Chapter 20
Effects of Positive and Negative Mood Induction on the Prefrontal Cortex Activity Measured by Near Infrared Spectroscopy

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Abstract The neurophysiological mechanism of positive versus negative emotions is insufficiently understood. In the present study, we examined the effect of event recall tasks on the prefrontal cortex (PFC) activity using near infrared spectroscopy (NIRS). Nine healthy adults were instructed to recall episodes of their life associated with positive (happiness) and negative (anger) emotion, both silently and verbally. Heart rate (HR) changes were simultaneously measured. NIRS showed an increased oxyhemoglobin (oxy-Hb) in the bilateral PFC during silent and verbal recall of both positive and negative episodes. The changes of oxy-Hb in the bilateral PFC during silent recall of negative episodes were significantly larger than those during silent recall of positive episodes ($p<0.01$). There was no difference in average changes of oxy-Hb between silent and verbal recall of negative episodes ($p>0.95$), while changes of oxy-Hb during verbal recall of positive episodes were larger than those during silent recall of positive episodes ($p<0.05$). Both verbal and silent recall of positive and negative episodes increased HR; however, verbal recall caused larger increases of HR than silent recall ($p<0.01$). The present results suggest that recall of negative episodes affect the PFC activity, which plays a key role in cognitive control of emotions, more than positive episodes.

Keywords NIRS • Emotional recall • HR • Anger • Happiness

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1 Introduction

The prefrontal cortex (PFC) is a cerebral region involved in a number of high-level functions. Indeed, it supports cognitive functions that are necessary to organize behavior in time and in context, as social behavior [1], and it has a key role in cognitive control of emotions [2].

In the past 40 years, the branch of affective neuroscience extensively studied the bond between emotions and the brain, leading to various hypotheses about the role of specific brain regions in regulating and experiencing emotions [3]. Rohr and colleagues [4] reviewed four major emotion processing hypotheses: (a) the right hemisphere hypothesis (emotions are processed only by right hemisphere); (b) the valence hypothesis (right hemisphere has a major role in negative emotion processing, while the left one in positive emotion processing); (c) the one-network hypothesis (all emotions are processed by a specific set of brain regions); and finally (d) the localist hypothesis (specific emotions are processed by specific brain regions). The valence hypothesis has been recently studied with near-infrared spectroscopy (NIRS), which has been established as a useful tool for evaluating the association between right/left asymmetry of PFC activity and psychological stress/emotional responses [5–7]. Importantly, NIRS is suitable for studies focused on emotion because it offers some advantages as compared with other neuroimaging techniques. In particular, NIRS is less sensitive to external noise sources (e.g. movements), and requires less time and burden (both physical and psychological) for the preparation of the subjects and the application of the probes [6–8]. For example, unlike the other neuroimaging techniques, individuals can undergo NIRS recording while speaking and interacting with another person, an important condition for the evaluation of emotions. Indeed, personally relevant recall tasks are known to induce stronger physiological arousal than tasks that are not personally relevant [9–11].

Several studies investigated the relationship between the autonomic nervous system (ANS) activation and the experiencing of emotions [12]. One common result is that positive emotions evoke differential heart rate (HR) acute responses as compared to negative ones, with the latter being associated with a major acute sympathetic activity (or reduced parasympathetic activity), which results in higher HR [10]. By contrast, positive emotions seem to be associated with an increased acute parasympathetic activity (or reduced sympathetic activity), resulting in a reduced HR [10]. Some studies also explored the use of both central and autonomic nervous system indexes, revealing an association between the activation of the PFC and that of the ANS in response to emotional experiencing [10, 13, 14].

The purpose of the present study was to investigate simultaneously the physiological and neural underpinnings of emotion experiencing. Using high-ecological validity recall tasks designed to induce positive and negative emotions, we aimed to examine the role of mood induction in NIRS responses and ANS reactivity. In particular, we tested the hypotheses that emotion valence (positive vs. negative) may differently affect (i) the lateralization of the PFC activity, (ii) the HR, and (iii) the association between the PFC and ANS pattern of activation.

