

Emotional memory retrieval. rTMS stimulation on left DLPFC increases the positive memories

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Abstract A suggestive hypothesis proposed that the lateral prefrontal cortex (LPFC) may be identified as the site of emotion-memory integration, since it was shown to be sensitive to the encoding and retrieval of emotional content. In the present research we explored the role of the dorsolateral prefrontal cortex (DLPFC) in memory retrieval of positive vs. negative emotional stimuli. This effect was analyzed by using an rTMS paradigm that induced a cortical activation of the left DLPFC. Subjects were required to perform a task consisting of two experimental phases: an encoding phase, where some lists composed by positive and negative emotional words were presented to the subjects; a retrieval phase, where the old stimuli and the new stimuli were presented for a recognition performance. The rTMS stimulation was provided during the retrieval phase over the left DLPFC. We found that the rTMS stimulation over this area affects the memory retrieval of positive emotional material, with higher memory efficiency (reduced RTs). This result suggested that left DLPFC activation promotes the memory retrieval of emotional information. Secondly, the valence model of emotional cue processing may explain decreasing of RTs, by pointing out the distinct role the left hemisphere has in positive emotional cue processing.

Keywords Memory · Emotions · DLPFC · rTMS · Retrieval

Introduction

Several studies have indicated that the prefrontal cortex (PFC) plays a crucial role in integrating different aspects of the mind functioning. The PFC seems to be involved in cognition and memory and, secondly, in emotional regulation by managing the cognitive control over emotional stimuli and emotional behavior. Specifically, neuroimaging and transcranial magnetic stimulation (TMS) studies showed an involvement of the dorsolateral prefrontal cortex (DLPFC) during working memory (WM), with a specific role in manipulation tasks, and possible consequences on long-term memory (LTM) formation (Sandrini et al. 2003). About emotions, the prefrontal contribution was reported in many studies. In fact, models of the processing of emotional information suggested a network of interconnected neuro-anatomical regions including the amygdala, hippocampus, thalamus, and prefrontal cortex (PFC) (LeDoux et al. 1990; Davis 1992). It was found PFC governs the executive control of information processing and behavioral expression, including the ability to inhibit irrelevant stimuli and impulses, and evaluate and select the appropriate response (Knight et al. 1999; Miller and Cohen 2001). PFC could be crucial in mechanisms underlying the regulation of emotion, such as inhibition. Specifically a top-down control of PFC on the amygdala allows for a cognitive modulation of emotional processes by frontal brain structures (Hariri et al. 2000; Kalish and Robins 2006). However, some evidence suggests that multiple regions of the PFC have the capacity to perform multiple types of executive control functions (i.e. evaluate, maintain, inhibit, or select). In particular, evidence indicates that the orbitofrontal cortex (OFC) participates in the executive control of information processing and behavioral expression by inhibiting neural activity associated with irrelevant, unwanted, or uncomfortable (e.g. painful)

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information (Shimamura 2000). The lateral OFC, extending to the ventrolateral PFC, could facilitate successful goal-oriented behavior by inhibiting the influence of emotional information in the context of physical sensation, selective attention, and emotion regulation.

However, little research has examined whether and where emotion and memory could be integrated in the brain (Gray et al. 2002). A suggestive hypothesis proposed that the (LPFC) may be identified as the site of emotion-cognition integration, since it was shown to be particularly sensitive to the activation of memory and emotion (Gray et al. 2002). With regards to the specific brain area contribution during the memory task, neuroimaging studies showed an increased activation of the DLPFC during tasks requiring organization of information and the necessity to manage their relationships. This process of manipulation promotes the strengthening of inter-item association with a resulting enhancement of memory formation (Blumenfeld and Ranganath 2006). Some studies also showed a significant relationship between the DLPFC activation and the long-term memory performance (Blumenfeld and Ranganath 2006). However, other studies, although they showed an increased activation of DLPFC during the manipulation of the item, failed to find a correlation between this cortical area and memory performance (Davachi et al. 2001). Recent research using TMS provided new evidence around the involvement of prefrontal areas in memory processes (Manenti et al. 2010). An rTMS study showed the DLPFC implication in long-term memory, both in encoding and retrieval phase. Specifically, while in the encoding phase a bilateral involvement of the DLPFC was observed, only the right DLPFC involvement was reported during the retrieval phase (Sandrini et al. 2003). It was suggested that bilateral involvement of the DLPFC during the encoding phase may reflect the use of verbal and non-verbal strategies, localised respectively in the left and right DLPFC.

