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Resting lateralized activity predicts the cortical response and appraisal of emotions: an fNIRS study

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This study explored the effect of lateralized left–right resting brain activity on prefrontal cortical responsiveness to emotional cues and on the explicit appraisal (stimulus evaluation) of emotions based on their valence. Indeed subjective responses to different emotional stimuli should be predicted by brain resting activity and should be lateralized and valence-related (positive *vs* negative valence). A hemodynamic measure was considered (functional near-infrared spectroscopy). Indeed hemodynamic resting activity and brain response to emotional cues were registered when subjects ($N = 19$) viewed emotional positive *vs* negative stimuli (IAPS). Lateralized index response during resting state, LI (lateralized index) during emotional processing and self-assessment manikin rating were considered. Regression analysis showed the significant predictive effect of resting activity (more left or right lateralized) on both brain response and appraisal of emotional cues based on stimuli valence. Moreover, significant effects were found as a function of valence (more right response to negative stimuli; more left response to positive stimuli) during emotion processing. Therefore, resting state may be considered a predictive marker of the successive cortical responsiveness to emotions. The significance of resting condition for emotional behavior was discussed.

Keywords: resting state; emotion; fNIRS; valence; lateralization

INTRODUCTION

Recent research has revealed that the processing of emotional visual stimuli leads to increased activation of various cortical areas, including the amygdala, the medial prefrontal cortex (PFC) and the dorsolateral prefrontal cortex (Davis and Whalen, 2001; Pessoa *et al.*, 2002; Phan *et al.*, 2002). Although other cortical sites were found to be relevant in emotional cue processing, in this research we focused on the prefrontal area to test the direct effect of PFC and resting state in visual emotional cue comprehension. Indeed more recent studies have identified the PFC as a key region in the experience and regulation of emotional responses, based on the lateralization effect (Damasio, 1996; Davidson, 2002; Ochsner and Gross, 2005; Balconi *et al.*, 2011; Balconi and Bortolotti, 2012). In addition, recent results suggested a significant and specific lateralization effect of PFC activation, based on the positive (more directly processed by the left hemisphere) and the negative (more directly processed by the right hemisphere) valences of emotions (Everhart *et al.*, 2003; Balconi and Mazza, 2010). The valence model supposes that cortical differences between the two hemispheres are attributable to positive *vs* negative valence of emotions (Silberman and Weingartner, 1986; Everhart *et al.*, 2003; Russell, 2003). Based on the valence model, the right hemisphere is specialized for negative emotions and the left hemisphere for positive emotions. However, some other perspectives suggested a dichotomy on approach/avoidance attitude to emotions, the first more frontal left-related and the second more frontal right-related (Davidson, 1995; Harmon-Jones, 2003; Balconi and Mazza, 2009). Based on the approach–withdrawal model of emotion regulation, the emotional behavior should be associated with a balance of activity in the left and right frontal brain areas that can be explained in an asymmetry measurement (Harmon-Jones and Allen, 1997; Sutton and Davidson, 2000). Resting frontal asymmetry, mainly measured by electroencephalography (EEG), has been hypothesized to relate to appetitive (approach-related) and positive and aversive (withdrawal-related) or negative motivation, with heightened approach tendencies reflected in left-frontal activity and heightened withdrawal tendencies reflected in relative right-frontal activity (Balconi and Pozzoli, 2003; Balconi and Lucchiari, 2007; Stewart *et al.*, 2014).

In addition, according to the asymmetry hypothesis, the left/right asymmetry of the PFC activity is correlated with specific emotional responses to stressors and personality traits (Davidson *et al.*, 2000; Canli *et al.*, 2001; Fischer *et al.*, 2002). Indeed, EEG has demonstrated that subjects with greater relative left PFC activity exhibited more positive and less negative dispositional mood (Tomarken *et al.*, 1992) than their right-dominant counterparts. In contrast, right frontally activated subjects responded more to negative affective challenges and less to positive affective challenges than their left dominant counterparts (Wheeler *et al.*, 1993). Two main models were adopted to explain stable subjective asymmetries in brain activity within the frontal areas: the dispositional model of frontal affective style, which postulates that people possess a general tendency to respond predominantly with either an approach or withdrawal behavior despite the situational differences (Davidson, 1998; Balconi and Mazza, 2010); and the situational model, such as the capability model, which postulates that individual differences are better represented as interactions between the emotional demands of specific situations and the emotion-monitoring abilities individuals use to respond to those situations (Wallace, 1966; Lilienfeld *et al.*, 2000; Coan *et al.*, 2006). Moreover, Harmon-Jones (2004) has argued that we may integrate the valence/approach models to include both motivational and valence components. Through the development and tests of competing hypotheses, Harmon-Jones *et al.* (2004) have pursued the goal of specifying more precisely what the emotional and motivational functions of asymmetrical frontal brain activity might be. They have identified a valence model of brain asymmetry in which high levels of relative left frontal activity are associated with the expression and experience of positive emotions and high levels of relative right frontal activity are associated with the experience and expression of negative emotions. In addition, they identified a motivational direction model in which high levels of relative left frontal activity are associated with the expression of approach-related emotions and high levels of relative right frontal activity

