DLPFC implication in memory processing of affective information. A look on anxiety trait contribution

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Abstract

Recent studies suggested to approach to the analysis of the emotions and cognition from an integrating point of view rather than investigate the two constructs per se. In line with this research approach, the present study aims to investigate how emotions can affect memory processes and which cerebral areas are involved in this mechanism. We also aim to understand if and how this processing is influenced by specific personality traits, as anxiety trait. Using a rTMS measure, participants were asked to performance a memory task (a retrieval task) composed by verbal material with and without emotional content. Subjects were also assessed for their anxiety trait (high and low anxiety subjects). Our study provided a strong evidence for the influence of the emotional content and personality trait on the memory processes. Secondly, the role of the Left Dorso-Lateral Prefrontal Cortex in emotional memory was pointed out with a specific function of this frontal network in managing the emotional memories.

Keywords: Recognition memory; Emotional content; Anxiety trait; Dorso-Lateral Prefrontal Cortex, rTMS

1. Introduction

There is a general agreement on the role of the Prefrontal Cortex (PFC) in cognitive processes. In particular, the Dorso-Lateral Prefrontal Cortex (DLPFC) involvement was reveled in memory processes, where Working Memory was active (WM) (Goldman-Rakic, 1996). Ventral regions of the DLPFC seem to be involved in maintaining information in WM whereas more dorsal regions are involved in the selection and manipulation of information (D'Esposito, Postle, Ballard & Lease, 1999; Petrides, 2000). 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 the Long Term Memory (LTM) formation (Blumenfeld & Ranganath, 2006). Some studies showed also a significant relationship between the DLPFC activation and the long-term memory performance (Blumenfeld & Ranganath, 2006). However, other studies, although they showed an increased activation of DLPC during the manipulation of the item, failed to find a correlation between this cortical area and memory performance (Davachi, Maril & Wagner, 2001).

Recent studies using Transcranial Magnetic Stimulation (TMS) provided new evidences around the involvement of prefrontal areas in memory processes. A rTMS study showed the DLPFC implication in long-term memory processes, 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, Cappa, Rossi, Rossini & Miniussi, 2003). Sandrini and his colleagues 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. Moreover, another rTMS reported that there may be a specific differential implication of the right and the left DLPFC in the retrieval process of familiar and non familiar stimuli depending on the presence or the lack of memory strategies. Specifically, performing memory task subjects who used memory strategies showed an interference effect consequently to the rTMS stimulation of the right DLPFC. Indeed, subjects who did not use memory strategies showed an interference effect consequently to the rTMS stimulation of the left DLPFC (Manenti, Cotelli, Calabria, Maioli & Miniussi, 2010).

The PFC is also assumed to be involved in emotional evaluation processes (Davidson & Irwin, 1999). Nevertheless, there is little understanding around how prefrontal areas accomplish both emotional and cognitive functions (Balconi, Ferrari & Amenta, 2010). Dolcos and coll. (Dolcos, Labar & Cabeza, 2004) in a fMRI study investigating the PFC role in emotional memory, 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 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 Long-Term Memory LTM formation, thought the strategic encoding processes supported by PFC.

Further studies suggested 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) showed that the emotional reactions 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, Shafto, Taylor, Marian, Abrams & Dyer, 2004). This mechanism implicates that there may be different memory routes for emotional and non emotional information. Recently, Mikles and coll. (Mikles, Reuter-Lorenz, Beyer & Fredickson, 2008) suggested that there may exist distinct mechanisms for affective and non affective information maintenance and manipulation. The authors provided new evidences supporting the hypothesis of the existence of memory processes specialized for emotion. However, some authors concluded in favour of the fact that both classes of information relay on the same memory processes (Kensinger & Corkin, 2003; Perlstein, Elbert & Stenger, 2002).

The debate is still open and recently a new approach, that focuses on the interaction and integration of emotion and cognition, drew attention. A reduced number of research has examined whether and where emotion and cognition could be integrated in the brain (Gray, Braver & Raichle, 2002). A suggestive hypothesis proposed that the Later Prefrontal Cortex (LPFC) may be identified as the site of emotion-cognition integration, since it was showed to be particularly sensitive to the integration of memory and emotion (Gray et al., 2002). In fact, in a fMRI study, Gray 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 behavioural response. Furthermore, Drevets and Raichle (1998) supposed that the relationship between cognition and emotion is connected to a neural map located between limbic-paralimbic and neocortical regions.