With regards to emotional memories, recent studies showed further implication of the DLPFC. More generally the PFC is assumed to be involved in emotional evaluation processes (Davidson and Irwin 1999). In fact, in an fMRI study, Gray et al. (2002) found that LPFC was the main cerebral region to be active in response to the interaction between memory task and emotional valence of the stimulus, predicting the subject's behavioral response. Nevertheless, there is little understanding around how prefrontal areas accomplish both emotional and memory functions (Balconi et al. 2010). In an fMRI study Dolcos et al. (2004), investigating the PFC role in emotional memories, concluded that the enhancing effect of emotion (specifically related to the emotional arousal) on memory formation is partly mediated by changes in PFC activity (left ventrolateral and dorsolateral PFC) and specifically may involve the amplification of working memory operations mediated by

lateral PFC regions. They also suggested that there is a specific way in which emotion can affect memory process, thought the strategic encoding processes supported by PFC. This mechanism implicates that there may be different memory routes for emotional and non emotional information. Recently, Mikles et al. (2008) suggested that there may exist distinct mechanisms for affective and non affective information maintenance and manipulation. Further studies showed that emotions may affect memory not only eliciting specific strategies during the encoding phase but also during the retrieval phase. A recent study that used a different version of the Stroop paradigm (implicating a memory task) revealed that the emotional reaction to the meaning of a taboo-word create a blinding mechanism that links the taboo-word to the contextual information. This link between the taboo-word and its context of occurrence seems to facilitate the recall of the word and of its related characteristics (Donald et al. 2004).

However, it remains to be explored the distinct contribution of left vs. right DLPFC, since significant evidence was reported in favor of right or left role in retrieving the emotional stimuli. In this regard, a promising and alternative theory called the “valence-model” explains the relationship between emotional information processing and hemispheric lateralization effect, supposing withdrawal-related emotions are located to the right hemisphere, whereas approach-related emotions are biased to the left hemisphere (Balconi et al. 2009; Balconi and Mazza 2010; Davidson et al. 1999). Thus, different effects of left/right DLPFC on memory retrieval may be due to the emotional valence of the stimuli and to distinct contribution the two hemispheres may have in manipulating such memories (Balconi and Mazza 2010). To elucidate these critical points, in the present research the effect of left DLPFC was tested by performing a memory task in which familiar (previously encoded) vs. novel (previously not encoded) positive or negative emotional information had to be recognized. Specifically, memory retrieval of emotional stimuli was used to verify the effect of the prefrontal network on retrieving emotional information. We first opted to analyze the contribution of the left side in comparison with right side by adopting the valence hypothesis and taking into account the underlying interhemispheric competition effect. In fact, the large contribution of the left hemisphere for positive emotions was previously verified (Balconi and Mazza 2010), whereas more heterogeneous and contrasting results were revealed for the right hemisphere, with regard to some negative, withdrawal emotions (such as anger) (Reuter-Lorenz et al. 1983). Secondly, we considered the left hemisphere contribution in emotional memories since LPFC was found to be the main cerebral region to be active in response to the interaction between memory task and emotional valence of the stimulus (Gray et al. 2002).

TMS activation paradigm applied on DLPFC was performed to analyze the contribution that this frontal region

gives on retrieval of emotional information. An activation TMS paradigm may be used to increase the cortical excitability of the left hemisphere in order to enhance the response to positive emotional cues and to guarantee a better retrieval process for these cues (Balconi and Mazza 2010; Balconi and Lucchiari 2005; Davidson et al. 1999). TMS method (high frequency, 5 Hz) was applied to induce an increased activation of the left (approach-emotion regulator) DLPFC. We tried to obtain a potentiation of the hemisphere reputed to restore the positive emotions, since high frequency electrical stimulation is known to induce long-term potentiation whereas low frequency stimulation is known to induce long-term depression (Miniussi et al. 2008). Whereas the long-lasting effects of this stimulation paradigm are actually not completely tested, a significant contingent potentiation/depotentiation was observed related to the high/low stimulation frequency (Balconi and Caldironi 2011), with significant effect on behavior. Thus, this paradigm may directly manipulate the causal relationships between the neural activity and the subject's performance (Miniussi et al. 2010).

