widely used non-parametric methods. With comparable parameters, these methods produce similar results (Gross, 2014).

The fast Fourier transform will be briefly introduced as being the frequency decomposition method used in the study. Short-term Fourier Transform is a variation of Fourier transform that accounts for time-varying structure of the frequency data and assumes that the data is stationary over short periods of time (Cohen, 2014). Data points in a segment of a trial are weighed by a tapering function and the Fourier transform is applied. This transformation yields a complex spectrum in the frequency domain. Following, another data segment is selected for tapering - usually overlapped segments of the trial are utilized, and the Fourier transform is applied. Finally, the absolute value is averaged across the trials for each time window separately creating a time-frequency spectrum (Gross, 2014). The number of frequencies for which power estimates can be computed through the fast Fourier transform equals N/2 + 1, where N is time points in each segment.

Time-frequency-based approaches have three major advantages (Cohen, 2014). First one is that results can be interpreted with respect to the neuropsychological mechanisms of neural oscillations. Secondly, oscillations can be viewed as a bridge to link from within neuroscience and cross-disciplinary. In addition to these, lack of extensive literature provides a possibility to perform data-driven analysis and explore new theories. Finally, task-relevant dynamics of EEG data can provide with more information when decomposed using TFD methods compared to ERPs due to averaging procedure of ERPs.

There are also two limitations for time-frequency methods (Cohen, 2014). First of all, time-frequency decomposition methods decrease the temporal precision. In other words, some of the time information is lost due to transformation algorithms. Secondly, applicability of high number of analysis can be misleading in terms of data interpretation.

2.3.3 Frequency Bands

Traditionally frequencies used in frequency decomposition methods are grouped into the following bands: delta (1 - 4 Hz), theta (4 - 8 Hz), alpha (8 - 13 Hz), beta (13 - 30 Hz), and gamma (36 - 44 Hz) bands. This traditional account for human EEG recordings was questioned by Klimesch (1999, 1997) arguing towards a definition of individual alpha frequency (IAF). The notion of IAF, or subject-specific alpha frequency, was supported by a number of researches. For example, Haegens et al. (2014) argue that alpha rhythm operates on a larger interval compared to the traditional predetermined alpha band. In addition to this, Klimesch et al. (1998) suggest the notion of upper and lower band distinctions such that a band of width of IAF – 6Hz, IAF – 4 HZ would be labeled as theta band, a band of IAF – 4 Hz to IAF – 2 Hz range of lower “1” alpha; (IAF, IAF – 2 Hz) – lower “2” alpha; IAF, IAF + 2 Hz – upper alpha.

2.3.4 Cognitive processes and Oscillations

Although the role of oscillations in cognitive processes is controversial, studies tried to link cognitive processes to specific bands. Some studies link delta band oscillations to attention and cortical collaboration. Memory processes, such as declarative and episodic memory processes, memory encoding, and memory load are said to be related to theta band (Sauseng and Klimesch, 2008). Modulations of alpha oscillations can be viewed as a mechanism that facilitates attention and memory in goal-directed setting (Payne and Sekuler, 2014). Lower alpha oscillations are related to attentional processes while upper alpha is related to semantic information (Klimesch, 1996). Beta band oscillations are linked to motor functions. In addition to this, there is evidence suggesting importance of beta band oscillations in memory, attention, and linguistic processing (Sauseng and Klimesch, 2008). Multisensory information is reflected by gamma band (Sauseng and Klimesch, 2008). In addition to this, interactions between neural oscillations of different frequencies are reported to be involved in attention and memory related cognitive processes (Hanslmayr and Staudigl, 2014).

Evaluation of power change over the bands in time is one of the approaches to study brain oscillations as it reflects the synchronization of different neural populations. A relative change in power (i.e., with respect to a baseline, or other idling period) can be characterized in terms of power increase (event-related synchronization, ERS) or power decrease (event-related desyncronization, ERD) (Pfurscheller & Lopes da Silva, 1999).

2.3.5 Interpretation of Oscillatory Mechanisms

Cortical idling hypothesis was one of the first hypotheses proposed. It is based on the observation that alpha power increased when subjects were awake but did not have a task (Jensen & Mazaheri, 2010). Pfurscheller & Lopes da Silva (1999) suggested that low amplitude ERD can be interpreted as an electrophysiological correlate of activated areas involved in sensory or cognitive information processing or motor behavior preparation activities. Widespread amplitudes, on the other hand, may correlate with an involvement of a larger network involved in information processing. ERS occurs due to a synchronized action of large population of neurons. Coherent activity in alpha band suggests that active processing of information is not performed and the network is deactivated. Inhibition and excitation are other important concepts. According to idling hypothesis there are some areas in the brain which are synchronized and other areas which are desynchronized at the same time (Pfurscheller & Lopes da Silva, 1999).

Inhibition–timing hypothesis, on the other hand, claim that the areas not directly involved in the task are inhibited. Klimesch et al. (2007) notes that the dissociation observed in ERS and ERD should relate to their involvement in different processes. Wide-spread ERD reflect a state of high excitability, while ERS reflects inhibition. Inhibitory state reflects control of top-down processes on certain cognitive mechanisms. For example, Klimesch et al. (2007) suggests that, contrary to idling hypothesis, ERS reflects inhibitory top-down control processes that prevent retrieval of previously encoded information during encoding stage. In addition to this, Klimesch et al. (2007) argue that processes which are reflected by this inhibition can be attributed to a broader term of central executive processes in Baddeley's WM theory (Klimesch et al., 2007). These top-down processes act as attentional control mechanism which suppresses interference from task-irrelevant brain areas or processing systems by inhibition. For example, ERS during retention in memory task can be understood as a top-down control on stored information by an inhibition of retrieval of competing, interfering, information. Similar interpretations can be drawn in other paradigms and sensory systems. Increase in alpha power in motor task can be interpreted as an inhibition of stored information by suppression of previously learned responses or suppression of interfering motor traces. Topographically ERS occurs in the areas that are not task relevant. Although of generators of alpha waves are controversial, it can be suggested that top-down control aids in processing in task relevant areas.

Palva and Palva (2007) questioned the degree to which alpha band oscillations reflect inhibition. They argued that increase in alpha amplitude is linked to inhibited or disengaged cortical states. Palva and Palva (2007) propose that alpha suppression in retrieval reflects the termination processes. In addition to this alpha band power is modulated by attention.

A more recent account tries to answer the 'how information is gated from a sending region to one of two receiving regions' question. Jensen & Mazaheri (2010) in gating by inhibition hypothesis suggest that information flow in the brain is directed by a functional block of task-irrelevant pathways. Alpha band reflects this inhibition processes by reducing the processing capabilities of a brain region.

2.4 Oscillations and memory research

2.4.1 Auditory Alpha rhythms

Existence of alpha rhythm in audition was question for a long time. As a result, a number of oscillatory studies using auditory paradigms were not high. First of all, usually auditory alpha is not easily observable on the topographical representation of time-frequency. The size of auditory cortex is smaller compared to visual cortex so the oscillatory traces produced by it can be weaker (Bastiaansen and Brunia, 2001). In addition to this, it is difficult to measure auditory perception because auditory perception is spontaneous. Together with an increasing number of oscillatory studies, it is possible to say that as “tau rhythm” (alpha rhythm elicited in auditory presentation, Lehtelä et al. (1997)) is successfully recorded using non-invasive EEG and MEG systems (Weisz et al., 2011).

2.4.2 Attentional modulations of alpha band

Attentional modulations can be driven by bottom-up and top-down perceptional processes. Bottom up attention can be linked to stimulus-specific properties, while top-down perception is linked to goal-directed behavior and anticipation.

Top-down attentional modulations of alpha band oscillations (8 - 14 Hz) are suggested to suppress distractive information in somatosensory (Haegens et al., 2012), auditory (Banerjee et al., 2011; Bastiaansen and Brunia, 2001; Muller and Weisz, 2012; Mazaheri et al., 2014) and visual modalities (Jensen et al., 2002), as well as challenging listening situations – such as adverse listening conditions (Obleser et al., 2012; Wilsch et al., 2014). In these studies alpha power increase is linked to increased cognitive demands. At the same time, irrelevant brain regions are inhibited. Lange et al. (2013) suggests that alpha power decreases on the regions relevant to the task.

One of the first studies using auditory stimulus was presented by Bastiaansen and Brunia (2001). In this study, the modulation of alpha power in anticipation paradigm was detected in 2 out of 5 subjects. Banerjee et al. (2011) suggests that auditory spatial attention and visuospatial attention are modulated by similar mechanisms. In addition to this, differences in topographical representation of power modulations suggest also an involvement of sensory-specific mechanisms. Muller and Weisz (2012) try to find the association between anticipatory modulations of auditory alpha power and top-down processes. Auditory alpha power increases ipsilaterally during the processing of irrelevant information. Top-down modulation of alpha power is suggested to gate the information in the cortex, focusing on relevant information and suppress the distracting information in a cross-modal task (attending either auditory or visual information based on a visual cue) (Mazaheri et al, 2014).

2.5 Research questions

Taking together, these studies indicate an importance of top-down mechanism of attention and its role in suppression of irrelevant information. However, up to our knowledge, most of the evidence is based using external distractors only. This study tries to provide additional scientific evidence for better understanding of human cognitive control system. The main focus is to determine whether alpha band power plays a role in suppression of internal distractions similarly to the mechanisms observed in suppression of external distractors. If so, it would be possible to observe that modulation of alpha power plays also a role in suppression of semantic interference during stimulus free retention period. Additionally, failed suppression of semantic interference might lead to false memory errors. Therefore, another line of this research is to compare false memory instances with correctly inhibited trials.