1.1. Memory and anxiety

Besides the emotional contents of the information, memory processes may be also affected by anxiety component. Studies examining memory processes in anxiety have produced contrasting findings. On one hand, there are consistent evidences towards the existence of the influence of anxiety on implicit memory processes, while evidences towards an influence on the explicit memory processes are more controversial. At this regard, several studies failed to demonstrate an anxiety effect in explicit memory (Mathews & MacLeod, 1985; Mogg, Mathews & Weinman, 1987), whereas other studies, employing an implicit (word completion) and an explicit memory task (cued recall), found that explicit memory performance was correlated with trait anxiety (Mathews, Mogg, May & Eysenck, 1989). Eyesenk (1979) suggested that anxious subjects engage in more task-irrelevant cognitive processes than non-anxious subjects. To compensate for the detrimental consequences of such task-irrelevant activity, they increased the cognitive effort, affecting the WM activity. Impaired cognitive control over specific stimuli (for example, threat-related information) may have a key role in anxiety development. However some studies suggested that anxiety state, rather that anxiety trait, affects memory processes (Beuzen & Belzung, 1995).

From a neuropsychological approach, the functioning of the PFC is crucial to explain the relationship between anxiety and the cognitive/emotive performance. Neuroimaging studies showed that the PFC is strictly connected with the limbic regions and it is normally involved in the inhibition of the amygdala. In the absence of this normal inhibitory mechanism, the amygdala activity is uncontrolled and goes on to maintain the learned aversive responses. The left prefrontal areas seem to play an important role in this mechanism with possible consequences on anxiety disorder development (Davidson, 2002). Specifically, the dorso-lateral regions of the PFC are interconnected with paralimbic structures, such as the hippocampus and anterior cingulate (Goldman-Rakic, 1987; Morris, Pandya & Petrides, 1999), and they are connected with limbic regions though the Orbito-Frontal Cortex (OFC), the latter being involved in the DLPFC modulation (Hikosaka & Watanabe, 2000).

Moreover, several authors have suggested that different factors may contribute to alter the normal functioning of the PFC. For example, stressful conditions may interfere with the connection operations between regions that are implicated in emotion regulation (amygdale region) and that are critical for the cognitive and behaviour regulation (PFC region) (Perlstein et al., 2002).

It should be pointed out that only few studies investigated the impact of anxiety on memories emotion-related, and none of them has adopted a neurospychological approach. However, the present study aims to investigate the complex interaction between memory, emotion and anxiety variables, focusing on the contribution of specific cerebral regions in memory retrieval process. To examine the role of particular brain region we used repetitive Transcranial Magnetic Stimulation (rTMS) paradigm, that, thought the creation of a "virtual lesion", offers a unique opportunity to interact directly with the functioning of a cortical area during the execution of a specific task. Thus, this paradigm may directly manipulate the causal relationships between the neural activity and the subject's performance (Miniussi, Ruzzoli & Walsh, 2010). Based on our hypotheses, anxiety, and specifically anxiety trait, could affect memory performance in relationship with the emotional content of the stimuli compared with the non emotional content. Secondly, the DLPFC should have a crucial role in this process. Specifically, by using a rTMS stimulation paradigm, we induced a transient interference of the left DLPFC during the retrieval phase. We expect this stimulation may interfere with the memory functioning in different ways as a function of the high/low trait anxiety group and the emotional vs. nonemotional stimuli.

2. Methods

2.1. Subjects

Twenty eight healthy volunteers (17 females and 11 males) aged between 21-39 years (mean = 26.6 S.d. = 4.49) participated in the experiment after obtaining a written informed consent. All the participants were right-handed and Italian native speakers.