2 Methods

We studied nine healthy university students. All participants were right-handed; they were matched for gender (four males); the mean age was 25 (SD = 3.9) years. The study was conducted in accordance with APA (American Psychological Association, 1992) ethical standards for the treatment of human experimental volunteers (see also the Declaration of Helsinki, BMJ, 1991; 302, 1194).

Participants were seated in a comfortable chair, in a silent room. During psychophysiological recording, they were instructed to limit any movement of the body and to minimize those of the head.

A 5-min rest period (baseline) was followed by completion of two personally relevant recall tasks, designed to evoke positive (happiness) or negative (anger) affects. Both the happiness and anger recall tasks involved a 2-min silent and a subsequent 3-min verbal recall phase, during which NIRS and psychophysiological measures were recorded. The order of the two tasks was randomized across participants.

Regarding the Anger Recall task, the participants were asked to talk about an incident that made them feel angry, frustrated, or irritated—as described previously—[for a full description of the procedure see for example 9, 10]. They were asked to recreate the incident from the beginning to the end relaying what was said and done and describing associated thoughts and feelings. During the silent phase (2 min), the participants were asked to think about this situation, focusing on visualizing different aspects of it (e.g., location, people involved). During the verbal phase (3 min), the participants were invited to tell the experimenter about the situation. As the experimenter listened, he/she prompted the participants for details.

Regarding the Happiness Recall task, the participants were asked to discuss an event that made them feel happy, glad, or cheerful [10]. The procedure was the same as for the Anger Recall task.

We used a Bluetooth® CW NIRS system (Pocket NIRS, Hamamatsu Photonics K.K., Japan) for measurements of the concentration changes of oxy-Hb, deoxy-Hb, and total-Hb in the PFC. It uses light emitting diodes of three different wavelengths (735, 810, and 850 nm) as light sources and one photo-diode as a detector, and has two channels, one left and one right. The sampling rate was 61.3 Hz. The concentration changes of hemoglobin are expressed in arbitrary units (a.u.). Statistical analyses were performed considering the differences between experimental conditions and the baseline due to fact that CW NIRS devices provides only relative hemoglobin concentration changes.

Regarding the physiological measurements, we used the Pulse sensor, a wearable Bluetooth® designed by STMicroelectronics and manufactured by MR&D (Italy). It monitors continuously different physiological parameters, among which heart's activity. In the present study, only data on HR are reported. The device was attached to the person's chest using an adhesive patch; the ECG of each subject was visually inspected in order to correct missing beats and artifacts.

For each experimental condition, we analyzed HR in terms of the difference from the mean baseline value. As regards the NIRS signal, the concentration changes

were averaged to a single mean for each condition (baseline, silent 1 and 2, verbal 1 and 2). The baseline mean was therefore subtracted from the mean computed for every experimental condition (e.g., silent recall 1—baseline).

The resulting mean Δoxy-Hb, Δdeoxy-Hb, and Δtotal-Hb and mean ΔHR were finally subjected to multifactorial repeated-measures ANOVAs. As for NIRS, the ANOVA factors were Task (happiness vs. anger), Condition (silent vs. verbal recall), and hemisphere (right vs. left). As for HR, the ANOVA factors were Task and Condition. Multiple Post-Hoc mean comparisons were performed using the Fisher test.

3 Results

NIRS showed an increase of Δoxy-Hb and Δtotal-Hb associated with a decrease of Δdeoxy-Hb, in the bilateral PFC during silent and verbal recall of both positive and negative episodes (see Fig. 20.1 for a typical NIRS signal during the experiment).