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are associated with the expression of withdrawal-related emotions. Although positive emotions are typically associated with motivations to approach and negative emotions are typically associated with motivations to withdraw, there are notable exceptions (for example anger-out) (Amodio and Harmon-Jones, 2012; Harmon-Jones and van Honk, 2012). In fact, whereas some negative emotional expressions, such as anger and sadness, are generated by negative, aversive situations, these emotions may introduce some differences in subjective response as a function of how people appraise their ability to cope with the aversive situation (Frijda, 1993; Hewig *et al.*, 2004).

Resting activity may contribute to assess the relevance of these models, defining the role of personality in affective behavior, as a predictive marker of the left- or right-asymmetry in specific emotion processing. Indeed, it was observed that spontaneous brain activity (explored by blood oxygen level dependent) was not just random noise, but was specifically organized in the resting human brain (for a review see Fox and Raichle, 2007). However, the role of resting activity in emotional responsiveness was explored only partially. Second, the impact of this resting activity for a successive lateralized response to emotional tasks was scarcely considered. No previous study has considered the direct relationship between resting activity within the left and right PFC and the brain response to emotional cues, also taking into account the explicit subjective evaluation of the significance (in term of valence and arousal appraisal) of the emotional cues.

In addition, neither the classical imaging (with fMRI) nor the electrophysiological measure seems to completely describe the depth of emotional context. Indeed, a methodological issue should be considered. Although studies have provided functional images of activated areas of the brain associated with emotional tasks, they have seldom addressed the temporal course of the activation. Due to its fast temporal evolution and its representation and integration among complex, widespread neural networks, emotion perception, together with its neurobiological correlates, should preferably be examined by means of imaging methods that offer good resolution in both temporal and spatial domains.

Among the different modalities available for monitoring brain activity, near-infrared spectroscopy (NIRS) is non-invasive and particularly well suited for evaluating PFC activity, one of the regions involved in emotional processing. Temporal resolution of NIRS is high enough for measuring event-related hemodynamic responses. In addition, some specific areas more directly related to emotional processing, i.e. the frontopolar cortex and the anterior lateral PFC are easily accessible for measurements by NIRS. For the reasons reported above, NIRS is particularly suited to explore the emotional domain. Interestingly, recent studies using NIRS investigating the neural correlates of emotion regulation processes also described an activation of the PFC (Hongyu *et al.*, 2007; Hermann *et al.*, 2008; Balconi *et al.*, 2015). Moreover, measurement of NIRS and EEG in a resting condition demonstrated that an increase of oxy-hemoglobin (O2Hb) was associated with an increase of neuronal activity whereas a decrease of O2Hb was associated with a decrease of neuronal activity (Hoshi *et al.*, 1998; Butti *et al.*, 2006).

In this study, we hypothesized that asymmetry of NIRS-measured O2Hb changes at rest in the PFC may predict emotional response to an experimental condition in which the subjects have to detect emotional cues. Namely, resting activity might have a predictive value for the successive subject's activity in response to emotional stimuli. Higher left activity at rest should be related to increased left activity in the experimental condition, whereas higher right activity should be related to increased right activity in the experimental condition.

Moreover, a specific valence effect should be found in the experimental condition. Based on the approach/withdrawal model of emotions (Russell, 2003), a significant and consistent higher prefrontal left activation was anticipated for positive emotional stimuli, whereas a consistent higher prefrontal right activation was expected in response to negative stimuli (Balconi and Mazza, 2010).

Taking these suppositions together, related to resting and valence effects, they may support the fact that subjective responsiveness to different stimulus categories should be predicted by resting activity and should be valence related. Therefore, we expected that a higher left resting activity will support a higher cortical responsiveness within the left hemisphere for the positive stimuli. In contrast, a higher right resting activity will support a higher responsiveness within the right hemisphere for the negative stimuli.

These two resting and experimental measures were then related to the explicit self-report correlates, that is the subjective appraisal in terms of valence (positive *vs* negative) by using self-assessment manikin (SAM; Russell, 1980; Bradley and Lang, 1994; Cuthbert et al., 2000; Balconi and Pozzoli, 2009; Balconi and Mazza, 2010;). Thus, in addition to the relationship between resting and experimental cortical responsiveness, brain activity at rest should predict the subjects' explicit appraisal of the emotional cues that is a specific polarization of the SAM rating based on the higher left/right resting activity is expected.