We hypothesized that this effect was observable on both accuracy and RTs measures. Specifically, a significant effect is seen for RTs with a direct reflex on the time required to identify the stimuli (more efficient process) for the positive stimuli. The same effect was seen in terms of performance effectiveness of memory retrieval, that is an increased accuracy for the positive cues. Secondly, this effect is seen more for novel (unfamiliar) than old (familiar) stimuli, since it should be more relevant on information that generally require more effort to be elaborated (since unfamiliar), in which the attentional control appears to be more salient. In fact, more elaborate information processing during retrieval of not previously elaborated stimuli was required (Petersen et al. 1998). Thus the potentiation effect induced by TMS on the left hemisphere would be more proficient in those cases which need a higher cognitive demand, that is unfamiliar stimuli (Eysenck et al. 2005).

Materials and methods

Subjects

Sixteen females and 11 males (21–37 years) participated in the experiment. They were all right-handed and with normal or corrected-to-normal visual acuity. Exclusion criteria were history of depression (Beck Depression Inventory, score 1–10) for the subjects or immediate family. No payment was provided for their participation. They gave informed written consent for participating in the study and the research was approved by the Ethical Committee institution where the work was carried out. Before participating in the experimental session each subject was screened for suitability to receive TMS

stimulation. No contraindication was found for the selected participants (Rossi et al. 2009).

Stimulus material and procedure

Subjects were seated on a comfortable chair in front of a computer screen. The experimental paradigm consisted of an encoding phase and a retrieval phase. In the encoding phase participants were asked to memorize some word lists during a specific time window (90 s for each list) for a successive retrieval phase. The retrieval phase was administered right after the encoding phase ended (see Fig. 1 for the whole procedure). In the retrieval phase, words were randomly presented one by one for 6 s on the computer screen, and subjects were asked to decide whether they had viewed the word before. We requested that they press one of the two buttons of the mouse (the left bottom, if they recognize the word, the right one, if they do not recognize the word) as soon as possible after the presentation of the word on the screen. Response accuracy and response time (RT) were recorded by E-Prime 2.0 Software.

Two sets of material were used, the first for the encoding phase and the second for the retrieval phase. In the encoding phase each list was presented on the computer screen, counterbalanced across-subjects. Words were Italian nouns (from four to seven letters). Each word was Arial 16 p.t. black font upon a white background. All the words included were counterbalanced relative to the word length and their abstract vs. concrete contents.

For the encoding phase 9 lists were used, and each list was composed of 20 words, 10 of them were relative to a positive emotional content and 10 were relative to a negative emotional content. For the retrieval phase, stimulus material was composed by a total of 270 stimuli, subdivided into 9

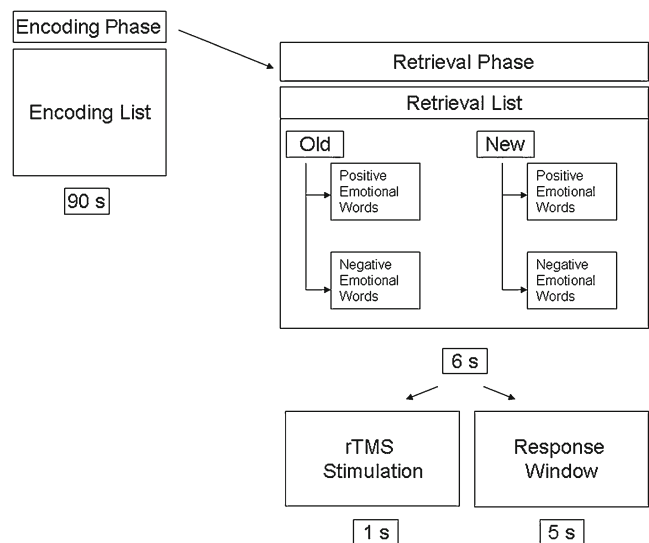


Fig. 1 Experimental procedure

lists. Each retrieval list was composed by 30 words grouped in the following categories: old (10 words contained in the encoding lists); new (20 words not contained in the encoding lists). Each category (old and new) was further divided into 2 equally distributed sub-groups: words with a negative emotional content; words with a positive emotional content.