The analyses performed on Δdeoxy-Hb and Δtotal-Hb evidenced no statistical significant effects. The analyses performed on Δoxy-Hb evidenced a significant interaction between Task and Condition ($F1,8 = 5.32$; $p < 0.05$). In particular, Δoxy-Hb in the bilateral PFC during silent recall of negative episodes was larger than that recorded during silent recall of positive episodes ($p < 0.01$). There was no difference in Δoxy-Hb between silent and verbal recall of negative episodes ($p > 0.95$), while Δoxy-Hb during verbal recall of positive episodes was larger than that recorded during silent recall of positive episodes ($p < 0.05$). Figure 20.2 reports all the means of Δoxy-Hb.

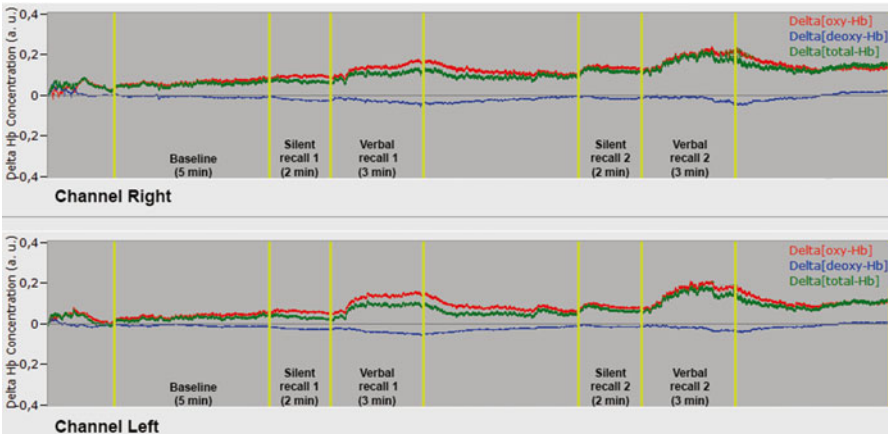

Fig. 20.1 Typical oxy, deoxy and total hemoglobin concentration changes during the experimental conditions recorded in one participant

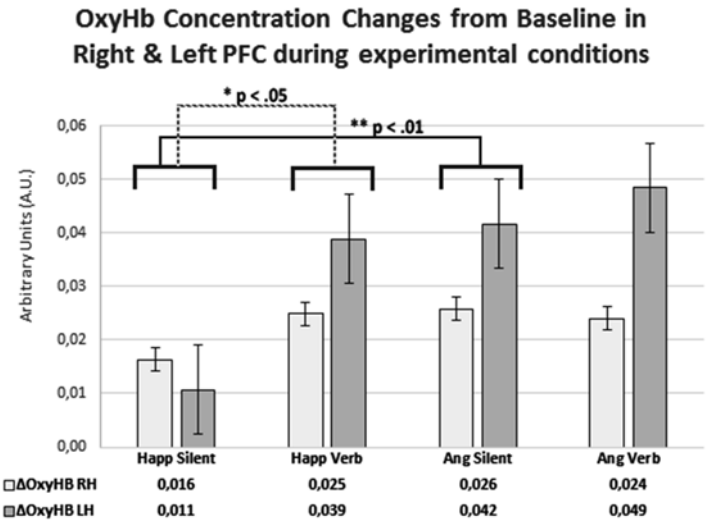

Fig. 20.2 Mean Δoxy-Hb among all subjects (n = 9) in the bilateral PFC during the experimental conditions. Below each condition are reported the related means, expressed in arbitrary units (a.u.). The lines between conditions represent the significant interactions (with the corresponding p-value) found in ANOVA