2.2. Materials

The stimulus material was composed by visual-verbal material (words). Each word was font Arial 16 p.t. bleu colour upon a white background. Two sets of material were used, the first for the encoding phase and the second for the retrieval phase. For the encoding phase the familiarity of the contents and 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, S.d. = 2.15). Familiarity was evaluated thought a four-points Likert-scale: all the words included in the study obtained similar high familiarity rates (mean = 3.65). Words that obtained low familiarity rate were excluded from the database. Emotional content was also evaluated for each word used in the experimental task on a four-points Likert-scale. All the words were divided in two categories: words with an emotional content (emotional, mean = 3.6) and words without an emotional content (neutral, mean = 1.8). Finally, the emotional valence was evaluated thought a nine-points Likert-scales, using the subscale of the emotional valence included into the Self-Assessment Manikin (SAM) (Lang, 1980). Based on the emotional valence mean score of each word included into the study, each list of words used in the study (in total nine final lists) obtained the following scores for the valence: list n. 1 = 2.2, list n. 2 = 2.8, list n. 3 = 2.9, list n. 4 = 6, list n. 5 = 5.7, list n. 6 = 5.3, list n. 7 = 5.6, list n. 8 = 4.6, list n. 9 = 4.3). Thus the nine lists were subdivided as a function of the degree of valence. Each study list was composed of 20 words, 10 of them were relative to an emotional content and 10 were neutral words. All the words included in the 9 word lists were counterbalanced relative to the word length and their abstract vs. concrete contents.

For the retrieval phase, stimulus material was composed by a total 270 stimuli, subdivided into 9 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).

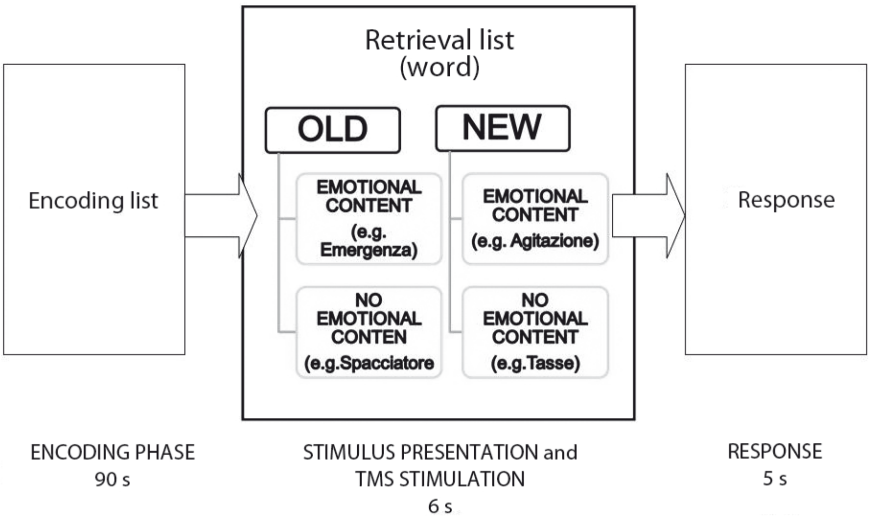
Each category was further divided in 2 equally distributed sub-groups:
- words with an emotional content (emotional words);
- words without an emotional content (neutral words).

2.3. Procedure

Subjects were sit on a comfortable chair in front of the pc screen. In the encoding-phase each learning list was presented for 90 seconds on a pc screen by E-Prima 2.0. Participants were asked to memorize the word list during this time window for a successive retrieval phase. The retrieval-phase was administered right after the encoding-phase ended (see Figure 1 for the whole procedure).

In the retrieval phase, each word was randomly presented one by one on a pc screen for 6 seconds, and subjects were asked to decide whether they had viewed the word before. They were requested to 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 Software.

Figure 1. Experimental procedure



After the experimental phase subjects were asked to answer the State-Trait Anxiety Inventory (STAI) (Spielberger, Gorsuch & Lushene, 1970). It is a self-report assessment composed by 40 items where the subject is required to evaluate how he feels about common daily situations, on a four-point Likert-scale. The STAI differentiates between the temporary condition of "state anxiety" (S-Anxiety subscale, 20 items) and the more general and long-standing quality of "trait anxiety" (T-Anxiety subscale, 20 items), and provides two different total scores, related to the two subscales. STAIs were scored using norms from the *Manual for State-Trait Anxiety Inventory* (Spielberger et al., 1970). Based on the STAI total scores we distinguished 2 groups referring to trait anxiety: high trait anxiety group and low trait anxiety group.

2.4. rTMS stimulation

rTMS was delivered using a Magstim Super Rapid$_2$ 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 (5Hz frequency) at 100% of the motor threshold on left DLPFC (F3; BA9) immediately upon each retrieval-word appearance. 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 (non 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. 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, 1994). Motor threshold was defined as the lowest TMS intensity capable of evoking a muscle twitch in the controlateral hand in 8/10 consecutive trials. All subjects received 90 trains of rTMS over the left DLPFC (F3; BA9), 90 trains of rTMS over the control site (CZ; Vertex) and 90 trains of rTMS in the sham phase. Stimulation condition order was randomly assigned and counterbalanced.

