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Modulation of alpha oscillations is required for the suppression of semantic interference

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ABSTRACT

Recent findings on alpha band oscillations suggest their important role in memory consolidation and suppression of external distractors such as environmental noise. However, less attention was given to the phenomenon of internal distracting information being solely inherent to the stimuli content. Human memory may be prone to internal distractions caused by semantic relatedness between the meaning of words (e.g., atom, neutron, nucleus, etc.) to be encoded, i.e., semantic interference. Our study investigates the brain oscillatory dynamics behind the semantic interference phenomenon, whose possible outcome is known as false memories. In this direction, Deese-Roediger-McDermott word lists were appropriated for a modified Sternberg paradigm in auditory modality. Participants received semantically related and unrelated word lists via headphones while EEG data were acquired. Semantic interference triggered the false memory rates to be higher than those of other types of memory errors. Analysis demonstrated that the upper part of alpha band (~10–12 Hz) power decreases on parieto-occipital channels in the retention interval, prior to the probe item for semantically related condition. Our study elucidates the oscillatory mechanisms behind semantic interference by relying on alpha functional inhibition theory.

1. Introduction

"Without selective interest, experience is an utter chaos", said William James while elaborating on attention (James, 1890). Performance level in goal-directed activities is highly dependent upon the successful suppression of various distractors. They include irrelevant perceptual inputs that would challenge the subject while attending to his own task. Alpha band oscillations have been considered to reflect cognitive processes such as selective attention (Ray & Cole, 1985; Foxe & Snyder, 2011) and perception (Van Dijk, Schoffelen, Oostenveld, & Jensen, 2008; Weisz, Hartmann, Müller, Lorenz, & Obleser, 2011) in various sensory modalities. The fundamental role of alpha activity has specifically been underlined as the inhibition of neural processing for task-irrelevant brain regions (Jensen & Mazaheri, 2010; Klimesch, Sauseng, & Hanslmayr, 2007). Insufficient alpha activity in these regions may lead to impairments in task performance. Besides, neural excitation in the task-relevant regions is accompanied by the decrease of alpha power (Lange, Oostenveld, & Fries, 2013). A monkey brain study supported these assertions of the so-called functional inhibition theory through micro level local field potentials and spike recordings by demonstrating the correspondence of increase/decrease in alpha activity and low/high neural firing rate (Haegens, Nacher, Luna, Romo, & Jensen, 2011).

In a recent study, Bonnefond and Jensen (2012) presented distractors prior to the probe items during a modified Sternberg working memory task. This resulted in the emergence of stronger alpha band activity in the left posterior regions as well as higher response times. In another study with a modified Sternberg working memory task, albeit in auditory modality, Obleser, Wostmann, Hellbernd, Wilsch, and Maess (2012) showed that the trials with distorted memory items are characterized with stronger alpha band activity during the retention interval in the right temporal-parietal regions. Furthermore, increase of memory items led to systematic increase of alpha activity, which confirmed similar previous findings (Jensen, Gelfand, Kounios, & Lisman, 2002; Leiberg, Lutzenberger, & Kaiser, 2006).

Aforementioned studies suggest that the suppression of the external distractors being necessary for the optimal working memory performance is coordinated by means of oscillatory mechanisms. One question in mind is that whether the above-described mechanics of alpha oscillations applies also for "distractors" that

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are intrinsic to the stimuli. Accordingly, the current study is specifically concerned with semantic interference while producing such "internal" distraction.

Internal distractors in daily life may lead to minor inconveniences or sometimes they may even be the cause of fatal accidents (Robertson, 2003). Human memory is known to be highly prone to distortions. Memory distortions, being byproducts of the efficient functioning of memory systems, can be divided into several domains such as imagination inflation, gist-based associative memory errors and post-event misinformation (see Schacter, Guerin, & St. Jacques, 2011 for a review). So-called false memories refer to the memory errors arising due to falsely recalling or recognizing a novel item, which is typically an associate of the previously presented items (Schacter et al., 2011). Deese-Roediger-McDermott (DRM) paradigm (Deese, 1959; Roediger & McDermott, 1995) is commonly utilized to induce false memories in a controlled experimental environment. In a typical DRM study, subjects are given a relatively large list of semantically related items to study (e.g., atom, molecule, neutron, nucleus, etc.). Later they are asked to remember the items that had been on the list. In the retrieval session, subjects might falsely recall a lure word, which is semantically related to the list (e.g., proton) but does not belong to the previously studied word list. This phenomenon remains consistent across a variety of tasks and situations (Roediger, 1996).

Recent studies have shown that false memories can be triggered in short time using short DRM lists containing a few (3–7) memory items (Atkins & Reuter-Lorenz, 2008; Coane, McBride, Raulerson, & Jordan, 2007). Although an fMRI study underlines the importance of left ventrolateral prefrontal cortex in semantic resolution (Atkins & Reuter-Lorenz, 2011), oscillatory neural mechanisms behind semantic resolution and false memory responses are still not clear and need thorough investigation.