Moreover the familiarity of the word content and the emotional valence were assessed for the whole stimulus material before the experimental task, by a group of 14 subjects (7 male, 7 female, mean age=26.7, SD=2.15). Familiarity was evaluated on a four-point Likert-scale: all the words included in the study obtained similar high familiarity rates (mean=3.60; SD=0.67). Words that obtained low familiarity rate were excluded from the database. Emotional content was also evaluated for each word used in the experimental task (“do you consider this word to have a positive/negative meaning?”) on a nine-point Likert-scale. Based on the emotional valence mean score of each word included in the study, the two word categories obtained the following scores for the valence: positive stimuli $M=8.6$; negative stimuli $M=8.8$. Thus each word category was correctly classified as a function of valence.

TMS stimulation

rTMS was delivered using a Magstim Super Rapid² magnetic simulator with a figure-of-eight coil (double wings of 70-mm diameter). The subjects were asked to wear a cap on which the positions of all the electrodes from the International 10/20 EEG system were reproduced (Jaspers 1958). We applied rTMS (5 Hz frequency) at 100 % of the motor threshold on left DLPFC (F3; BA9) immediately upon each retrieval word appearance.

The approximate location of the left DLPFC was automatically identified on the subject’s scalp using the SofTactic navigator system (BrainsightMagstim, SofTactic Optic 2.0), which uses a set of digitized skull landmarks (nasion, inion, and two preauricular points), and approximately 50 scalp points entered with a FastarackPolhemusdigiter system and an averaged stereotaxic MRI brain atlas in Talairach space (Talairach and Tournoux 1988). The average Talairach coordinates in the Softaxic navigator system were transformed through a linear transformation to each subject’s scalp. The Talairach coordinates of cortical sites underlying the coil locations were estimated on the basis of an MRI-constructed stereotaxic template (accuracy about 1 mm, Talairach space). This scan procedure suggested that TMS was applied over the DLPFC (Talairach -10,40,25 coordinates, middle frontal gyrus) (Fig. 2).

To control the effect of the rTMS stimulation we adopted two control conditions: the stimulation of a cortical control site (Cz) that is not supposed to be involved in memory processes, and a sham condition (no stimulation). During the sham condition the same intensity and timing of

stimulation was used but the coil was held in the way in which no magnetic stimulation reached the brain, since TMS coil was placed at a 45 ° angle to the head and the point of maximal activation was superficial compared with active stimulation. (George et al. 1997; Kimbrell et al. 1999; Wassermann et al. 1998). The subjective sensation of coil-scalp contact and discharge noise were similar to the real stimulation phase

Single pulse TMS was applied at increasing intensities to determine individual motor threshold by standard procedure (Rossini et al. 1994). Motor threshold was defined as the lowest TMS intensity capable of evoking a muscle twitch in the contralateral hand in 8/10 consecutive trials. In the retrieval phase, a train of 5 pulses at a frequency of 5 Hz was applied at the onset of each word, with an inter-train interval of 2 s over the left DLPFC or the control site (Cz Vertex). This resulted in a total number of 900 pulses per participant. On the contrary, no real stimulation was performed in the sham condition (for safety guideline see Rossi et al. 2009). Stimulation condition order was randomly assigned and counterbalanced and the entire sequence was sub-divided into four sub-sequences.