METHODS

Participants

Nineteen subjects, 11 females and eight males (M age = 29.61; SD = 5.38; range = 23–47) participated in the experiment. All subjects were right-handed, with normal or corrected-to-normal visual acuity. Exclusion criteria were neurological or psychiatric pathologies based on responses to Beck Depression Inventory (BDI-II; Beck *et al.*, 1996), for the subjects or immediate family. Also, the absence of documented head injury was considered based on the subjects' clinical history. They provided informed written consent for participating in the study and the research was approved by the Ethical Committee institution where the work was carried out. The experiment was conducted in accordance with the Declaration of Helsinki and all the procedures were carried out with adequate understanding from the subjects, who read and signed the Research Consent Form before participating in this research. No payment was provided for their participation.

Stimuli and SAM

One hundred stimuli were chosen from the International Affective Picture System (IAPS) (Bradley and Lang, 2007), depicting 40 pleasant and 40 unpleasant pictures (20 low and 20 high arousing, each), and 20 neutral stimuli, previously validated on valence and arousal ratings (Balconi *et al.*, 2009). IAPS subjective ratings were obtained with the SAM scale, using an easier adapted 5-point version (Bradley and Lang, 1994, 2007). SAM is a non-verbal pictorial assessment technique that directly (using an analogical scale showing a manikin) measures the pleasure, arousal and dominance associated with a person's affective reaction to a wide variety of emotional stimuli. IAPS-selected stimuli numbers were chosen from a total of over 900 stimuli: (i) pleasant and low arousal; (ii) pleasant and high arousal; (iii) unpleasant and low arousal; (iv) unpleasant and high arousal; (v) neutral (Table 1). Based on IAPS dataset, the selected positive stimuli were classified as more positive than the negative stimuli; the high arousal stimuli were classified as more arousing than low arousal stimuli. However, the positive high arousal and the negative high arousal stimuli did not differ in terms of arousal level (high for both of them). Similarly, the positive low arousal and the negative low arousal did not differ in terms of arousal level (low for both of them).

After the experimental phase, subjects had time to rate their emotional experience on SAM evaluating valence and arousal on a bipolar scale applied to each picture (Bradley and Lang, 1994).

Procedure

A total of 180 s resting baseline was registered at the beginning of the experiment before the picture series. We used this period as baseline for the successive analysis. Participants performed resting eyes-closed baseline periods. Each participant was instructed to relax and allow the mind to disengage during these periods. Participants were seated in a dimly lit room, facing a computer monitor that was placed 70 cm from the subject. The stimuli were presented using STIM software (Stim^2, Compumedics Neuroscan, Charlotte, NC, USA) running on a personal computer with a 15-in. screen. Participants were required to observe each stimulus during functional NIRS (fNIRS) recording, and they were asked to attend to the images during the entire time of exposition. Pictures were presented in a random order in the center of a computer monitor for 6 s, with an inter-stimulus interval of 12 s. A familiarization phase was conducted, where subjects saw and rated five pictures (one for each emotional category), different from those used in the experimental phase (Figure 1).

Functional near-infrared spectroscopy

fNIRS measurements were conducted with the NIRScout System (NIRx Medical Technologies, LLC. Los Angeles, CA) using a 6-channel array of optodes (four light sources/emitters and four detectors) covering the prefrontal area. Emitters were placed on positions AF3–AF4 and F5–F6, while detectors were placed on AFF1–AFF2 and F3–F4. Emitter-detector distance was 30 mm for contiguous optodes and near-infrared light of two wavelengths (760 and 850 nm) was used. NIRS optodes were attached to the subject's head using a NIRS-EEG compatible cup, with respect to the international 10/5 system (Oostenveld and Praamstra, 2001).

Table 1 IAPS-selected stimuli numbers

		Pleasant	Unpleasant
Affective	Low arousal	1604, 1610, 1620, 1670, 1812, 2304, 2360, 2370, 2388, 2501, 2530, 5010, 5201, 5551, 5631, 5760, 5779, 5811, 7325, 7340	2206, 2312, 2399, 2490, 2491, 2520, 2590, 2722, 6010, 7054, 9000, 9001, 9045, 9090, 9110, 9220, 9330, 9331, 9390, 9472.
	High arousal	1650, 1710, 2208, 2216, 4220, 5470, 5621, 5628, 8030, 8034, 8080, 8185, 8186, 8200, 8251, 8341, 8370, 8400, 8490, 8500.	1019, 1120, 1201, 1525, 1932, 2683, 2703, 2811, 3022, 3170, 3500, 6230, 6313, 6350, 8485, 9254, 9300, 9410, 9433, 9910.
Neutral		1112, 1121, 1240, 1313, 1390, 1617, 1675, 1935, 1945, 1947, 2025, 2635, 2770, 2780, 2810, 4004, 5395, 6930, 7484, 9913.	

With NIRStar Acquisition Software, changes in the concentration of O2Hb and HHb were recorded from a 180-s starting baseline, using the modified Beer–Lambert law. Signals obtained from the six NIRS channels were measured with a sampling rate of 6.25 Hz, and analyzed and transformed according to their wavelength and location, resulting in values for the changes in the concentration of O2Hb and HHb hemoglobin for each channel (Figure 2). Hemoglobin quantity was scaled in mmol × mm, implying that all concentration changes depend on the path length of the NIR light in the brain.