CHAPTER 3

MATERIALS AND METHODS

3.1 Participants

Twenty-five native Turkish speakers (Mean age: 22.6±2.27, range: 19 - 28, 14 males) participated in the study. All subjects were right handed and reported having normal hearing and normal or corrected-to-normal vision. Prior to the experiment, participants gave written informed consent. In addition to this, participants filled in a questionnaire which included questions about demographic, medical, and educational history (Appendix A). Volunteers who had formal education in psychology, history of psychological or neural disorders, or were on psychiatric medication were not admitted to the experiment. Before the experiment, participants were asked to retain from alcohol, drug, and caffeine consumption and get enough sleep. The experimental procedure was approved by the local ethics committee of the Middle East Technical University.

3.2 Experimental Manipulation and Description of Database

3.2.1 Experimental Manipulation

Experimental modulation was performed among two parameters: semantic relatedness of the words in the set and type of the probe. The set type was either semantically *related* – i.e., when words in the set belong to the same semantic *lure*, a thematic word which is connected to all items in the set, – or *unrelated*, i.e., random words with no semantic ties. The set was associated with a probe, which was either positive (old) or negative (new). For semantically related sets, the negative probe was a lure word, whereas for semantically unrelated sets the negative probe was another random item that was not linked to the set.

3.2.2 Description of the database

This study employed a database of adapted to Turkish Deese-Roediger-McDermott (DRM; Deese, 1959; Roediger and McDermott, 1995) lists, which was developed previously in the Neuro Signal Laboratory of the METU Informatics Institute. The following section describes the creation of the database. The items in the database were taken from the original DRM lists (Deese, 1959; Roediger and McDermott, 1995) and translated to

Turkish. Afterwards, the translated items were tested for lexical and cultural validity. Items that were not common to Turkish culture and items that after translation were including a lure word were removed. In order to substitute for these words, an additional, Internet-based, questionnaire, in which the participants had to write items associated with the lure word, was performed. Subsequently, the associations between the words in the lists with the lure word, Backward Associative Strengths (BAS) were computed. In the end of the manipulation 136 sets of five items each (four items and a corresponding probe), composed of frequently used concrete and abstract content words (adjectives, adverbs, nouns, and verbs), were generated. A trained female speaker recorded the words in the soundproof room with 92 KHz sampling rate. Later the words were downsampled offline to 44.1 KHz. The average length of recording was 0.62 ± 0.14 s.

The sets were further divided into two. Half of the sets were randomly assigned to semantically related condition. For the other half, sets were randomly mixed and items in the sets were assigned to the new sets such that no items from the same set appear in the new set (see Table 2 for examples of sets). Positive probe items could appear from any part of the presentation set.

Table 2 Examples of stimuli manipulation in the study. Sets in the study were manipulated among two dimensions – semantic relations between the words in the set and probe type. S1, S2, S3, and S4 represent presentation stimuli, P – represents probe items.

Condition:	S1	S2	S3	S4	P
Unrelated (negative)	Spice	Building	Holiday	Long	Ring
Unrelated (positive)	Spice	Building	Holiday	Long	Building
Related (negative)	Vase	Rose	Tulip	Daisy	Flower
Related (positive)	Vase	Rose	Tulip	Daisy	Rose

3.3 Paradigm

The study employed a modified, auditory version Stenberg paradigm (Sternberg, 1966) (see Figure 3.1 for the schematic visualization of the experimental design). Each trial is composed by four intervals: pre-stimulus, encoding, retention, and recognition. A trial started with a one-second pre-stimulus where a fixation cross was shown on the screen. The encoding interval consisted of four lexical stimuli, sequentially presented with a rate of 1.2 s. The retention interval began with a mathematical question. Each mathematical question included two out of four basic arithmetic operations and was presented in the following format: $(a \pm b) / c = d$, or $(a \pm b) * c = d$, such that a, b, c < 10 (see Figure 3.1) for an example of mathematical question). All the equations were randomly generated. Half of the equations were generated mathematically “correct” whereas the other half was modified (addition or subtraction) by a random value between 1 and 4. Mathematical task was added to increase the complexity of the task. Participants had a maximum of four seconds to decide whether the presented arithmetic equation was correct or wrong. After the answer, fixation cross was shown on the screen until the end of the trial. The interval between the end of mathematical question and the onset of the probe will be subsequently referred as a stimulus free retention period.

Finally, in the recognition interval the subjects were presented with a probe item. Participants had to decide whether the presented probe was a member of the lexical set that they were familiar with within a three-second interval.

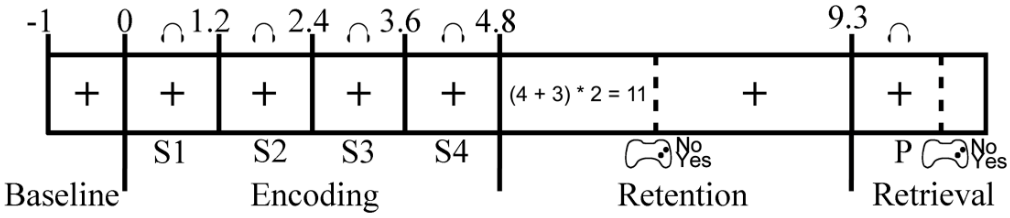

Figure 3.1 Schematic representation of a trial. Each trial starts by a one-second baseline period, with a fixation cross shown on the screen. Following, four experimental stimuli (S1 – S4) are presented sequentially with triggers set to 1.2 seconds from the previous item. The retention interval starts with a mathematical question. Participants give answers by using two buttons of the gamepad, set to yes and no respectively. After participant provide an answer a fiction cross is shown. The probe is then presented at 9.3 seconds starting from the beginning of the trial. Participants decide whether the probe word was in the presented set or not.

All the answers were collected by a gamepad using ‘green’ and ‘red’ buttons set to ‘yes’ and ‘no’, respectively. The participants were instructed to respond as quick and accurate as possible to mathematical and probe questions. In the literature, the degree of encoding – deep (semantic features) or shallow (physical features of the word) – is reported to affect memory formation (Hanslmayr and Staudigl, 2014). To balance the degree of encoding and ensure that the semantic properties of the lexical items were attended, the participants were instructed to imagine the presented items.

The experimental paradigm was implemented in MATLAB® (R2013a, The Mathworks Inc., Natick, MA) using the publicly available Psychophysics Toolbox (Brainard, 1997).

3.4 Experiment

3.4.1 Preparation for the experiment

During the preparation for the experiment “EasyCap Installation Guide” was followed. Preparation for the experiment consisted of three stages: cap fitting and mounting, electrode preparation and attachment, and electrode impedance minimization. During the first stage the subject's head circumference, and the distance between nasion and inion points were measured. To ensure the symmetrical position of the electrodes, the center of lateral sides was also measured. Central electrode ("Cz") location was centered to the intersection of lateral and inion-nasion locations. During the second stage, the hair of subject under the adapter was pulled with a cotton swab to one side until the skin was clearly visible. The skin was later degreased with alcohol. The electrodes were degreased with alcohol. Then the electrodes were fit to the corresponding adaptors. During the third stage, the electrodes were filled in with chloride-free, abrasive electrolyte gel ('Abralyt 2000'). Impedance levels were measured online and reduced by twirling on the skin with combination of gel and alcohol. The preparation procedure for each subject lasted around an hour.

To ensure hygiene, all the procedures were performed in disposable plastic gloves and using disposable supplementary material (i.e., cotton swabs, or cotton round pads). After the experiment, cap and electrodes were cleaned with a shampoo and a brush, and stored.

3.4.2 EEG procedure and data acquisition

Acquisition of EEG data was performed in an acoustically insulated and electrically shielded Faraday cage. EEG signals were recorded through a 32-electrode (Ag/AgCl) Brain Amp system (Brain Products, Münich, Germany) with the standard international 10-20 system electrode placement. The sampling rate of the recording was 1000 Hz. Two electrodes were placed at mastoids and two ground electrodes were placed on the ear lobes. Two electrodes (vertical and horizontal) were used to record electrooculogram. Impedance of electrodes was kept below 10 kΩ.

Participants were sited on a comfortable and stable chair in front of 21-inch monitor screen on which visual information was presented. Auditory stimulus was presented through headphones. Each participant adjusted the volume of headphones to a comfortable level. Experiment was introduced during the training stage where the subjects were presented with five semantically unrelated trials. Having completed the training successfully, the participants moved to the main task. Every 11 trials the participants had a self-paced break. In total, each subject completed 136 trials.

3.5 Analysis of Behavioral Data

Behavioral data analysis was performed using SPSS$^{©}$ 20 (IBM, Armok, NY). Response times (RT) were collected for each participant and then averaged for mathematical question and probe response. Only trials with correct mathematical and probe question pairs were analyzed.

A 2 × 2 [probe × condition] repeated measures analysis of variance (ANOVA) was carried out to investigate the effect of condition and probe on RT. The analysis was followed by pairwise comparisons. RT for mathematical equation question was analyzed using a two-tailed paired samples t-test.

Subsequently, error analysis was performed. Error rate for probe and condition type (semantically related positive, semantically related negative, semantically unrelated positive, and semantically unrelated negative) were calculated for each subject. Memory performance was analyzed using a one-way Friedman ANOVA. Due to the fact that the data violated the assumptions of homogeneity of variance and normality, Friedman ANOVA was used. Pairwise comparisons with Bonferoni correction were used as a follow up analysis.

3.6 Analysis of EEG Data

3.6.1 Data Preprocessing and Time Frequency Analysis

Oscillatory data analysis was performed using in-house build scripts with assistance of Matlab-based Fieldtrip toolbox (v. 7276) (Oostenveld et al., 2011). Raw data were band pass filtered between 0.2 and 100 Hz using the 4th order Butterworth filter. After trial separation the data was demeaned. Independent component analysis (Fast ICA) was used to perform eye movement related artifacts detection and removal. A visual inspection was performed to note and further discard the trials with remaining artifacts. Furthermore trials were grouped by conditions: semantically related and semantically unrelated and all correct trials together. Trials with incorrect mathematical and probe questions were discarded from this grouping. In addition to this, trials with wrong "new" probes for semantically related condition (i.e., false memory trials) were grouped together for each subject.