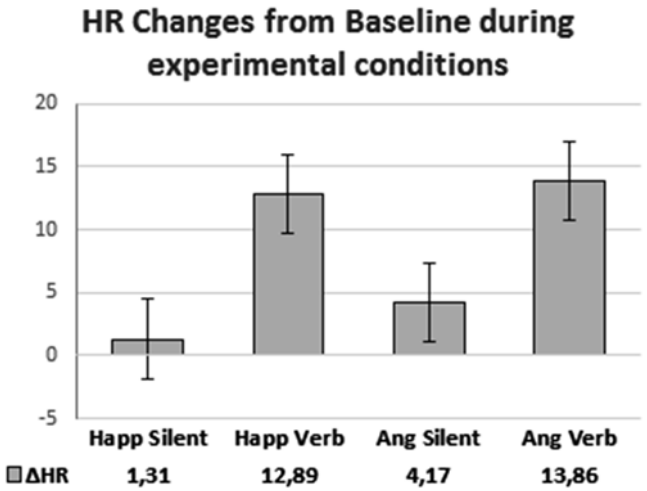

Fig. 20.3 Mean ΔHR among all subjects (n = 9). Below each condition are reported the related means

Overall, both verbal and silent recall of positive and negative episodes increased HR (Fig. 20.3). The effect of the Condition ($F1,8 = 9.80$; $p < 0.05$) suggested that verbal recall was associated with a larger increase of HR than silent recall. HR changes recorded during negative episodes (Mean = 9.4; SE = 2.21) were slightly larger than those recorded during positive episodes (Mean = 7.04; SE = 2.36); however, there was no statistical significance.

4 Discussion

The NIRS data evidenced an increase of the PFC activation in all task conditions with respect to the baseline. The hypothesis that emotion valence may differently affect the lateralization of the PFC activity [4–7] is not supported by the present results, as we observed an increase of oxy-Hb concentration changes over the PFC bilaterally. Interestingly, our results evidenced an increase of the PFC activation during both conditions (silent and verbal), when the participants were asked to recall negative episodes. Conversely, during the recall of positive episodes, significant increase of the PFC activation was observed only during the verbal condition (and not the silent one). That is, negative emotions increased neuronal activity of the PFC both when the participants were silently recalling the events and when they were narrating them. These findings suggest that the recall of negative episodes may affect neuronal activity of the PFC, which plays a key role in cognitive control of emotions [2], more extensively (i.e. across different experimental conditions) than positive episodes. This observation suggests some caution when using passive tasks (i.e. passive viewing of emotional images or video clips) in cognitive neuroscience studies: indeed, passive "induction" of positive emotions could not be directly comparable to the passive induction of negative emotions [10, 11].

Regarding the autonomic data, interestingly the inferior limit of the participants' standard error during silent happiness recall is negative (see Fig. 20.3). This suggests that some participants experienced a HR decrease, due to a reduced sympathetic activity or an increased parasympathetic activity. Anger recall is instead constantly associated with a slight—even if not significant—increase of cardiac frequency when compared to happiness one, according to the hypothesis of a major activation of sympathetic system (or reduced parasympathetic activity) during experiencing negative emotions [10].

Examined all together, these data suggest that autonomic responses to emotional tasks have a "linear" trend, while hemodynamic cerebral responses show a "more complex" activation pattern than one may expect according, for example, to the valence hypothesis [4]. This may be due to the high number of factors affecting the PFC activation. Concluding, neurophysiological correlates of emotions remain one of the most promising neuropsychological research fields, in which NIRS could provide—in the near future—a valuable help in understanding the underpinning factors of emotional experiences and (dys)regulation.

This study has some limits. First, it is a preliminary study, therefore all the data should be re-examined in the light of an increase of the sample size. Secondly, the open nature of the task allowed the participants to recall any memories, thus not permitting control of the exact type and the intensity of emotion described and experienced by participants.

Finally, the data's lack of support to the valence hypothesis could be partly explained by the high ecological validity of the task. When compared to more widespread and standardized paradigms (i.e. passive viewing of pictures or video clips) the free recall of personally relevant emotional episodes is similar to a realistic social

interaction. As such, it does not allow the researcher to control for a large number of experimental factors that could vary between individuals. Therefore, the recall task could be influenced by spurious variables (e.g. social interaction, self-regulation and narrative discourse production) known to be connected with prefrontal activity [1, 2]. Otherwise, these limits are strictly connected to the ecological validity of the protocol, which represents its strong point.

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