The raw data of O2Hb, HHb from individual channels were digitally band-pass filtered at 0.01–0.3 Hz. Then, the mean concentration of each channel within a subject was calculated by averaging data across the trials from the trial onset for 6 s. Moreover, in order to analyze left/right asymmetry of PFC activity at rest, we calculated the Lateralized Index Response (LIR, (right − left)/(right + left)) for the selected channels for O2Hb (for this procedure see also Ishikawa *et al.*, 2014). The index provides values in the range of (−1, +1). A positive LIR indicates that the right PFC is more active at rest than the left PFC on average, while a negative LIR indicates that the left PFC is more active at rest than the right PFC on average.

The cerebral blood oxygenation changes in the bilateral PFC were continuously monitored by NIRS also during the experimental condition. The mean control values (baseline values) were subtracted from the mean activation values (measured throughout task performance). In order to determine left/right asymmetry of PFC activity during the experimental task, we calculated a laterality index (LI) for the O2Hb concentration changes ((right − left)/(right + left)). $LI > 0$ indicates greater activity of the right PFC compared to left PFC, while $LI < 0$ indicates greater activity of the left PFC compared to right PFC (for this procedure see also Ishikawa *et al.*, 2014).

Data analysis

Analyses were conducted on the resting brain activity, the experimental brain activity and the comparison between these two phases. To exclude *a priori* gender effects, first a set of repeated measures ANOVAs was applied to the dependent measures of LIR. A second set of

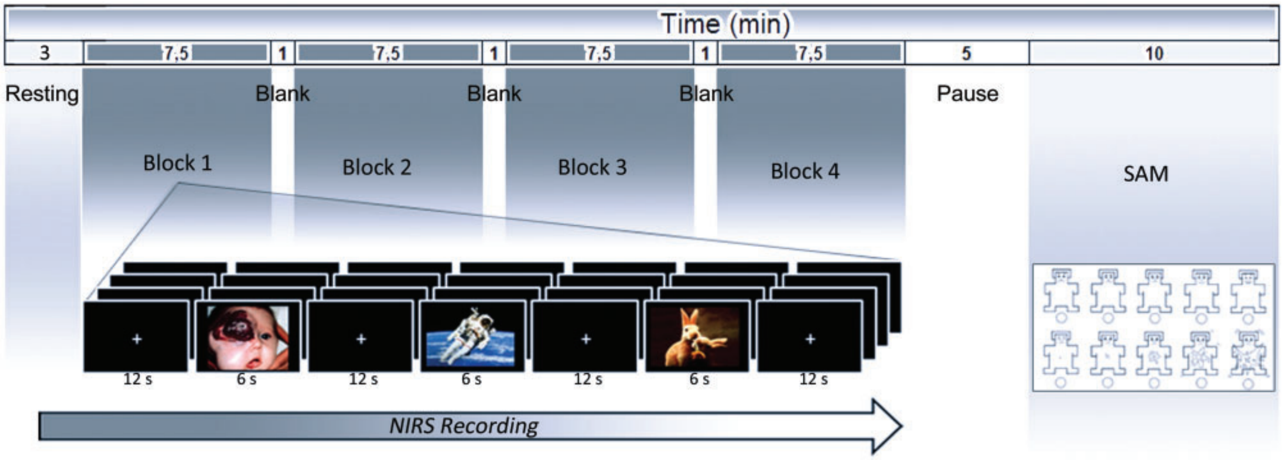

Fig. 1 Experimental setting during fNIRS recording.