Time frequency representation of the signal were estimated using fast Fourier Transform with a 500 ms long Hanning window and 50 ms shift for 2 to 32 Hz with 2 Hz increment. Subject and condition specific time frequency representations were further normalized considering the baseline as a reference. The normalization was performed as follows:

$$Pow(N) = \frac{Pow(C) - \mu(B)}{\mu(B)} \tag{3.1}$$

where *Pow(N)* is the normalized power value for each channel, frequency, and time point, *Pow(C)* is the original power values for each channel, frequency, and time point, and $\mu(B)$ is the average power for the baseline in the interval of (-1, -0.3) for channel, frequency dimension.

3.6.2 Band Definition and Frequency Selection

As frequency band of a task-related alpha activity changes depending on the age, task, and interpersonally (Haegens et al, 2014; Klimesch 1999, 1997), a notion of individual alpha frequency (IAF) range was introduced in this study. Alpha band was defined computationally based on a peak frequency within a frequency range of low and high alpha band frequencies (6 – 16 Hz) during stimulation-free delay period defined within [-1.8, -0.3] s before the onset of the probe. Matlab function “findpeaks”, a function to find local maxima, was used for this. For consistency, accuracy of the peak selection was confirmed through visual inspection of time-frequency pattern and topographical representations of each subject. The selected central frequencies for each subject can be seen in Appendix B.

3.6.3 Statistical Analysis

Statistical comparison of electrophysiological data is affected by a multiple comparison problem due to the multidimensional nature of the data. Each EEG data point (voxel) is spatially dependent from its time, frequency, and channel values (Maris and Oostenveld, 2007). EEG data is situated at a spatiotemporal dimension, meaning that signal is represented as a time-frequency-channel points. High number of comparisons over multi-dimensional space, increases a chance of family-wise error (false alarm) rate making it questionable to attend a standard statistical procedure. To control for multiple comparison false alarm rate, nonparametric cluster-based permutation test can be used as a statistical procedure (Maris and Oostenveld, 2007).

To perform the statistical analysis between semantically related and semantically unrelated conditions, nonparametric cluster-based test procedure was followed. After the estimation of time-frequency representations, data normalization, and frequency shift for each subject, time-channel-frequency data was adjusted to fit a range of (IAF-6 Hz, IAF + 10 Hz) and averaged across subjects. Average power in parietal and occipital regions was used as a spatial parameter for the test. The analysis was performed over 3000 iterations, employing a two-tailed dependent samples t-test, keeping the cluster alpha values at a 0.05 threshold and accepting a cluster as a significant at a 0.025 level of significance (for each tail), for time interval corresponding to stimulus-free retention period (i.e., from the approximate end of mathematical question to the onset of the probe). Average response to mathematical question (1.95±0.31 s) was assumed to be the approximate end of mathematical question, corresponding to -2.3 s before the onset of the probe.

A follow-up analysis was performed to check for additional power fluctuation across the all the channels in the time and frequency parameters of the cluster. Additional analysis parameters included 3000 iterations, two-tailed dependent samples t-test, and an alpha threshold of 0.05 and 0.025-significance level for each tail.

3.6.4 False Memory analysis

Due to low number of false memory trials, a comparison within cluster boundaries between power of correct trials in semantically related condition and power of errors was performed. Time-frequency representation of each trial was normalized using a common baseline and method described in 3.6.1. For each subject, power in semantically related condition and false memory condition was averaged. Furthermore, standard deviation of mean over all trials was calculated. An inferential statistics measure was used to estimate the probability of average power for false memory condition to fall in the 95% of 2-tailed t-distribution. The distribution was calculated using the following formula:

$$t = \frac{\bar{x} - \mu}{\sigma / \sqrt{n}}, \tag{3.2}$$

where $\bar{x}$ denotes the mean, σ – the standard deviation, *n* – number of trials, and *t* – the value of t-distribution corresponding to the 95% probability of corresponding df (where df = n -1).

3.6.5 Correlation Analysis

Average cluster power in semantically related and semantically unrelated conditions was correlated with average response times. For each participant average alpha power and average RT for semantically related and semantically unrelated conditions were calculated. Outliers were detected based on the individual deviation from other subjects. Two subjects, values of whom felt out from 95% confidence intervals of RT or alpha values, were removed from the analysis. The resulted values were correlated using Spearman’s correlation method.

CHAPTER 4

RESULTS

4.1 Behavioral Results

As expected, task performance was high during the experiment. On average subjects could recognize 97.9% ± 1.95% of probes successfully. The following sections describe the statistical analyses of response times and errors.

4.1.1 Response Times

Analysis of RT for mathematical question did not reveal any significant difference between semantically related and unrelated conditions ($p = 0.91$), as expected. This suggests that mathematical questions did not differ in difficulty among conditions.

A 2 × 2 ANOVA revealed a main effect of condition, i.e., semantically related vs. unrelated (F (1, 24) = 7.27, $p < 0.05$, $\eta_p^2 = 0.23$) and a main effect of probe (i.e., old vs. new) (F (1, 24) = 48.67, $p < 0.001$, $\eta_p^2 = 0.67$) (see Figure 4.1).

Related probes were answered slower (M = 1.045, Std. Error = 0.044) compared to the unrelated ones (M = 0.997, Std. Error = 0.038). In addition to this, it took longer to answer negative probes (M = 1.11, Std. Error = 0.05) compared to positive ones (M = 0.937, Std. Error = 0.039). Interaction between the probe type and condition was not significant (F (1, 24) = 2.78, $p = 0.109$, $\eta_p^2 = 0.104$).

4.1.2 Error Analysis

Rate of errors was evaluated by Friedman ANOVA and revealed a difference between semantically related positive (Mean rank = 2.46), semantically related negative (Mean rank = 3.02), semantically unrelated positive (Mean rank = 2.40), and semantically unrelated negative (Mean rank = 2.12) conditions, χ^2 (3, N = 25) = 10.19, $p < 0.05$.

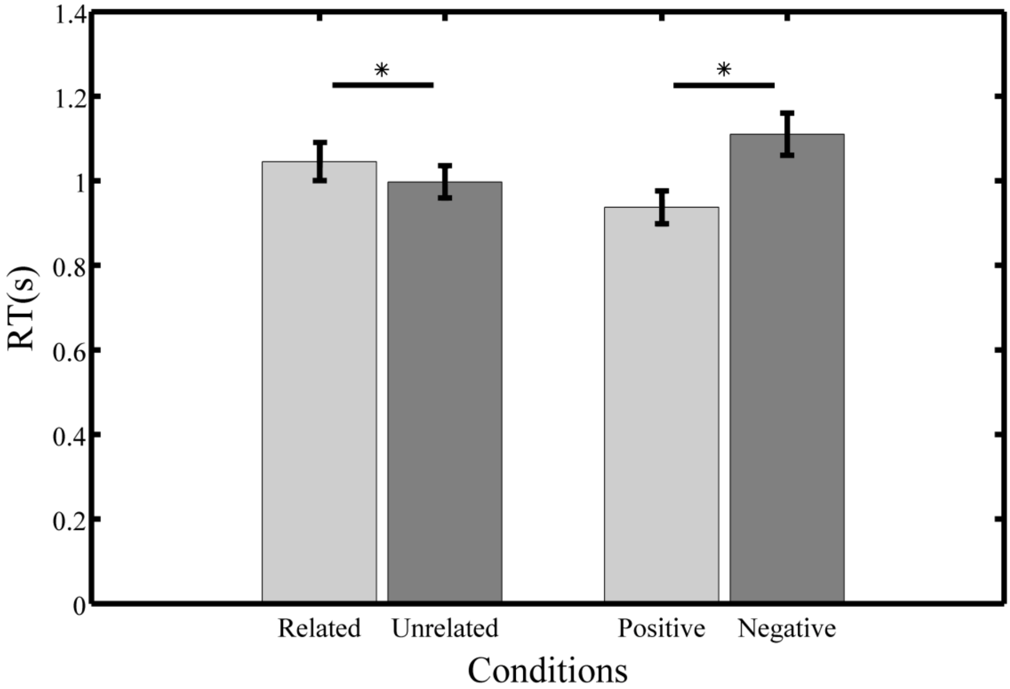

Figure 4.1 A comparison between mean RT for semantically related and unrelated conditions, and positive and negative probe types. Mean RT for related sets is higher compared to the one of unrelated. This suggests that semantic relations between items, indeed, create semantic interference. Average RT for negative (new) probe is higher compared to the positive one. This suggests that participants found it more difficult to correctly reject negative lures in comparison with positive ones. *<0.05

Pairwise comparisons indicated a trend between semantically related negative and semantically unrelated negative conditions (p = 0.084). No other significant comparisons were revealed. Comparison between false memory errors and the average of all other errors in all subjects revealed higher number of false memories; $p < 0.05$ (see Figure 4.2).

4.2 Oscillatory results

4.2.1 Task pattern

Task related alpha power modulations were observed during encoding, retention, and recognition intervals in alpha band. Event-related power synchronization (i.e., increase in alpha power) is common to encoding, following an event-related desynchronization (i.e., power decrease) during mathematical question. During the second part of retention period, stimulus-free retention period, alpha power increased among parietal and occipital regions for both conditions (see Figure 4.3).