Data analysis

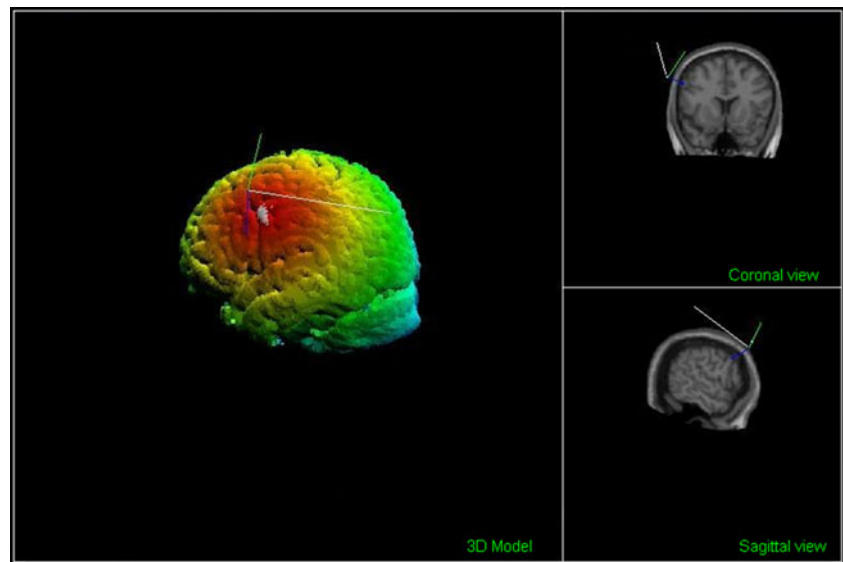
Two factorial repeated measures ANOVAs with three independent factors (EC, positive/negative emotional content; ON, old/new words; stimulation Condition, F3/control site/sham) were applied on the dependent measures of accuracy (total of correct response/total occurrence) and RTs. Type I errors associated with inhomogeneity of variance were controlled by decreasing the degrees of freedom using the Greenhouse-Geiser epsilon.

Results

Whereas no significant results were found for the main effects of Condition ($F(2, 26)=1.09$, $p=.12$; $\eta^2=.13$), ON ($F(1, 26)=1.11$, $p=.11$; $\eta^2=.11$), and EC ($F(1, 26)=1.22$, $p=.11$; $\eta^2=.14$), a significant interaction effect Condition x EC was observed ($F(2, 52)=6.12$, $p=.015$; $\eta^2=.42$). Specifically, as shown by the planned comparisons (contrast effects), RT values decreased (increased efficiency) in case of F3 stimulation for positive stimuli than negative stimuli ($F(1, 26)=4.13$, $p=.021$; $\eta^2=.36$). Moreover, a consistent reduction of RT was revealed for positive stimulus in the F3 stimulation condition compared to Cz ($F(1, 26)=4.09$, $p=.025$; $\eta^2=.32$) and sham ($F(1, 26)=4.98$, $p=.018$; $\eta^2=.37$) conditions. No other paired comparison was significant (all F value $p \geq .05$) (Fig. 3).

On the contrary, accuracy index did not show significant differences between the experimental conditions,

Fig. 2 Stimulation area (F3; BA9)



respectively for Condition ($F(2, 26)=1.01, p=.17; \eta^2=.10$), ON ($F(1, 26)=1.13, p=.14; \eta^2=.15$), and EC ($F(1, 26)=1.07, p=.15; \eta^2=.15$), and their two- and three-way interactions (all F value $p \geq .05$). Thus the same performance was observed for positive/negative stimuli and stimulation condition in response to old/new category (Fig. 4, Table 1).

Discussion

In the present research some main results may be reported. Firstly the contribution of left DLPFC in modulating the response to emotional memories was observed. Secondly, a significant TMS effect was revealed on left DLPFC for the positive stimuli in comparison with the negative stimuli. A possible familiarization effect was also tested, by comparing old/new stimulus category in retrieval task. A substantial analogous trend was shown for old and new categories in response to positive/negative emotional cues.

With respect to the cortical contribution, the present results allowed us to confirm a significant role by the frontal network in retrieving emotional memories. Specifically, we found a clear left DLPFC effect on the subjects' performance when F3 (presumably the middle frontal gyrus) was stimulated. Both RTs and Accuracy Index (AI) measures were considered. However, in this regard, only efficiency (RTs) and not effectiveness (AI) were shown to be affected by DLPFC stimulation.