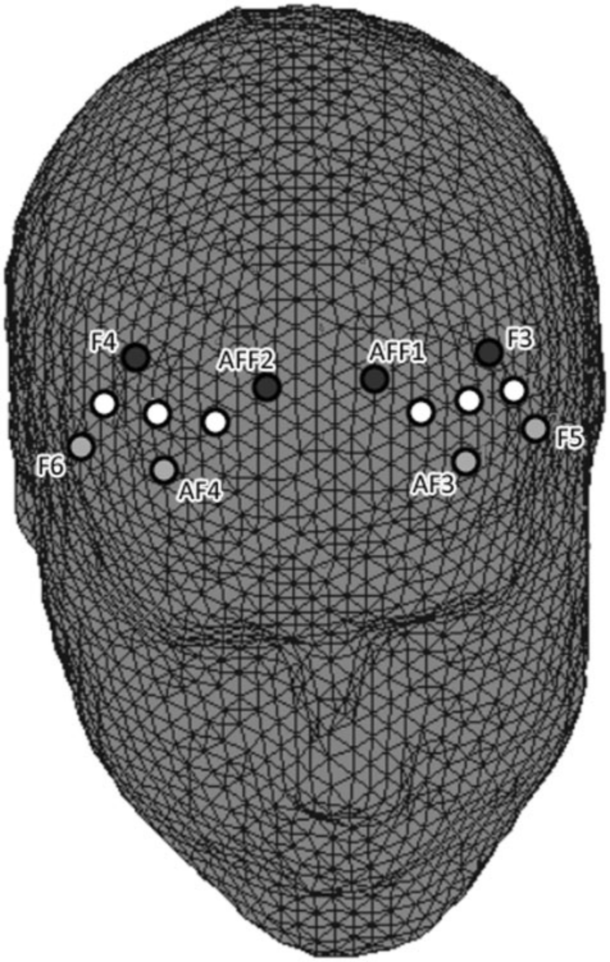

Fig. 2 The locations of the measurement channels. The emitters were placed on positions AF3–AF4 and F5–F6, while detectors were placed on AFF1–AFF2 and F3–F4. Emitter–detector distance was 30 mm for contiguous optodes and near-infrared light of two wavelengths (760 and 850 nm) was used. NIRS optodes were attached to the subject's head using a NIRS-EEG compatible cup, with respect to the international 10/5 system.

repeated measures ANOVAs with three independent factors (two gender × two arousal × two valence) was applied separately for the dependent measures of LI and SAM. For all of the ANOVA tests, degrees of freedom were corrected by Greenhouse-Geisser epsilon where appropriate. Contrast analyses (paired comparisons) were applied to significant main or interactions effects.

A successive set of regression analyses was applied to LIR (as predictor), LI and SAM (as predicted variables), to explore the effect of resting activity on the experimental response for both brain activation and appraisal process.

Lateralized index response

Statistical analyses were applied for both 02Hb and HHb concentrations. According to the analysis, HHb was not significant, thus we reported only results for 02Hb values. One-way ANOVA assessed the gender effect on the dependent measure 02Hb. As shown by the analysis, no significant differences were found for gender ($F(1,18) = 1.87$, $P = 0.092$).

Laterality index

Three factor (two gender × two arousal × two valence) repeated measures ANOVA was applied to LI measure. The main effect of valence ($F(1,18) = 9.78$, $P < 0.001$) was significant. Indeed LI values were higher (positive values, more right activity) for negative stimuli, and lower (negative values, more left activity) for positive stimuli. In contrast, gender ($F(1,18) = 1.12$, $P = 0.38$) and arousal ($F(1,18) = 0.87$, $P = 0.66$) main effects, and valence × gender ($F(1,18) = 1.37$, $P = 0.11$), arousal × gender ($F(1,18) = 1.98$, $P = 0.082$) and gender × valence × arousal ($F(1,18) = 1.03$, $P = 0.45$) interaction effects were not significant (Figure 3).

SAM ratings

Arousal and valence subjective ratings were analyzed with two separate three factor (two gender × two arousal × two valence) repeated measures ANOVAs. For valence ratings, the valence main effect was significant ($F(1,18) = 6.14$, $P < 0.001$). Indeed negative valenced stimuli were rated as more negative than positive stimuli (Figure 4). In parallel, regarding arousal ratings, arousal main effect was significant ($F(1,18) = 6.77$, $P < 0.001$): low arousal stimuli were rated as lower on arousal than high arousal stimuli. No other effect was statistically significant ($P > 0.481$).

Regression analyses

Regression analyses were performed in each condition (positive *vs* negative valence) for both LI and SAM variables. Results showed that LIR accounted for the LI in response to negative stimuli ($R^2 = 0.58$). Moreover, LIR also accounted for LI in response to positive stimuli ($R^2 = 0.52$). As shown by scatterplot (Figure 5a and b), LIR increased values (higher right resting activity) were related to LI increasing (higher right-activity), whereas LIR decreased values (higher left resting activity) were related to LI decreasing (higher left values). A similar trend was observed for SAM: indeed LIR explained the SAM rating in response to both positive ($R^2 = 0.57$) and negative ($R^2 = 0.49$) stimuli. As reported in the scatterplot, a significant increase in SAM (more positive value) was related to a decreased LIR value (more left resting activity), whereas a decrease in SAM (more negative value) was related to increased LIR value (more right resting activity) (Figure 6a and b).

DISCUSSION

This article aimed to explore the direct relationship between the lateralized resting brain activity and the emotional cue processing within the PFC. We found that the lateralization in resting state may predict the successive lateralized brain response to emotional cues. A second main result was related to the specificity of this relationship in terms of the valence. Indeed we observed a significant impact of positive *vs* negative cues in affecting, respectively, the left and right hemisphere activations. As a consequence, we found that the higher left *vs* right activity at rest was able to predict a specific increased lateralized (left and right, respectively) brain activation during emotion processing in response to the specific positive and negative emotions. Third, this valence-related predictive role of resting brain activity also affected the successive appraisal of emotional cues: indeed regression analysis confirmed the impact of the resting state on subjects' evaluation in terms of positive *vs* negative attribution to emotions.