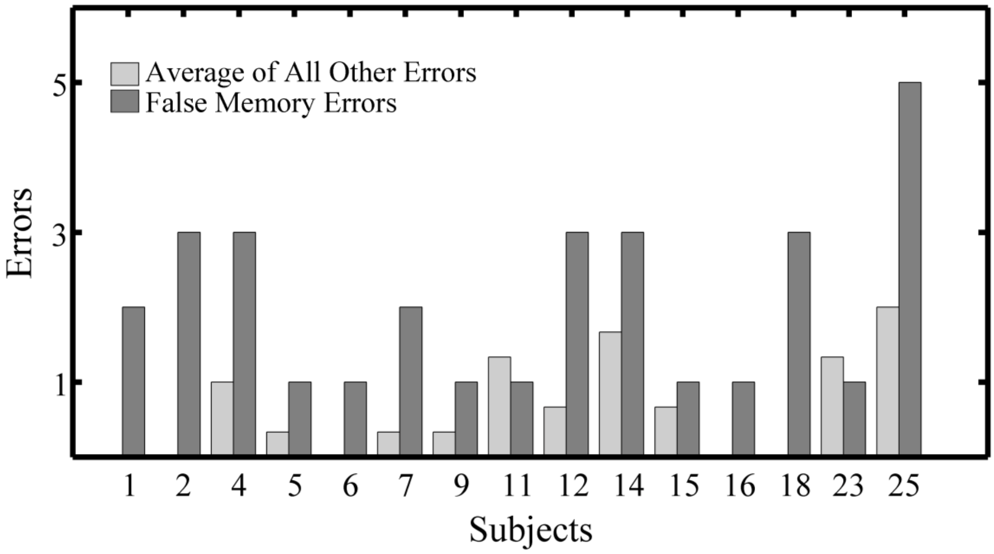

Figure 4.2 A comparison between the false memory errors and the average of errors in other conditions (i.e., semantically related positive, semantically unrelated positive and semantically unrelated negative). Only subjects who experienced false memories are shown.

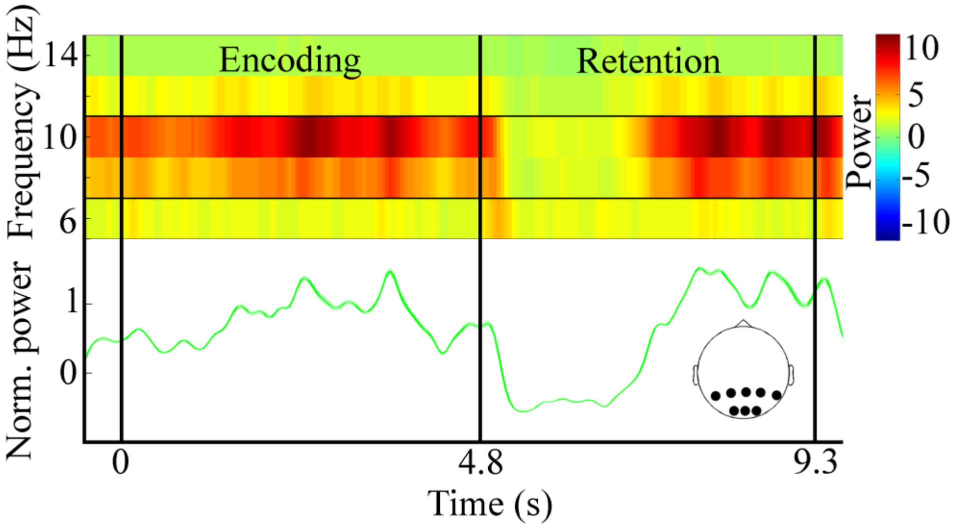

Figure 4.3 Upper plot: Task pattern for all correct trials for a representative subject for parietal and occipital channels. Power is not normalized. Lower plot: Time-power representation for 8-10 Hz for the representative subject. Power values are normalized. An increase during encoding is followed by a decrease in beginning of the retention (mathematical question), and another increase in the stimulus free retention period.

4.2.2 Statistical Analysis

The difference between the semantically related and unrelated conditions was analyzed using non-parametric cluster permutation test. The test yielded a significant cluster between 1.15 s and 0.35 seconds before the onset of the probe and in the frequency range of (IAF, IAF + 8) Hz, $p_{(\mathrm{corr.})} = 0.0187$ (Figure 4.5)

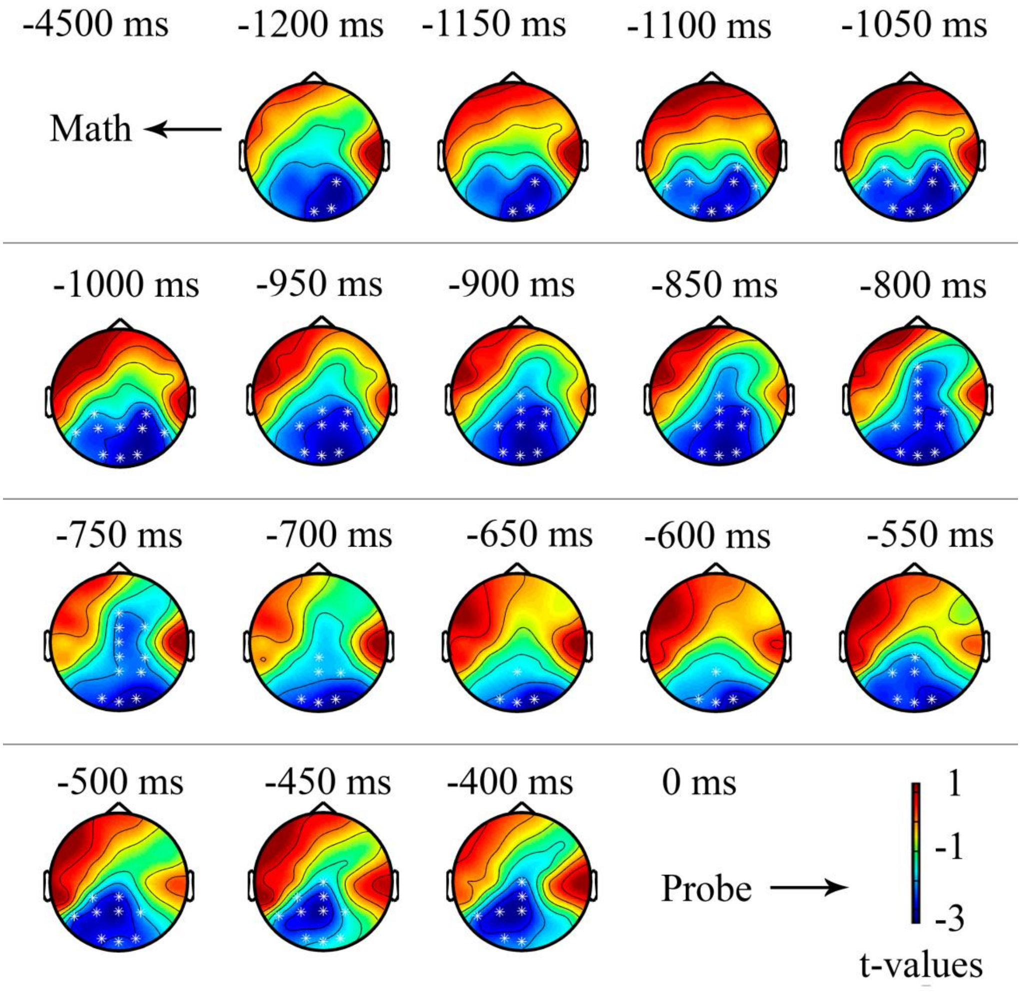

Figure 4.4 Spatial and temporal dynamics of cluster. Analysis of spatial and temporal dynamics show power fluctuation from right parietal and occipital channels to central and parieto-occipital channels, and finally to left parietal and occipital channels. Negative t-values represent higher power in semantically unrelated condition. White asterisks show significant channels.