The second main result was related to the valence effect. Based on the present experimental evidence, an increased facilitation to retrieve the positive emotional cues was confirmed by the reduction of the RTs, in case of left DLPFC stimulation. On the contrary, negative cue recognition was not influenced by the left frontal stimulation. The valence model of emotional processing may explain the reducing of

RT measure, by pointing out the distinct role the left hemisphere has in emotional cue elaboration. The specificity of the left hemisphere for positive-approach emotions was largely demonstrated and discussed in previous research (Balconi and Mazza 2010; Davidson 1995). In fact, neuroimaging, ERPs and EEG studies concluded in favor of the existence of two different frontal cortical networks, one reputed to process withdrawal, negative emotions (the right hemisphere) and one reputed to process approach, positive emotions (the left hemisphere) (Balconi and Pozzoli 2007; Balconi et al. 2009). A related conclusion about the valence effect can be reported, that is, when one of the two cortical systems, reputed to elaborate respectively the positive and negative emotional cues, is hyper-activated (rTMS potentiation effect), subjects had an unbalanced response to positive vs. negative cues, with a clear increase in memory performance for one of the two emotional categories (the positive one).

These conclusions are in line with previous results on clinical (such as panic disorder and PTSD) and sub-clinical samples (Heller and Nitschke 1998; Schutter et al. 2001; Van Honk et al. 1999). In fact, as expected by the valence model, left side high frequency stimulation (potentiation) should induce an increased responsiveness to positive stimuli as well as analogously a right side low frequency stimulation (depotentiation) should induce a reduced responsiveness to negative stimuli due to the “depressive” effect of on the right DLPFC. In parallel, an interesting study that has applied a low frequency TMS paradigm on frontal left hemisphere, that temporarily “inactivates” the left side and that introduces potential limitations to the positive stimulus processing, revealed an increased attention toward negative stimuli (d'Alfonso et al. 2000). Taken together, these studies confirmed the valence model of emotional cue elaboration, and the specificity of the left and right side in processing