More specifically regarding the first result, in this study we evaluated the asymmetry of the resting activity in the PFC in terms of LIR. We found a significant relationship between the lateralized prefrontal activity at rest and the lateralized activity of the same brain area in response to emotional stimuli. Indeed LIR scores indicated that subjects with more right-dominant activity at rest (positive values of LIR) showed higher LI scores (more right activity), while those with left-dominant O2Hb changes at rest (negative values of LIR) showed lower LI scores (more left activity). In NIRS activation studies, changes of

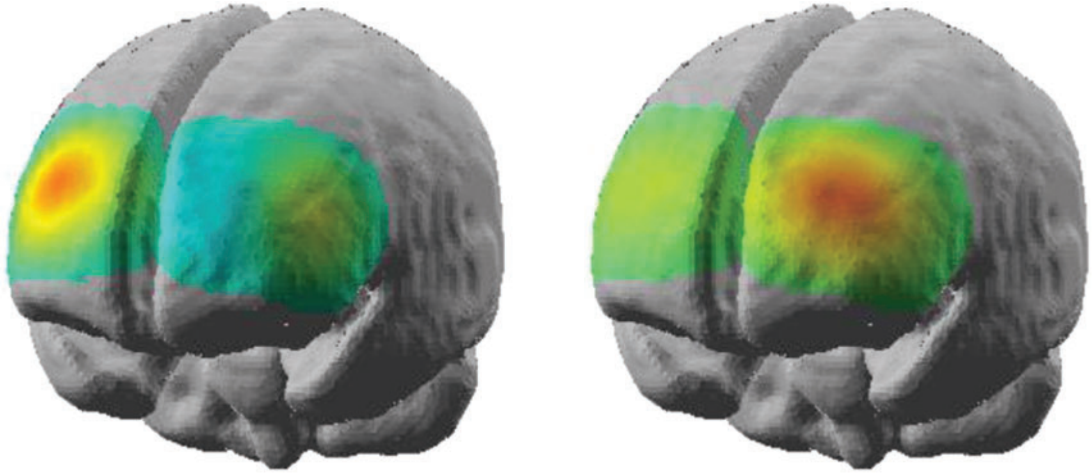

Fig. 3 O2Hb concentration during resting brain activity: higher LIR values for negative (left figure), and lower values for positive stimuli (right figure).

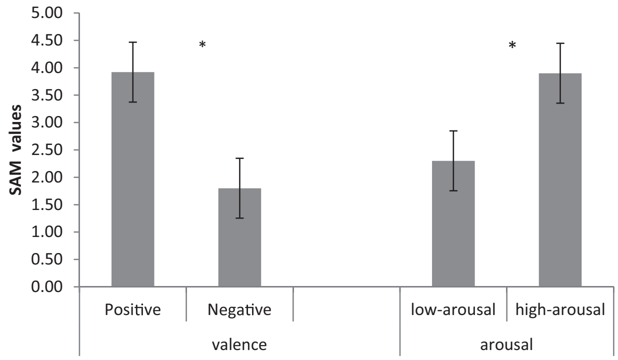

Fig. 4 SAM rating as a function of valence and arousal features of emotional stimuli.

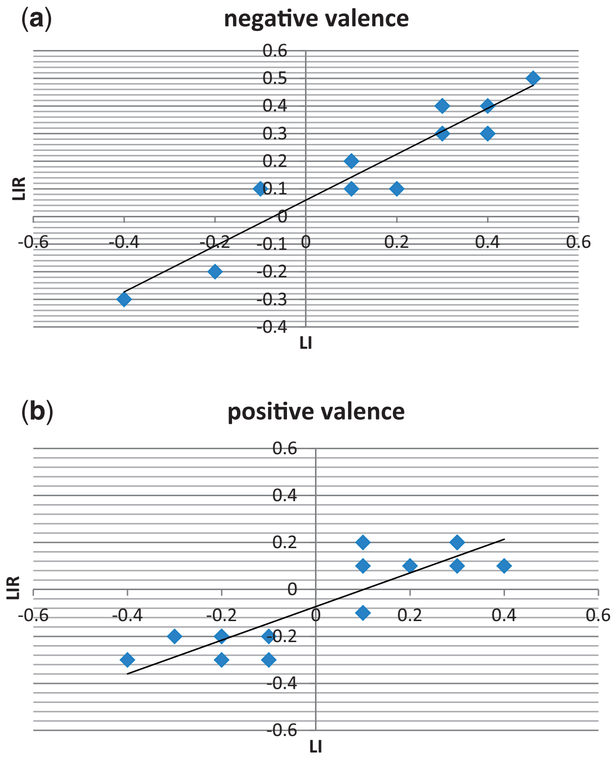

Fig. 5 Scatter plot of LIR and LI while viewing negative (a) *vs* positive (b) stimuli.