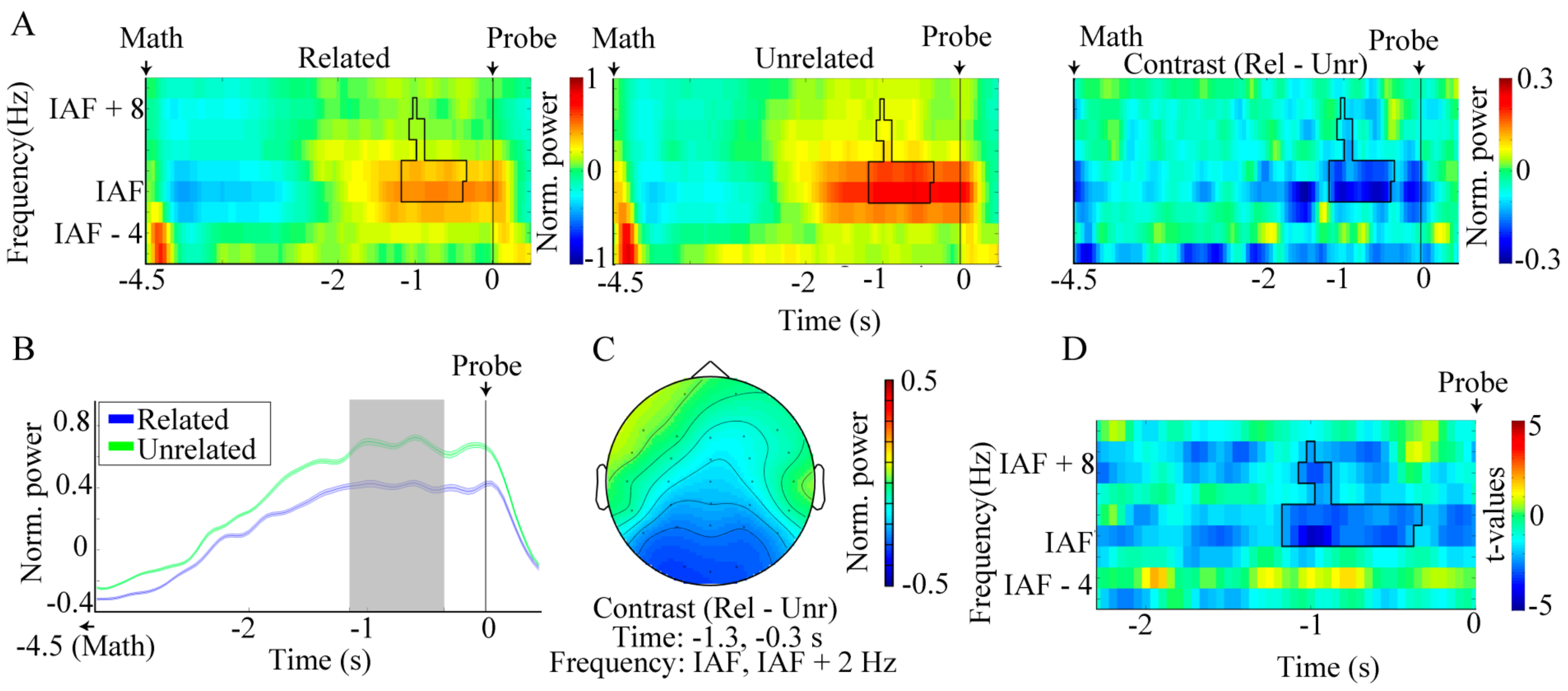

Figure 4.5 (A) Grand averaged time-frequency representations for semantically related, semantically unrelated, and the contrast between semantically related and semantically unrelated trials. Power values in semantically related and semantically unrelated conditions were normalized for each subject prior averaging. Averaged time frequency representations were subtracted from each other. Negative values represent higher power for semantically unrelated condition. Significant cluster is highlighted. (B) Time-power plot for semantically related and semantically unrelated conditions. The time of the significant cluster is highlighted in grey. (C) Contrast of power between semantically related and semantically unrelated conditions for time and frequency range of significant cluster. (D) Time-frequency representation of t-values for comparison between two conditions. Negative values represent higher power in semantically unrelated condition. Significant cluster is highlighted.

Due to time and frequency variations of cluster, a "narrow" cluster of frequency (IAF, IAF + 2Hz) and time (1.10, 0.4s) was used for follow-up analyses. A non-parametric cluster permutation test was used to evaluate spatial evolution of power in time. An analysis of spatial and temporal dynamics show a fluctuation of power from right parietal and occipital sites to central, parietal and occipital channels, and finally to left parietal and occipital channels (Figure 4.4).

4.2.3 False Memory comparison

Only 15 of 25 subjects experienced false memory formation. On average a 3.2% of lure cases were answered incorrectly. In 11 subjects the averaged power in false memory condition is higher than the one of semantically related condition (Figure 4.6). For 9 (subject id: 5, 6, 9, 11, 14, 15, 16, 18, 23) subjects the power exceeded the threshold of 99% of semantically related condition. For other subjects false memory power was lower than the average or in the range of correct power. For 4 subjects (subject id: 1, 2, 12, 25) the power in false memory condition was lower than that of 99% of power of correct trials.

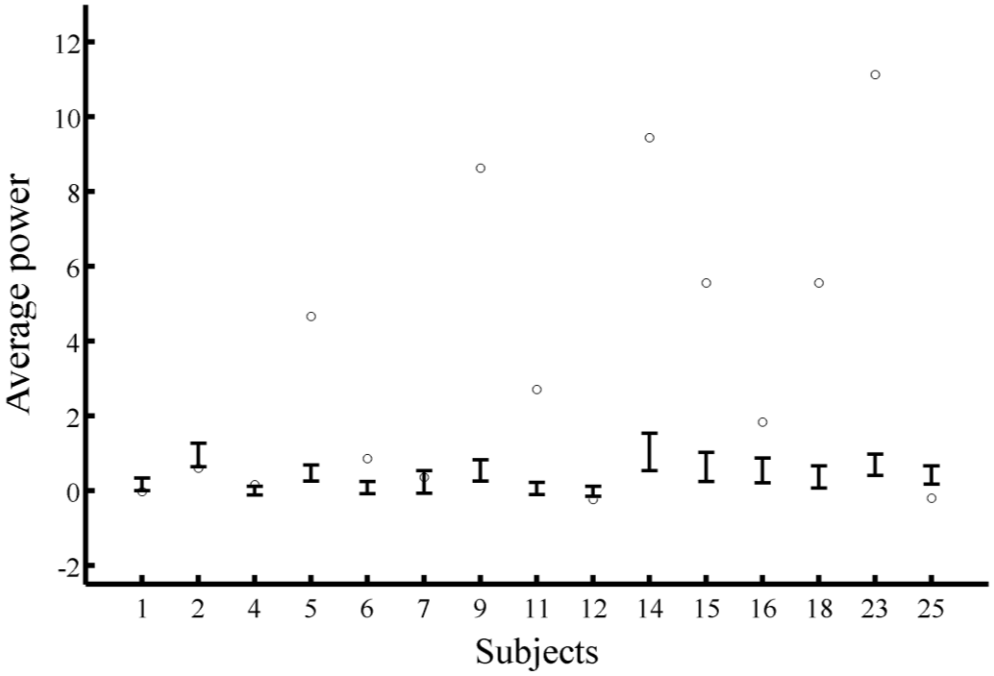

Figure 4.6 Alpha power (IAF, IAF + 2 Hz) in semantically related (black bar, height of the bar represents 99% threshold for trials) and false memories (white circles) for each subject who experienced false memories. For 10 subjects power in false memory condition exceeds 99% threshold of semantically related power.

4.2.4 Correlational Analysis

A negative correlation of RT with alpha power averaged within the significant cluster is observed, Spearman's rho = -0.3174, *p* = 0.0321 (Figure 4.7). The higher the power in alpha band (IAF, IAF+2), the quicker the responses were given.

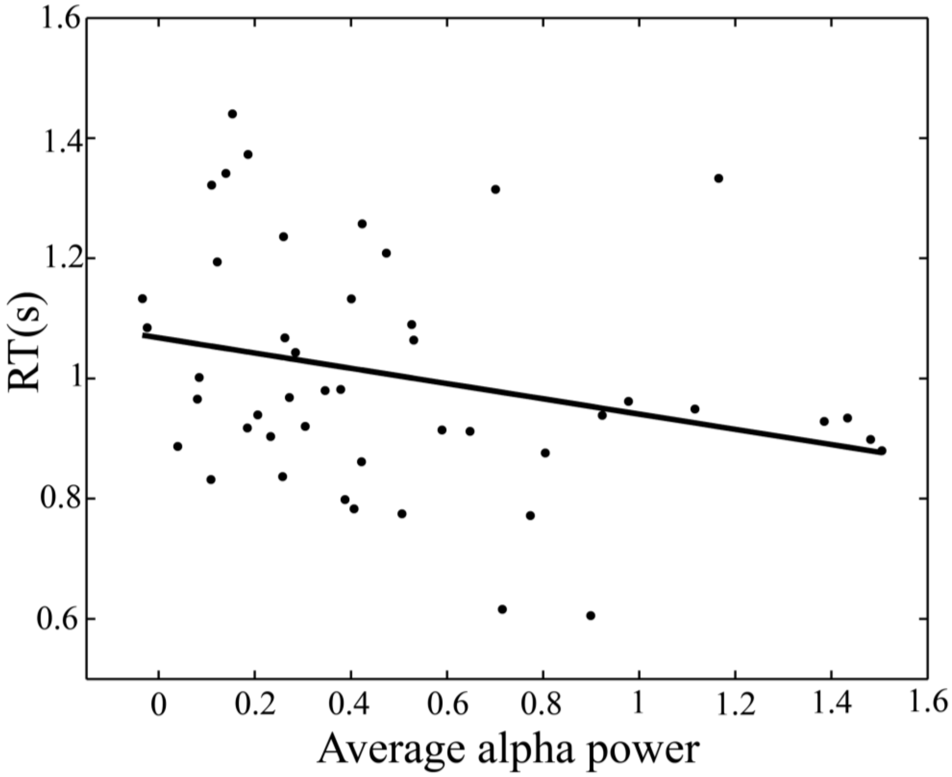

Figure 4.7 A negative correlation between RT and alpha power (IAF, IAF + 2 Hz), (*r*= -0.3174, *p* = 0.0321).

CHAPTER 5

DISCUSSION AND CONCLUSION

5.1 Discussion

Current study investigated the neural mechanisms of semantic interference suppression during auditory working memory task. Response times for semantically related condition are higher compared the ones in semantically unrelated. This suggests that successful resolution of semantic interference require more cognitive resources (Sternberg, 1966).

In addition to this, in oscillatory analysis we found that the power in semantically unrelated condition was higher compared to the semantically related one during stimulus free retention interval. Together with enhancement in upper alpha band over the parietal-occipital channels, greater power synchronization is observed in semantically unrelated condition (Figure 4.5). In literature this increase in upper alpha power over posterior regions is associated with active suppression of distraction and facilitation of attention (Foxe and Snyder, 2011; Rohenkohl and Nobre, 2011; Haegens et al., 2012; Payne and Sekuler, 2014; Wilsch et al., 2014). Moreover, a parametric increase in alpha power was observed together with an increase in cognitive load (Obleser et al., 2012).

In this experiment, contrary to the expectation that alpha power increases parametrically with cognitive load, alpha power in a cognitively “costly” (measured by response times) semantically related condition exhibits a relative decrease compared to the semantically unrelated one. It might be possible to suggest that together with increase in alpha power in both conditions, the power in semantically related condition decreases (Jensen and Mazaheri, 2010) allowing a successful resolution of semantic interference in the prefrontal cortex (Glaser et al., 2013). Enhancement in upper alpha band suggests that this modulation is related to semantic content of the stimuli as previous studies reported an involvement of the upper alpha during the processing of semantic information (Klimesch, 1996).