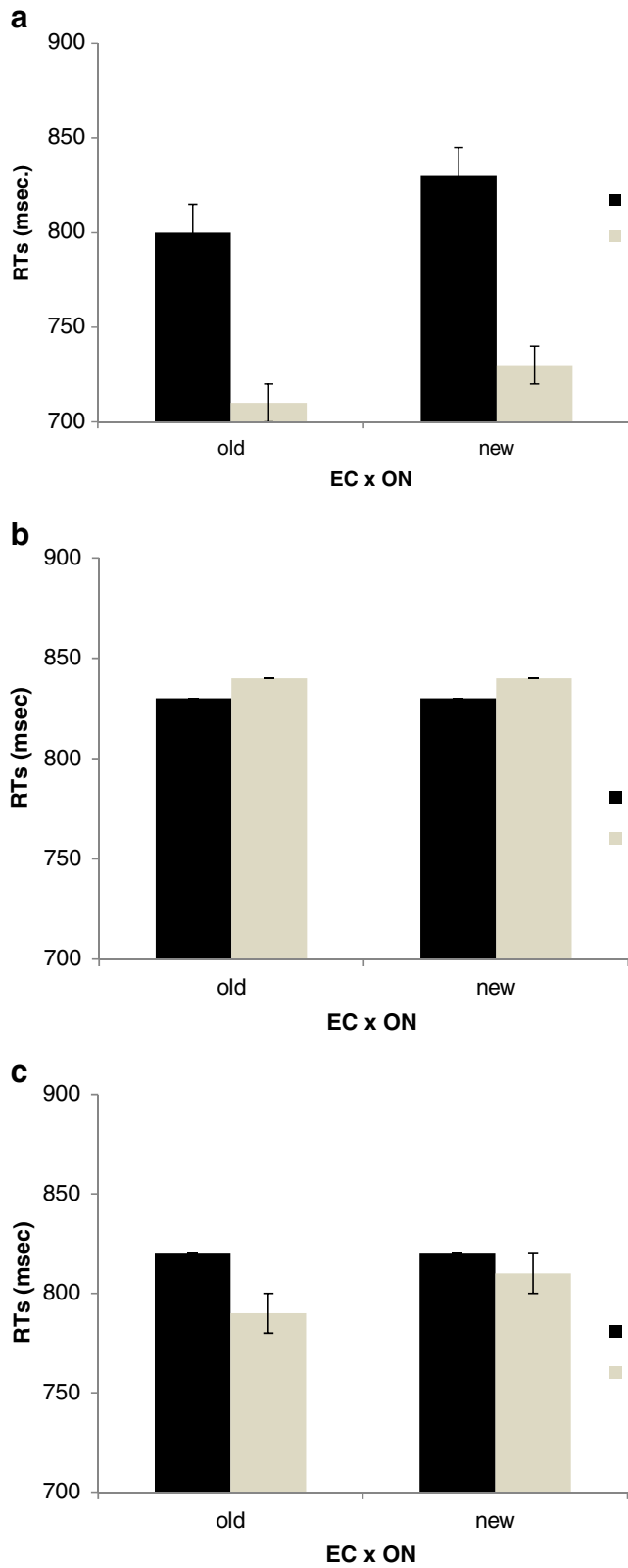


Fig. 3 RTs for old/new stimuli as a function of positive/negative stimuli for F3 (a), Cz (b), and sham (c) stimulation condition