Brain mapping techniques such as EEG with its capability of high temporal resolution could help further to track neural activity in order to elucidate the oscillatory mechanisms behind short-term memory and attention. In this study, we hypothesized that modulation of alpha activity plays a pivotal role for increased cognitive demands caused by semantic interference in working memory during stimulus free delay period of retention interval prior to the probe item. Moreover, failure to suppression the semantic interference would lead to false memories in short term. We conducted a modified Sternberg paradigm comprising semantically related and unrelated auditory items to test these hypotheses.

2. Material and methods

2.1. Participants

Twenty-five (Mean age: 22.6 ± 2.27, range: 19–28, 14 males) right-handed native Turkish speakers participated in the experiment. All subjects reported normal hearing and normal/corrected-to-normal vision. Formal education in psychology, history of neurological or psychiatric disorders and use of medication were accepted as criteria for exclusion from the experiment. Participants gave written informed consent prior to the beginning of the experiment. The local ethics committee of METU approved all experimental procedures.

2.2. Word-list preparation and auditory recording

Experimental stimuli were considered mainly in two aspects: semantic relations between the words (i.e., semantically related or semantically unrelated items) and the probe type (i.e., positive or negative). Please note that if the probe item were one of the words to be memorized, then we denote the stimulus as positive; otherwise it is accepted as negative.

Adaptation of the DRM lists to the Turkish language was actualized as follows. Lexical items were taken from the extended DRM lists provided by Roediger, Watson, McDermott, and Gallo (2001) and translated to Turkish. These items included frequently used concrete and abstract content words as adjectives, adverbs, nouns, and verbs. Backward associative strength (BAS) refers to a measure reflecting the association between studied words and lure words. BAS values for the words were acquired via a Turkish norm dictionary (Göz, 2005). The translated lists were further subdivided into 136 sets based on BAS values of words, i.e., these sets were subsets of the original DRM lists. A unique lure word for each set was determined from within the corresponding DRM list by considering the BAS values of the items. Each set comprised four words and the corresponding lure word (totally 680 words = 136 sets $\times$ 5 words).

Due to the cultural and linguistic differences in Turkish and English, we replaced 60 word items from the original DRM list with more appropriate words while keeping the BAS values at a similar level. For example, for the lure word 'baby', the corresponding item 'carriage' (that is translated as '*bebek arabasi*' in Turkish, meaning literally 'baby's car') was replaced with 'feeding bottle' ('*biberon*'), since the translated word contained the lure word itself.

Additionally, an internet-based questionnaire (number of participants 85, all native Turkish speakers) was pursued in order to balance the BAS values of the words. Participants were given one word from the set and were asked to write the first associative word that came to their minds. The resulted lists were compared to the translated ones and 72 incongruent items were replaced with better alternatives obtained through the questionnaire. All 680 words were vocalized by a female speaker in a soundproof room. Sampling rate of the recordings was 92 kHz. Recorded waveforms were separated into single words using the sound editor software Audacity®. The words (items) were all shorter than 1.2 s (mean length = 0.62 ± 0.14 s). Audio material was further downsampled offline to 44.1 kHz.

The sets were divided randomly into two groups of equal size. One group was labeled as semantically *related*. For the other half, items were mixed and drawn randomly such that words came from a different set. The resultant group was labeled as semantically *unrelated* one. Each group was further divided into two in order to form positive and negative probe groups. For the positive trials, the probe word was one of the items included within the four-word set; while for the negative ones, the probe word was a novel word (Fig. 1B). The lure word associated with the presented four words served as the target probe in negative trials of the semantically related list. Each group comprised 68 (34 positive + 34 negative probes) trials.

After the encoding of the memory items, an additional task involving a mathematical question was presented in order to increase cognitive load (Atkins & Reuter-Lorenz, 2008; DeStefano & LeFevre, 2004; Kalaman & Lefevre, 2007). Participants were to respond whether the displayed mathematical equation was true or false. Equations were composed of basic arithmetic operations – one addition/ subtraction and one division / multiplication of one-digit numbers such that the degree of difficulty was similar for all equations, i.e., $(a \pm b)/c = d$, or $(a \pm b) * c = d$. All equations were randomly generated. Half of the equations were made arithmetically "correct", while for the other half, the true result was altered by a random integer between 1 and 4 (additive or subtractive; see Fig. 1A for a sample equation).

2.3. Paradigm

A modified Sternberg paradigm (Sternberg, 1966) with auditory content was performed (Fig. 1A). Each trial started with a one-second pre-stimulus interval with a fixation cross displayed at the center of the monitor. Four words were delivered sequentially