Subsequent analysis of cluster power revealed the spatial modulations of upper alpha (IAF, IAF+2) power, over time; suggesting that, although, the power is modulated over various channels (mostly in posterior and central regions), the power contrast is higher on the right posterior channels with shift to the left posterior channels when approaching 500 ms towards the probe presentation (Figure 4.4). Although it is hard to judge the spatial properties of the signal due to low number of channels, left posterior modulations of alpha power could be related to the storage of verbal information. For example, Meyer et al. (2013) proposed the verbal memory related function of left parietal cortex functions as an inhibitor of the premature release of verbal information in a sentence comprehension task. Right-lateralized posterior alpha power, on the other hand, acts as a suppression mechanism for upcoming auditory stimulus (Dube et al., 2013).

Error rate in false memory condition was found to be higher compared to the errors in other conditions. This suggests that the paradigm could induce false memories. Average power in false memory condition for the majority of subjects falls out of 95% and 99% of confidence intervals of semantically related correct trials. This can indicate that inability to maintain appropriate level of alpha activity and higher excitation result in inability to correctly reject the lure item. Although the number of trials is not sufficient for statistical reliable analysis, it is possible to suggest that deviation of alpha power out of specific power range can increase the chance of getting false memories. As a result, maintaining alpha power in a specific range is crucial to escape from the formation of false memories.

Finally, mean response times significantly correlate with cluster power: the higher the power in the upper alpha band, the quicker the responses were given.

In summary, the oscillation modulations that were observed in this study suggest that they might be attributed to an indication of the work of cognitive control system. With similar results coming from other modalities, it is possible to assume that facilitation of attention and suppression of distractive information lay on a similar network that modulates the external distractors.

5.2 Limitations

In this study some limitations were found out as well. First of all, although we tried to balance encoding by asking the participants to imagine the word they hear, we did not take into account individual differences between subjects. For example, while for some imagining a word they have heard could be a useful and familiar strategy that they have used for (i.e., foreign) word memorizing, for others (for example, participants who mostly rely on written form) this could have been a greater distractor. In addition to this, it is not possible to estimate whether the mental imagery task was performed for the whole duration of the experiment.

In addition to this, it could have been better to have more control over stimulus material. Adaptation of DRM database to Turkish was a pioneering work, which relied on the original lists but did not take into account the type of the semantic relationship between the words. Processing of different types of semantic relations (hyponymy, synonymy, antonym, etc.) may involve different neural mechanisms. Moreover, the frequency of each word, its abstractedness or concreteness, or the part of the speech it belongs to might have introduced some factors in the data which were not fully controlled.

Finally, due to low number of error trials, it was not possible to perform a proper time-frequency analysis on false memory data. In order to obtain a better idea of power modulation between correct trials and errors, a paradigm which would elicit a comparable number of false memory errors could be developed. In addition to this, an assumption that all errors in semantically related, lure cases are “false memory” errors might be an ambitious one. As a result, better definition of “false memory” should be introduced for further research.

5.3 Conclusion

To summarize, this study suggests that cognitive control system plays an important role in resolution of semantic interference. In addition to this, cognitive control is supported by similar processes both in suppression of internal and external distractions. Furthermore, it is possible to assume that successful interference resolution is accomplished by a successful inhibition of language related regions and successful suppression of occipital and parietal sites. As a result, failure to suppress successfully can lead to occurrence of false memory errors. These findings suggest that modulation of upper alpha power has an important role in resolution of semantic interference.

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APPENDIX A

PRE-EXPERIMENT QUESTIONNAIRE

General Information		**Exp. No:** **Date:**	________________ ________________
Subject Name:	__________________	**Gender:**	**M☐ F☐**
Phone:	__________________	**Age:**	___________________
E-mail:	__________________	**Handedness:**	**R☐ L☐**
Vision:	__________________	**Menstruation**	**Yes☐ No☐**
Hearing:	__________________		
Education Information:			
University:	______________________	**Mother Tongue:**	__________________
Department	______________________		
Level:	**UG☐ BS☐** **MS☐ PhD☐**	**Other Languages**	______________: __/5 ______________: __/5
Substance consumption history:			
Drugs:	**In past week☐ Yesterday☐**		
Smoking:	**Yes☐ No☐**	**Daily amount: ___________**	
Alcohol:	**Yesterday: Yes☐ No ☐**		
Caffeine:	**Yesterday: Yes☐ No ☐** **Today: Yes☐ No ☐**	**Amount: ___ cups**	
Medicine:	**In past week ☐ Yesterday☐**	**Type: __________________**	
Sleep:	**Average usual amount: ___ h**	**Hours of sleep yesterday: ___ h**	
Exercise:	**Yes☐ No ☐**	**Number of training sessions: ___ per week**	
Previous participation:			
Did you participate in our previous experiment?			**Yes☐ No☐**
If yes, when? ______________________			

APPENDIX B

PARTICIPANT INFORMATION

Subject no	**Age** (years)	**Gender**	**cf*** (Hz)	**Performance**	**Errors****			
					unr pos	**unr neg**	**rel pos**	**rel neg**
1	24	f	14	98.53 %	0	0	0	2
2	22	f	14	97.79 %	0	0	0	3
3	20	m	12	99.26 %	0	1	0	0
4	21	f	12	95.59 %	1	1	1	3
5	25	f	12	98.53 %	1	0	0	1
6	21	m	12	99.26 %	0	0	0	1
7	26	m	10	97.79 %	1	0	0	2
8	24	f	10	97.79 %	2	0	1	0
9	21	f	10	98.53 %	0	0	1	1
10	21	f	12	100 %	0	0	0	0
11	25	m	12	96.32 %	0	2	2	1
12	23	f	14	96.32 %	1	0	1	3
13	23	m	10	99.26 %	1	0	0	0
14	25	f	10	94.12 %	3	1	1	3
15	21	m	10	97.79 %	0	1	1	1
16	24	m	12	99.26 %	0	0	0	1
17	24	m	8	100 %	0	0	0	0
18	28	f	8	97.79 %	0	0	0	3
19	22	f	10	98.53 %	1	1	0	0
20	22	m	10	100 %	0	0	0	0
21	20	m	8	98.53 %	1	0	1	0
22	24	m	12	99.26 %	1	0	0	0
23	19	m	10	96.32 %	1	1	2	1
24	19	m	12	99.26 %	0	0	1	0
25	21	m	12	91.91 %	1	1	4	5

Table 3 Subject Information. Subject ids, age, gender (m = male, f = female), defined central frequency (cf), performance (out of 100%), and number of errors for each condition are presented.

*****cf = central frequency
****** Errors are coded as the following:

Unr pos – semantically unrelated positive (old)
Unr neg – semantically unrelated negative (new)
Rel pos – semantically related positive (old)
Rel neg – semantically related negative (new)

APPENDIX C

RESPONSE TIMES
(seconds)

Subject no	Semantically Related positive	Semantically Related negative	Semantically Unrelated positive	Semantically Unrelated negative
1	0.81	1.15	0.76	1.01
2	0.84	1.07	0.87	1
3	0.87	1.13	0.73	1.21
4	1.07	1.22	1.11	1.01
5	0.91	1.09	0.94	1.22
6	1.01	1.36	0.94	0.99
7	1.11	1.62	1.07	1.1
8	1.35	1.52	1.29	1.35
9	0.9	0.98	0.82	1.03
10	0.83	1.05	0.82	0.98
11	0.72	0.95	0.77	0.79
12	1	1.15	1.18	1.08
13	0.66	0.9	0.71	0.79
14	1.52	1.58	1.32	1.33
15	0.97	1.31	1.02	1.17
16	0.84	0.98	0.92	0.91
17	0.63	0.6	0.58	0.64
18	0.82	1.04	0.9	1.08
19	0.79	1	0.82	0.94
20	0.84	0.76	0.67	0.86
21	0.94	0.84	0.88	0.96
22	1.16	1.31	1.18	1.23
23	1.04	1.52	1.04	1.52
24	0.87	1.09	0.76	0.92
25	1.17	1.39	1.12	1.53

Table 4 Behavioral data: Response Times. Mean response times for each participant and each condition.

APPENDIX D

AVERAGE ALPHA POWER FOR CORRELATION ANALYSIS

Cluster Alpha Power (normalized)		**Response Times (seconds)**	
Semantically Related	Semantically Unrelated	Semantically Related	Semantically Unrelated
2.323653	2.784889	0.968314	0.837891
3.675906	4.936432	0.903465	0.912698
2.627581	1.385456	0.928403	0.925966
1.223707	2.585405	1.13292	1.001969
2.375887	2.339857	1.089947	1.04352
3.80171	4.286763	1.160642	0.883043
2.145626	2.555256	1.372961	1.084841
2.923042	4.035165	1.394833	1.278914
6.511671	5.585832	0.890513	0.908984
1.806799	1.936947	0.857286	0.86868
2.256963	2.265105	0.743769	0.861639
2.277414	2.933052	0.98121	1.132607
3.595647	4.144458	0.681571	0.706794
2.481059	3.908963	0.835423	0.794445
5.951711	8.183264	0.553798	0.595698
4.221318	4.288747	0.834255	0.871448
5.385679	6.249689	0.821505	0.791155
4.260926	8.897526	0.733283	0.704861
2.259879	2.200132	0.780096	0.767055
2.080072	2.221065	1.236287	1.143193
3.909261	6.372756	1.287811	1.333376
1.822038	2.330428	0.933761	0.741054
2.451697	1.730062	1.257473	1.341456

Table 5 Correlation analysis: Average Alpha Power and RT(s).