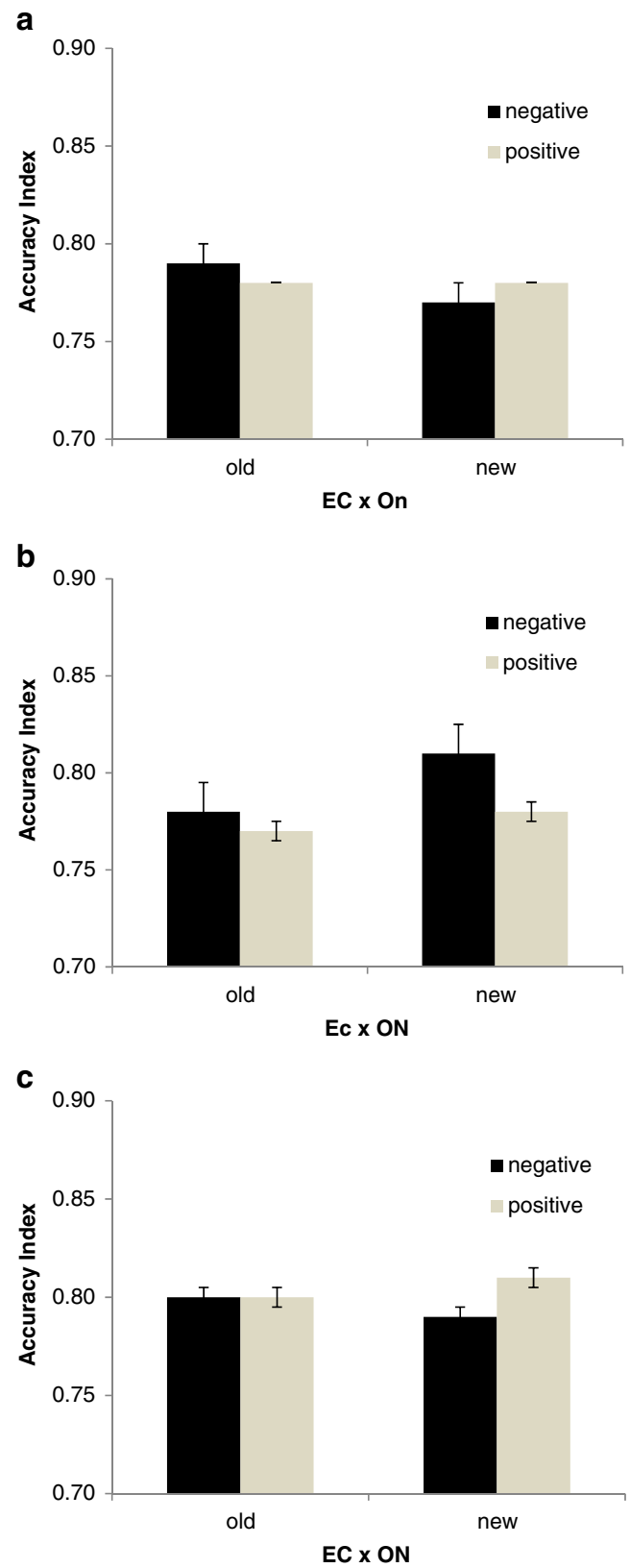


Fig. 4 Accuracy Index for old/new stimuli as a function of positive/negative stimuli for F3 (a), Cz (b), and sham (c) stimulation condition

Table 1 Mean accuracy index (AI) and response times (RTs, msec), as a function of stimulation and emotional valence for the old and new stimuli

F3	AI		RTs		AI		RTs	
	old				new			
	M	(SD)	M	(SD)	M	(SD)	M	(SD)
negative	0.79	0.31	800	0.32	0.77	0.31	830	0.39
positive	0.78	0.28	710	0.38	0.78	0.30	730	0.33
Cz (control)								
negative	0.78	0.27	830	0.24	0.81	0.27	830	0.24
positive	0.77	0.29	840	0.22	0.78	0.34	840	0.20
sham effect								
negative	0.80	0.31	820	0.30	0.79	0.23	820	0.30
positive	0.80	0.35	790	0.29	0.81	0.30	810	0.29

respectively positive and negative emotional cues and their complementary function.

More generally we suppose the central executive could be responsible for this higher efficiency in case of left DLPFC stimulation, with a consistent reduced delay in performing the task (Eysenck and Calvo 1992). Thus, one could hypothesize that a direct contribution by working memory may have induced a consistent “facilitation effect” in retrieving the positive cues. DLPFC activation could support this enhancement by the potentiation of the emotional memory formation and retrieval, as shown in previous studies which have applied fMRI (Dolcos et al. 2004), and that found amplification of working memory operations mediated by lateral PFC regions in case of emotional information.

However, in the present research the enhancement of the left activity produced an increased efficiency (reduced RT) of the cognitive system finalized to retrieve the emotional information but not an increased effectiveness (increased performance) in responding to positive emotional cues. We may suppose the stimulation effect may have been more relevant for the efficiency of the cognitive system in producing a correct response more than in an increase in the response correctness per se.

The effect due to stimulus familiarity, that we hypothesized would have a more significant impact on the left DLPFC activation for the new (unfamiliar) category, was not supported by the present results. Our previous supposition was based on the assumption that the left hemisphere potentiation induced by TMS would be more proficient in conditions which call for a higher cognitive demand, that is in the case of new stimulus processing. These suppositions were based on the account that the new stimulus category generally requires more effort to be elaborated (since unfamiliar). Thus the attentional control should be more relevant

for this category, and the unfamiliar new stimuli would be advantaged by the hyper-stimulation of the left cortical side.

However, we did not observe an increased benefit for retrieval of the new stimuli in response to the left side stimulation. A possible explanation for this unattended result could be related to the relative facility of the retrieval task, which showed a consistent good performance for all the subjects. This fact may have reduced in general the difference between the old/new categories, limiting at a minimum the effort related to the cognitive processing of the unfamiliar information.

Future research may elucidate some important questions that the present research has pointed out. Firstly, it is necessary to test whether the effect of the left DLPFC in response to positive stimuli was due mainly to the valence hypothesis (with an increased activation due to the approach attitudes) or to the main contribution of this frontal area to the memory retrieval mechanism. In other words the relevance of the left DLPFC for positive emotion processing and for memory retrieval, with specific reference to the working memory contribution, should be better explained. Secondly, the present study could be replicated by inducing a cortical perturbation of the right DLPFC by adopting an inhibitory paradigm. In fact, the increasing of memory performance on positive cues should be obtained also by reducing the cortical excitability of the right hemisphere, that was reputed to respond to aversive and potentially threatening information. Finally, the long-lasting effect of rTMS stimulation and its impact in terms of cortical potentiation/depression related to the facilitation/disruption response should be verified.

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