3. Data analysis

Two factorial repeated measures ANOVAs with four independent factors (Condition, F3, control site, sham; old/new (ON), old/new words; emotional content (EC), emotional/neutral words; trait anxiety, low/high anxiety subjects) were applied on the dependent measures of accuracy and RT. Type I errors associated with inhomogeneity of variance were controlled by decreasing the degrees of freedom using the Greenhouse-Geiser epsilon.

3.1. RT data

A main significant effect of ON was found ($F(1, 27) = 33.468$, $p = .000$): subjects showed longer RT for old words compared with new words. Furthermore, a main effect of EC was significant to the analysis: subjects recognized the emotional words slower than the neutral words. We also observed a main effect for the anxiety trait ($F(1, 27) = 5.34$, $p = .029$): subjects with higher trait anxiety trait showed longer RT in comparison with the subjects who obtained lower trait anxiety scores (Table 1).

Table 1. Response Time (RT)

High anxiety												
C*1	F3				CZ				SHAM			
ON*2	OLD		NEW		OLD		NEW		OLD		NEW	
EC*3	E*4	N-E*5	E	N-E	E	N-E	E	N-E	E	N-E	E	N-E
Mean	1544 (S.d. = 78)	1471 (S.d. = 69)	1380 (S.d. = 85)	1414 (S.d. = 92)	1542 (S.d. = 86)	1441 (S.d. = 69)	1389 (S.d. = 65)	1355 (S.d. = 63)	1550 (S.d. = 87)	1506 (S.d. = 79)	1387 (S.d. = 86)	1337 (S.d. = 78)
Low anxiety												
C	F3				CZ				SHAM			
ON	OLD		NEW		OLD		NEW		OLD		NEW	
EC	E	N-E	E	N-E	EC	N-E	E	N-E	E	N-E	E	N-E
Mean	1381 (S.d. = 97)	1285 (S.d. = 85)	1318 (S.d. = 97)	1285 (S.d. = 85)	1414 (S.d. = 107)	1279 (S.d. = 86)	1139 (S.d. = 81)	1014 (S.d. = 78)	1322 (S.d. = 108)	1268 (S.d. = 99)	1129 (S.d. = 107)	1100 (S.d. = 97)

C*1: Condition.
ON*2: Old/New.
EC*3: Emotional Content.
E*4: Emotional.
N-E*5: Non Emotional Content.

Table 2. Accuracy Index (AI)

High anxiety												
C*[1]	F				CZ				SHAM			
ON*[2]	OLD		NEW		OLD		NEW		OLD		NEW	
EC*[3]	E*[4]	N-E*[5]	EC	N-E	E	N-E	E	N-E	E	N-E	E	N-E
Mean	.715 (S.d. = .038)	.740 (S.d. = .061)	.943 (S.d. = .022)	.908 S.d. = .025)	.701 (S.d. = .041)	.772 (S.d. = .044)	.957 (S.d. = .017)	.941 (S.d. = .016)	.762 (S.d. = .041)	.808 (S.d. = .045)	.957 (S.d. = .018)	.957 (S.d. = .015)
Low anxiety												
C	F[3]				CZ				SHAM			
ON	OLD		NEW		OLD		NEW		OLD		NEW	
EC	E	N-E	E	N-E	E	N-E	E	N-E	E	N-E	E	N-E
Mean	.473 (S.d. = .047)	.592 (S.d. = 076)	.961 (S.d. = .027)	.966 (S.d. = .031)	.692 (S.d. = .051)	.607 (S.d. = .054)	.964 (S.d. = .021)	.976 (S.d. = 020)	.587 (S.d. = .051)	.552 (S.d. = .056)	.961 (S.d. = .027)	.946 (S.d. = .019)

C*[1]: Condition.
ON*[2]: Old/New.
EC*[3]: Emotional Content.
E*[4]: Emotional content.
N-E*[5]: Non Emotional content.

3.2. Accuracy Index (AI)

We observed a significant main effect of ON ($F(1, 27) = 90.50$, $p = .000$), since subjects showed higher accuracy for new in comparison with old words. We also observed a significant main effect of anxiety trait ($F(1, 27) = 7.01$, $p = .014$). Subjects with higher levels of anxiety trait showed a better accuracy in comparison with the subjects who obtained low levels of anxiety.