O2Hb during activation imply evoked changes of rCBF in response to neuronal activation, since changes in O2Hb were correlated with changes in rCBF (Hoshi *et al.*, 2001). In addition, simultaneous measurements of NIRS and EEG at rest demonstrated a relationship between O2Hb change and mean EEG peak frequency (Hoshi *et al.*, 1998). These observations indicate that changes of O2Hb concentration at rest measured by NIRS reflect neuronal activity at rest. We can also suggest that the relationship we found between resting activity and experimental response was not random and that the modulation found at rest is predictive of the successive hemodynamic activity in the brain. Indeed, as shown by regression analysis, the resting state activity highly predicted the successive subjects' responses to the emotional cues. However, since in this research we used a compound index (left or right higher activity as a function of the contralateral brain activity) and no an absolute right *vs* left hemisphere activation, the results we obtained should be considered as a measure which expresses the balance between left or right brain activity and not an absolute lateralization (absolute left/right prevalent activity) measure. Future research should test more deeply the separate effect of the left *vs* right hemisphere in both resting and experimental condition. In addition it should be noted that the present results were related to 02Hb modulation. In contrast we did not obtain a significant effect for HHb, as shown by the statistical analysis. The reason why only one of the two measures was effective in inducing significant results should be explored in future research. However, based on the present data, we may suggest that the two 02Hb/HHb measures which express the local cerebral blood flow increasing (respectively related to higher and lower values) may be not exactly two asymmetrical measures, as shown in some previous research (Ferrari and Quaresima, 2012).

Interestingly, this effect was observed in a strong relationship with the emotional stimuli category. Namely, regression analysis applied to LIR and LI revealed that subjects with left (or right) prevalent PFC activity at rest also exhibited left (or right) prevalent PFC activity during the emotional processing and that this activity was responsive, respectively, to the positive *vs* negative content of the emotional cues. In other words, the predictive role of resting brain activity was not indistinct but specifically related to the left *vs* right activation of the

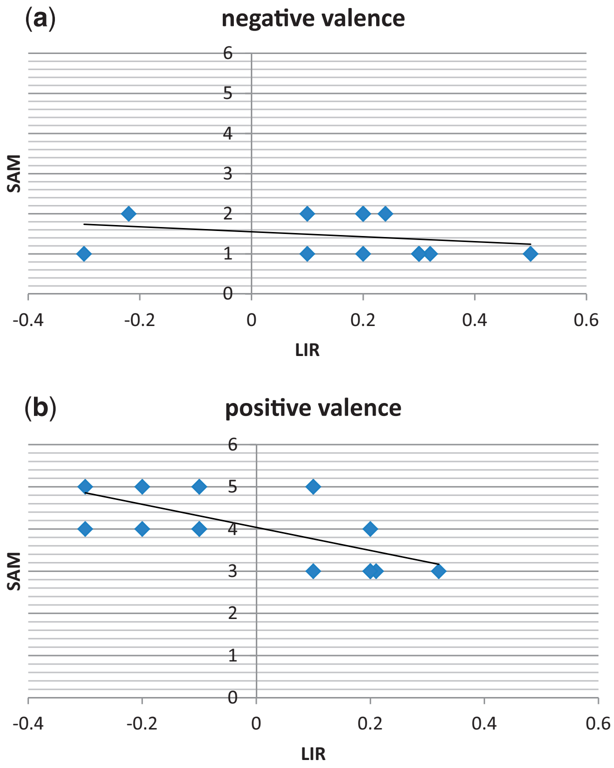

Fig. 6 Scatter plot of LIR and SAM while viewing negative (a) *vs* positive (b) stimuli.

brain when a positive *vs* a negative emotional stimulus was processed. Indeed, O2Hb increasing (more right activity) during the resting state explained the successive greater right hemisphere response to negative cues during the emotion processing. In contrast O2Hb decreasing (more left activity) during rest supported greater left activity to positive cues.

As a direct consequence of these results, the resting–activation relationship was characterized by two main effects. First, a valence-related lateralization effect was found. As shown by O2Hb increasing within the right and the left hemisphere in response to different category types, a significant difference was found based on valence of the stimuli, which was able to activate different cortical sides. PFC was found to support this valence-related emotional cue processing. This result confirmed previous research which found that PFC plays a crucial role in the integration of different aspects of cognition, memory and emotional regulation by managing the cognitive control over emotional stimuli and emotional behavior (Knight *et al.*, 1999; Hariri *et al.*, 2000; Miller and Cohen, 2001; Kalish and Robins, 2006; Balconi and Ferrari, 2012).

Also the appraisal process was affected by this valence effect. Indeed the explicit level of emotional cue processing (SAM rate) showed a clear arousal- and valence-related dichotomy. Accordingly, we found a significant polarization of judgment by the subjects as a function of valence feature, using positive and negative dichotomy for both low- and high-arousing categories. To explain this effect, as stated by Lang *et al.* (1990), two motive systems may be proposed in the brain to explain the model of valence. Appetitive and aversive/defensive stable systems account for the hedonic valence and arousal evaluation in emotional comprehension. The defensive system should be primarily activated in negative contexts, with a basic behavioral repertoire built on withdrawal, escape or attack. Conversely, the appetitive system is activated in positive contexts that promote survival, sustenance and nurturance, with a basic behavioral repertoire of ingestion and caregiving (LeDoux, 1990; Fanselow, 1994; Davis and Lang, 2003; Balconi *et al.*, 2011).