APPENDIX E

FALSE MEMORY ANALYSIS

Description	Values					
Lower Bound (95% CI)	0.0220	0.6813	-0.1064	0.2764	-0.0684	-0.0306
Higher Bound (95% CI)	0.3019	1.2048	0.0918	0.6522	0.2162	0.4873
Lower Bound (99% CI)	-0.0045	0.6317	-0.1252	0.2408	-0.0954	-0.0797
Higher Bound (99% CI)	0.3284	1.2545	0.1106	0.6879	0.2431	0.5364
Mean Cluster Power *	0.1619	0.9431	-0.0073	0.4643	0.0739	0.2284
Subject	1	2	4	5	6	7
False Memory Power	-0.0267	0.5969	0.1605	4.6676	0.8535	0.3546
Lower Bound (95% CI)	0.2939	-0.0811	-0.1355	0.6122	0.3068	0.2616
Higher Bound (95% CI)	0.7765	0.1884	0.0894	1.4411	0.9548	0.8067
Lower Bound (99% CI)	0.2481	-0.1063	-0.1566	0.5347	0.2462	0.2106
Higher Bound (99% CI)	0.8222	0.2136	0.1104	1.5186	1.0154	0.8577
Mean Cluster Power*	0.5352	0.0536	-0.0231	1.0267	0.6308	0.5342
Subject	9	11	12	14	15	16
False Memory Power	8.6343	2.7079	-0.2370	9.4425	5.5560	1.8382

Continues on the next page

Description	Values		
Lower Bound (95% CI)	0.1123	0.4433	0.2115
Higher Bound (95% CI)	0.6089	0.9292	0.6182
Lower Bound (99% CI)	0.0659	0.398	0.1735
Higher Bound (99% CI)	0.6553	0.9746	0.6563
Mean Cluster Power *	0.3606	0.6863	0.4149
Subject	18	23	25
False Memory Power	5.5592	11.1324	-0.1962

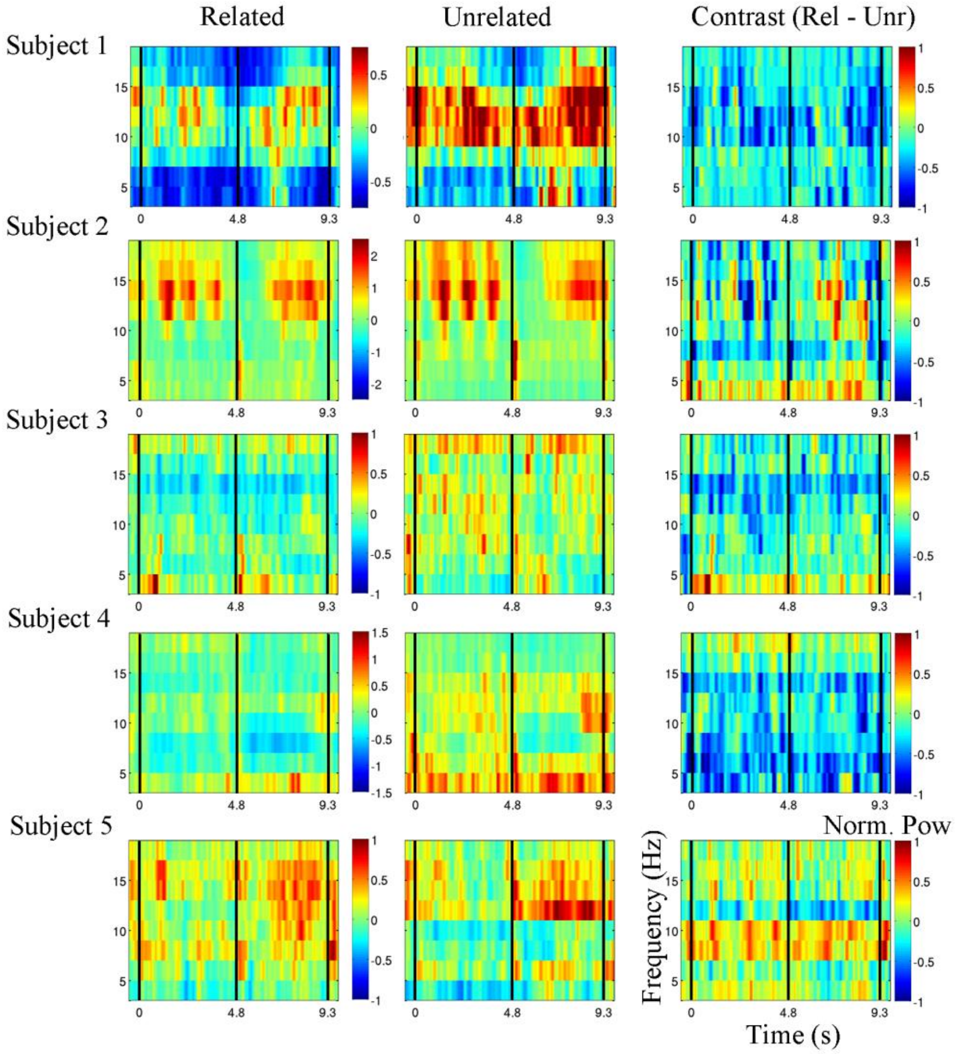
* Mean Cluster Power is Averaged power for semantically related condition, correct trials.

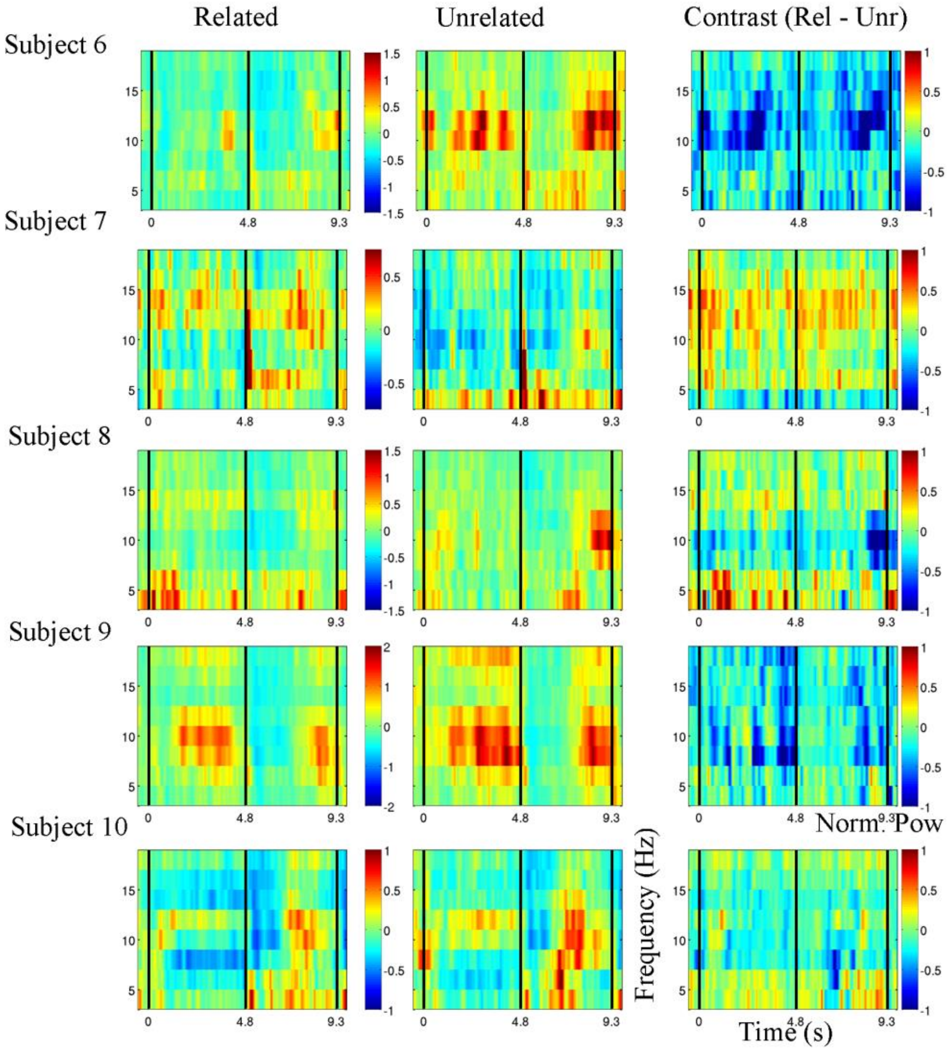
Table 6 False memory analysis. Lower and higher points of 95% and 99% CI distribution, mean power of cluster for correct semantically related condition, subject id and mean power for false memory condition is shown.