Moreover, an interaction effect condition × EC × STAI was observed ($F(2, 54) = 3.67$, $p = .032$). Specifically, subjects with low anxiety levels and high anxiety levels differed about the accuracy performance during F3 and control site stimulation condition. In particular, low anxiety subject showed a worse performance during the F3 stimulation compared to the control-site stimulation for the emotional words. Contrarily, high anxiety subjects did not show these statistical differences (Table 2).

4. Discussion

The aim of the present study was to investigate the interactive effect of two main variables, the emotional content and anxiety trait on memory processes. Secondly, we focused on the specific role of some cerebral areas involved in managing these effects. Before our investigation, only few studies tried to understand how a personality trait, as anxiety trait, and emotional content of the stimuli, may interact and affect human memory. In addition none of these studies approached the topic from a neuropsychological point of view. Even if our results cannot provide a comprehensive explicative hypothesis about the functioning of the emotional memory in anxiety, we think that the findings can furnish interesting insights on this complex issue and they can provide new ideas for further researches. It's worthy to note that the two effects we investigated varied in significant measure at the statistical analysis, suggesting that both anxiety trait and emotional content can affect memory processes per se and through their interaction. The following discussion will elucidate the main significant points found in the present study, by underling the role of these variables. Finally, the conclusive remarks will be focalized on the specific DLPFC role for the emotional memories as a function of anxiety trait.

4.1. Emotional vs. non emotional content effect on memories

The first result of the present research we considered is the memory performance for emotional and non emotional (neutral) stimuli, with increased RTs for emotional vs. neutral stimuli. The fact that subjects took longer time to answer to stimuli with an emotional content in comparison with the stimuli without an emotional content suggests in primis that emotional material may be more complex to be recalled. However, in literature, investigations usually reported that words with and emotional valence are easier to remember when compared to neutral words, because of the effect they elicited during the encoding phase (for example as a function of the arousal): in memory tasks, it was found the memory rates are higher for items with an emotional valence or higher arousal than neutral words (Kensinger & Corkin, 2003). Also taboo words, that were able to elicit an arousing responses, are reported to have a similar trend. A study using a revised version of the Stroop Paradigm, in which a surprise effect memory test was included, found a better recall for taboo words compared to neutral words (Dolcos et al., 2004).

Nevertheless, it is important to underline that findings reporting the enhancement effect on the memory processes due to the emotional material usually refer to stimuli with specific emotional valence (negative/positive) and at the same time with high level of arousal. In the present study we used words with an emotional content, but which may vary in terms of their arousing power. Thus the comparability of the empirical results with some other studies is doubtable and no conclusive remarks may be adduced without a clear dissociation between valence and arousal feature. Furthermore, some authors proposed that, in certain case, the enhancement of the retrieval process by the emotional material is not due to their valence connotation per se. On the contrary, emotionally valenced words should have stronger inter-item associations than sets of unselected neutral words. This inter-item associations could facilitate the memory process of the related items in comparison with the un-related items. However, other studies showed that the presence of these associations generally produces higher false alarm rates than unrelated items (Maratos, Allan & Rugg, 2000). The evidences from these studies are in line with our results: even if we did not find significant difference in the accuracy index, longer RTs for emotional words could suggest that the recognition of related information requires a higher cognitive effort. We can also hypothesize the existence of an interaction effect of these two phenomena: the recognition of related-item may require longer to be accomplished but the retrieval success (accuracy rate) may not be affected by this variable.

4.2. "Old" vs. "new" information processing

Furthermore, independently by the emotional content of the words, the recognition process of stimuli previously encoded (old) appears to be longer than the recognition of material not presented before (new). In support of this result, we can hypothesize that longer RTs may be linked to the monitoring mechanism, a process that allows people to evaluate the relevance of retrieved information in relation to the task requirements. In episodic memory, monitoring mechanism takes part in a later phase after the retrieval process (for this reasons it is describes as a post-retrieval monitoring mechanism) (Achim & Lepage, 2005). This integrative processing would operate on the cognitive products of the retrieval phase, finalized to integrate the memory processing with the aim to accomplish the behavioural task requirements. Indeed, in memory recognition tests, in which subjects are required to distinguish between old items and new items, old items are more likely to trigger post-retrieval monitoring than new items, with general better performances (higher rate) than new items (Achim & Lepage, 2005). This post monitoring mechanism specific for old stimuli may be accounted for longer RTs. However, the debate on this issue is still open, since many studies failed to report longer RTs relative to old words (Van Petten & Senkfor, 1996), whereas other studies reported that old words elicit shorter RTs compared to new words (Johnson, Pfeffrbaum & Kopell, 1985).