This resting predictive value on brain response to emotions also appears to suggest a second main explanation: the contribution of a possible stable subjective component in emotional behavior and in emotional responsiveness. Indeed the present results were consistent with the valence asymmetry hypothesis where the left/right asymmetry index of PFC activity was correlated with specific emotional responses to personality traits (Davidson *et al.*, 2000; Canli *et al.*, 2001; Fischer *et al.*, 2002). Therefore, a main consequence of this 'lateralization', as shown by resting brain activity, is that each subject has a specific 'attitude' in response to the emotional context. This trait is manifested in both a main left or right hemispheric activation in the absence of a specific task or emotional processing; and in sensitivity to more positive *vs* negative cues, as reported by the increased lateralized activation and in the explicit appraisal. We may suppose that this personal attitude successively affects the brain responsiveness (as revealed by LI) and the conscious process of valence attribution (as revealed by SAM).

Furthermore, the present results were also consistent with the hypothesis of a connection between bilateral frontal cortex activity and behavioral activation; i.e. the behavioral activation system (BAS) and the behavioral inhibition system (BIS) may be related to anterior asymmetry (Hewig *et al.*, 2006). Specifically, induced negative affect increases relative right-sided PFC activation, while induced positive affect elicits an opposite pattern of asymmetric activation (Tomarken *et al.*, 1992; Wheeler *et al.*, 1993). Indeed, another main factor affecting subject's response to emotional stimuli was the subjective sensitivity to the environmental emotional cues (Allen and Kline, 2004). The roles that temperament and personality play in influencing emotional responses was confirmed by a great number of empirical studies, for both normal and clinical samples (Heller, 1993; Everhart and Harrison, 2000; Mardaga *et al.*, 2006). A prevalent view suggests that the bases of the emotional construct correspond to two general systems for orchestrating adaptive behavior (Gray, 1981; Carver and White, 1994). The first system halts ongoing behavior while processing potential threat cues and is referred to as BIS (Gray, 1990; Lang *et al.*, 1990). A second system is believed to govern the engagement of action and has been referred to as BAS (Fowles, 1980; Gray, 1982). Empirical evidence suggests that people with highly sensitive BAS may respond in great measure to positive, approach-related emotions, such as the expression of happiness and positive effect, that allow the subject to have favorable behavior toward the environment (Davidson *et al.*, 1990; Tomarken *et al.*, 1992).

Although the BIS/BAS model concerns behavioral regulation, recently researchers have become interested in how these constructs are manifested in individual differences and emotional attitudes. Gray's model has tried to explain the behavioral motivational responses in general and, second, the generation of emotions that are relevant to approach and withdrawal behavior (Gray, 1981; Gray *et al.*, 1997). In a clinical context, patients with major depressive disorder exhibited reduced left frontal EEG activity in the resting state compared with normal controls, suggesting that asymmetry in PFC activity at rest measured by EEG is correlated with the emotional state (Kemp *et al.*, 2010).

A second consequence is that, also in a clinical condition, the 'unbalance effect' between left *vs* right activity may be predictive of pathological conditions, as shown in the case of anxiety disorders. Indeed it was found that an increased level of anxiety might be associated with a dysfunctional increased activation of the frontal right-hemisphere in resting condition or a reduced activation of frontal-left-hemisphere (van Honk *et al.*, 1999; Zwanzger *et al.*, 2009). This model has furnished clear evidence about the different behaviors induced by positive *vs* negative emotional stimuli in specific emotional tasks, supposing a successively more right frontal hyperactivation for high-anxiety subjects in comparison with the left side, inducing an unbalanced processing of the two stimuli categories, with a consistent bias for the negative one. Specifically, in line with the valence model, hypervigilant attention was found to interfere with the high-anxiety subjects' performance, with a specific attentional bias (Eysenck, 1997).

However, future research should better explore the intrinsic relationship between personality traits, personality components and resting brain activity to better define the role personality has in affective behavior. That is, future research may more directly test the relationship between BIS/BAS construct and resting state, from one hand; and between BIS/BAS and emotional cue processing as predicting by resting brain activity. Second, the lateralization effect we found for both resting and activation condition should further be explored by other cortical measures, such as EEG. Indeed the dynamic modulation of emotional process could be better analyzed by integrating hemodynamic and electrophysiological indexes. A critical point of the present research was the exclusive focus on the prefrontal sites. Indeed we considered the role of the resting of the PFC as impacting the successive emotional cue processing. Future research should extend the analysis to other cortical sites. Finally, a possible limitation of the present study concerning the baseline period should be mentioned. Our baseline period (3 min) was relatively short compared with that used in other studies. However, the stable effect we found related to LIR may suggest we adopted a significant time-window to compare resting state with activation response.

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