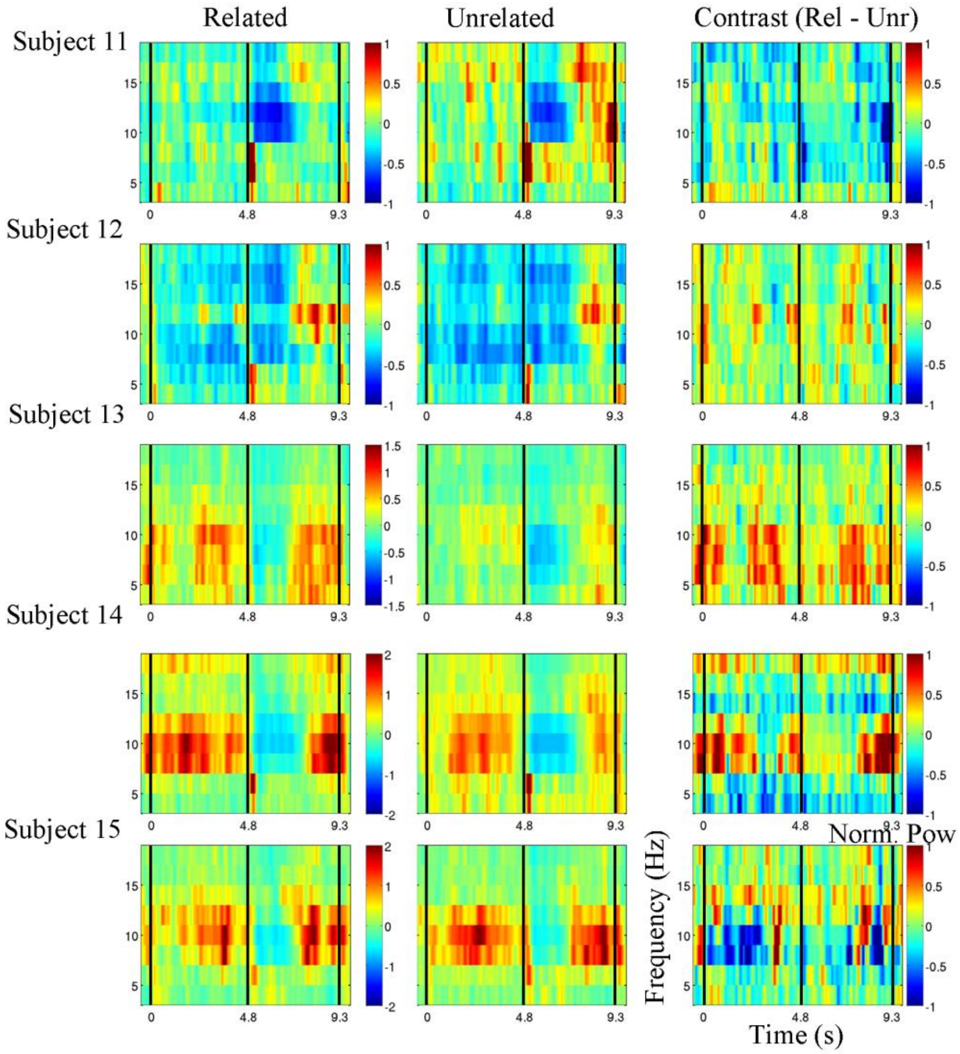
APPENDIX F

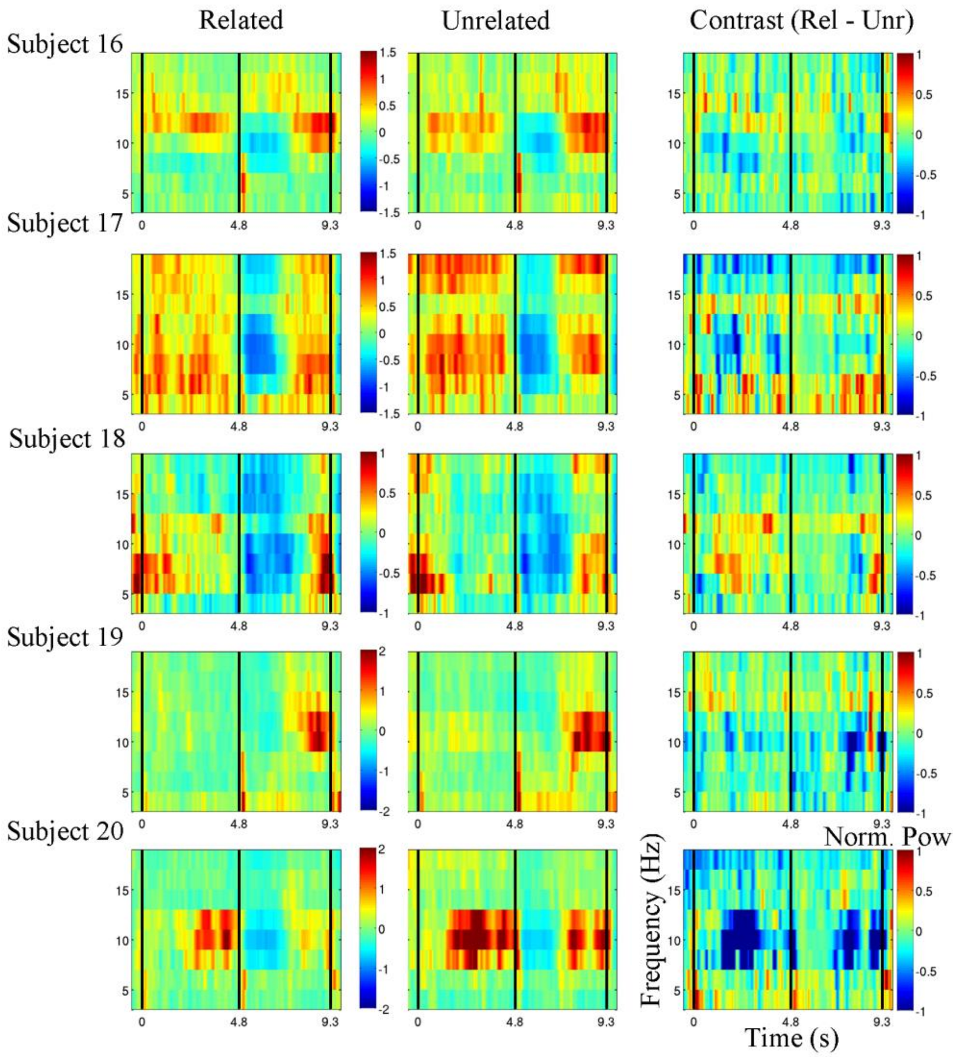
SUBJECT SPECIFIC TIME-FREQUENCY REPRESENTATIONS

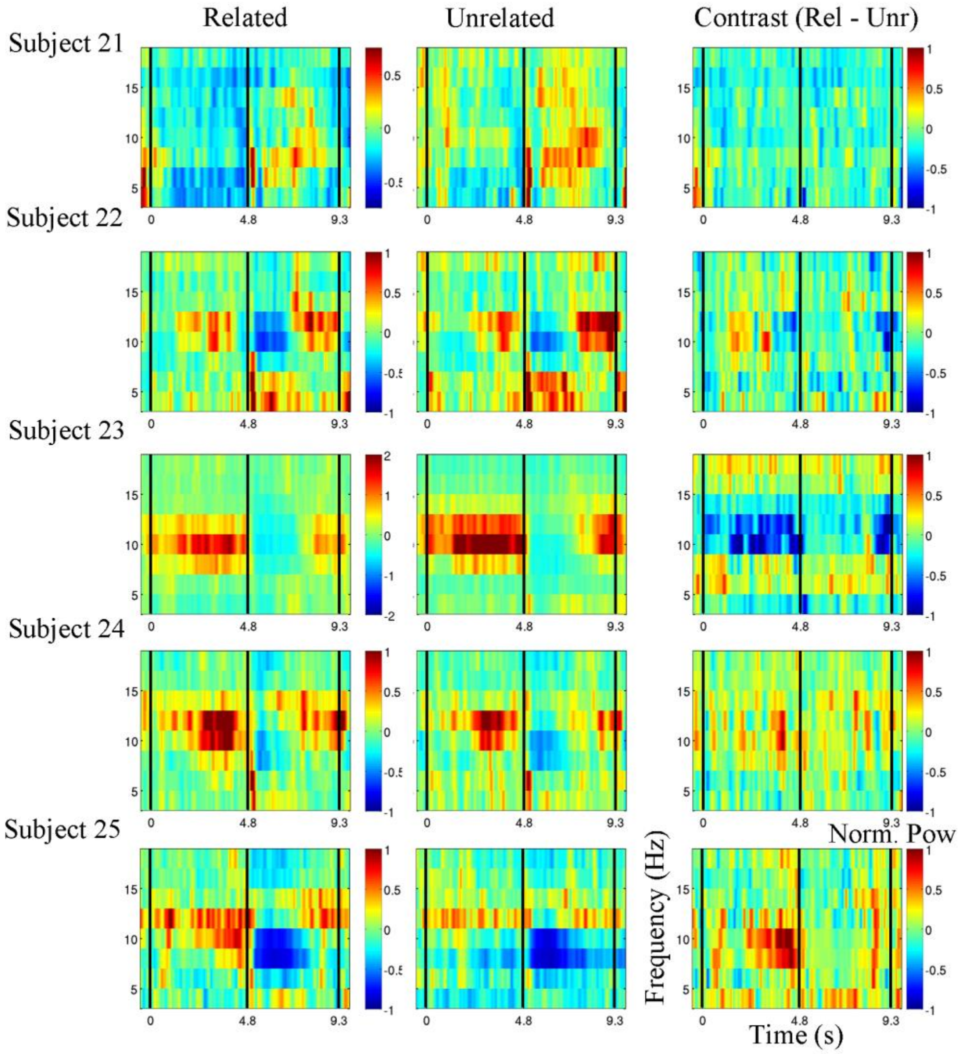
Figure A.6 Subject-specific time frequency representations of correct semantically related, correct semantically unrelated and the contrast between these conditions (Rel – Unr). Time-frequency representations are normalized for each subject. Encoding interval lasts from 0 to 4.8; retention period from 4.8 to 9.3.




Related
Unrelated
Contrast (Rel - Unr)
Subject 6
Subject 7
Subject 8
Subject 9
Subject 10
15
10
5
0
4.8
9.3
1.5
1
0.5
0
-0.5
-1
-1.5
2
-2
Frequency (Hz)
Time (s)
Norm. Pow


Related
Unrelated
Contrast (Rel - Unr)
Subject 11
Subject 12
Subject 13
Subject 14
Subject 15
Frequency (Hz)
Time (s)
Norm. Pow
5
10
15
0
4.8
9.3
1
0.5
0
-0.5
-1
1.5
-1.5
2
-2


Related
Unrelated
Contrast (Rel - Unr)
Subject 16
Subject 17
Subject 18
Subject 19
Subject 20
Frequency (Hz)
Time (s)
Norm. Pow
0
4.8
9.3
5
10
15
1.5
1
0.5
0
-0.5
-1
-1.5
2
-2


Related
Unrelated
Contrast (Rel - Unr)
Subject 21
Subject 22
Subject 23
Subject 24
Subject 25
5
10
15
0
4.8
9.3
-2
-1
-0.5
0
0.5
1
2
Frequency (Hz)
Time (s)
Norm. Pow