4.3. Anxiety trait and memory retrieval

The construct of cognitive control seems to be crucial to explain the difference we have found in memory performance between subjects with low and high anxiety. Subjects with high level of anxiety showed higher accuracy rate but longer RTs in comparison with subjects with low level of anxiety in memory retrieval. Firstly subjects with high anxiety level could have a better performance in response to material to be memorized in consequence to their sustained and accurate behavioural monitoring of the external signals (Eysenck, Derakshan, Santos & Calvo, 2007). Nevertheless, they need more time to process information probably because they have to cope with some interference effect (McNally, English & Lipke, 1993). Even if we cannot generalize this clinical phenomenon to a non clinical sample, we can hypothesize that anxiety trait may affect the memory processes with the same mechanism in which also clinical anxiety affects memory. Several studies using various paradigms reported the in anxious subjects attention is captured in excessive way by emotional information, with a possible interference effect.

ERP studies confirm that anxious individuals selectively attend and deploy more processing resources to emotional (threatening) information (Aftanas, Pavlov, Reva & Varlamov, 1996), and this mechanism may cause possible consequences on the subsequent performance (Engels, Heller, Mohanty & Miller, 2007). More generally, subjects with high anxiety trait may be able to control the interference of emotional material, increasing the cognitive effort (longer RTs). Some authors, in fact, suggested that anxiety may not impair performance effectiveness (quality of performance) when it leads to the use of compensatory strategies. In other words the process would be represented as: enhanced effort increased use of processing resources (Eysenck et al., 2007). In line with the evidence from Eysenck and coll. (2007) we hypothesized that cognitive iper-control allows anxious subjects to obtain better accuracy outcome.

4.4. DLPFC contribution

This cognitive iper-control showed by high anxiety trait subjects could be reported to explain also how the same cerebral area can affect in different ways the memory process in case of its activation or deactivation. Our results showed that left DLPFC apparently affects the memory processing of emotional stimuli only in low anxiety subjects, because only this type of subjects showed a different performance during the inhibition of this area compared with the control stimulation phase. Nevertheless, evidently we do not think that DLPFC is involved in emotional memory only for low anxiety trait subjects. Contrarily we retain that when there is an interference (deactivation) of this area (as in a condition of a rTMS stimulation) only the high anxiety subjects were able to compensate this DLPFC deactivation with the cognitive iper-control that developed for managing the emotional stimuli. Thus this integrative process may help them to limit the transitory disfunction of the prefrontal area, with no consequences on their accuracy performance. Instead, low anxiety subjects were not able to compensate the disfunctional activation of the left DLPFC with a consequent worse accuracy performance during the memory task.

Finally, about the lateralization effect, the present finding showed that left DLPFC is involved in the processing of emotional information rather than non emotional information. The most of the studies agree to report a link between the left DLPFC and the processing of positive emotional material (Engels et al., 2007) while the right DLPFC is generally reported to be involved in the processing of negative information (Borod, Andelman, Obler, Tweedy & Welkowitz, 1992; Silberman & Weingartner, 1986). Some

ERP studies reported how frontal zones showed a differential lateralization for positive and negative emotion with left-hemispheric activation for positive emotions and right-hemispheric activation for negative emotions (Ahern & Schwartz, 1985; Balconi & Mazza, 2009). Furthermore, another significant variable should be taken into consideration, that is the verbal/spatial effect related to cerebral hemispheric specialization: in verbal task, activation seems to be more localized on the left than the right hemisphere, whereas in spatial task an activation of both the hemispheres or of the right hemisphere only was reported (Smith, Jonides & Koeppe, 1996). Since the present study used verbal material we can suppose that verbal effect may account for the specific involvement of the left DLPFC.

In conclusion, our study provided a strong evidence for the role of the DLPFC in emotional memory and suggests its specific function in managing the emotional memories. However, futures studies will be required to further investigate the emotional memory process and the cerebral area involved with specific reference to the lateralization effect, from one side, and to distinguish the important differences between the retrieval phase and the encoding phase of this memory process.

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