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## *Integration of cognitive and affective processes in perception and decision-making*

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# ABSTRACT

The relationship between emotion and cognition is a topic that raises great interest in research. Recently, a view of these two processes as interactive and mutually influencing each other has become predominant. This dissertation investigates the reciprocal influences of emotion and cognition, both at behavioral and neural level, in two specific fields, such as attention and decision-making.

Experimental evidence on how emotional responses may affect perceptual and attentional processes has been reported. In addition, the impact of three factors, such as personality traits, motivational needs and social context, in modulating the influence that emotion exerts on perception and attention has been investigated.

Moreover, the influence of cognition on emotional responses in decision-making has been demonstrated. The current experimental evidence showed that cognitive brain regions such as the dorsolateral prefrontal cortex are causally implicated in regulation of emotional responses and that this has an effect at both pre and post decisional stages.

There are two main conclusions of this dissertation: firstly, emotion exerts a strong influence on perceptual and attentional processes but, at the same time, this influence may also be modulated by other factors internal and external to the individuals. Secondly, cognitive processes may modulate emotional prepotent responses, by serving a regulative function critical to driving and shaping human behavior in line with current goals.

# ACKNOWLEDGMENTS

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# INTRODUCTION

After many years of neglect, over the course of the last decades scientists have started to increasingly recognize the importance of emotions for survival and adaptation of the human being (Damasio, 1994). Many studies emphasize how emotions affect our decisions, learning and memory, and how they provide the motivation to act when facing incoming stimuli from the environment. A topic that has been the object of particular attention in the field of cognitive neuroscience is the relationship between emotion and cognition, and how they interact on a neural level. Do emotion and cognition act in completely independent ways or rather are they interactively related? The debate concerning the existence of a neural functional separation between the "emotional" and "cognitive" brain is still open. For a long time, emotion and cognition have been viewed as largely separated systems in the brain with specific and independent neural correlates. Popular examples of a functionally specialized brain organization described the amygdala as the center of emotion and the lateral prefrontal cortex as the center of cognition in the brain. More recently, however, research has started to point at an interactive neural network as the key to understanding complex human behaviors (Pessoa, 2008). Studies on brain lesions have paved the way for this direction. The classical case of Phineas Cage, for instance, is one of the first pieces of evidence that damage in specific brain regions, such as the *prefrontal cortex*, may cause impairments in both cognitive and emotional behavior (Damasio, 1994). The increasing use of neuroimaging and neurophysiology techniques has contributed to clarify the neural functioning of emotional and cognitive processes and eventually their interplay. Indeed, several studies have shown that brain regions mediating emotion overlap with

those that mediate cognition to such a degree that it is difficult to distinguish between them (Gray, 2004). The best examples of the mutual influence between emotion and cognition derive from studies on attention and executive functions. For instance, it has been demonstrated by using different tasks that emotionally positive and negative stimuli, compared to neutral ones, may direct the allocation of attention, commonly conceived as a cognitive function, in an automatic way and without awareness (Eastwood et al., 2001; Ohman et al., 2001; Anderson, 2005; Vuilleumier & Schwartz, 2001). On the other hand, there are many studies that indicate the crucial role of cognitive processes in inhibiting and controlling emotional behavior (Ochsner et al., 2002, 2004).

In the present thesis, the interactive relationship between emotion and cognition will be further addressed. In particular, this work will focus on whether and how emotional responses may affect cognitive processes, as well as on how emotional responses may be influenced by cognitive processes, including the brain regions that are causally implicated in the cognitive control of emotions.

This dissertation is divided into three main parts: The first part provides an overview of the previous literature concerning emotion and cognition, by addressing in particular the definition of these two processes and their neural correlates (Chapter 1). The second part reviews extant literature on the impact of emotion on cognition, with particular focus on how emotions affect perceptual and attentional processes (Chapter 2). In this framework, three experimental studies will be presented, each investigating a different factor that may affect the impact that emotion exerts on cognitive processes: personality

traits of participants (Chapter 3), the motivational needs of participants (Chapter 4), and, finally, the social context (Chapter 5).

Specifically, the study reported in chapter 3 will investigate the influence of a particular trait of personality, such as aggression, in discriminating facial expressions of different emotions, using two different tasks with static and dynamic stimuli. The experiment presented in chapter 4 will focus on attentional processes, showing that internal changes in the motivational value of stimuli may modulate attention allocation. Finally, the study presented in chapter 5 will show that emotional stimuli guide allocation of attention but that this bias may be itself altered, in turn, by other aspects such as social context.

The third part of the present thesis will focus on the influence of cognitive processes on emotion. Specifically, in chapter 6 previous literatures on this topic will be reviewed, providing examples of the regulative function of cognitive processes mainly from the field of decision-making. Two further experimental studies will be reported in the last two chapters, in the attempt to clarify the role of cognitive brain regions such as dorsolateral prefrontal cortex (DLPFC) in regulation and control of human behavior. In particular, two techniques (TMS and tDCS) have been used to disrupt activity in DLPFC in two different decision-making situations, such as moral judgment (Chapter 7), and change of preferences after difficult decision-making (Chapter 8), where regulation of emotional responses is required.

The general conclusions will include further discussion of the present experiments and aim to offer cues for possible future research.

## CHAPTER 1 - Emotion and Cognition: an overview

### 1.1 Cognition and Emotion: What does this mean?

What are emotions? What is their function? What neural systems underlie them? These are only some of the key questions that cognitive psychology and affective neuroscience have attempted to answer in the last 30 years, after the explosion of interest towards emotion field. Hundreds of studies about emotion exist but the debate concerning a unique and exhaustive definition of the term *emotion* has not been solved yet. The difficulty of a definition that find a general agreement is likely due to the fact that emotions arise from the interaction of several factors, and that they involve human beings in several ways. For instance, some authors conceive emotions as *personal subjective experiences*, elicited by rewards and punishments (Rolls, 2000); others define them as the expression or *manifestation of somatic and autonomic reactions* (Damasio, 1999). Additional theories focus on emotions as *states that lead to behaviors* judged as emotional (e.g. fear or anger), and that are crucial for adaptation and survival for both animals and humans to their environment (Ekman, 1992). Moreover, during evolution, emotions were shaped by culturally acquired conventions and rules as shown by more extended definition of emotions, including moral emotions such as envy and pride (Haidt, 2001).

Despite the great number of features of human emotion, almost everyone accepts the assumption that emotions are associated with physiological reactions. This vital link between emotional states and physiological responses has been the starting point of most of the studies concerning emotion in both animals and in humans. Historically,

among the great number of theories concerning emotion, some have focused on events that happen on the periphery of the body (James-Lange, 1884), others on neural processes (Cannon-Bard, 1931), and others more on the integration of these two aspects (Schachter & Singer, 1970).

Although a clear definition of emotion has generated many controversies, there is relative agreement about what constitutes *cognition*. Usually, when we refer to cognition, we indicate those processes, such attention, memory, working memory and problem-solving, that involve high-level mental functions and that are characteristic of human beings (Pessoa, 2008). One of the major functions of cognitive mechanisms is inhibition and control of behavior, which we can refer to as cognitive control. Cognitive control is a fundamental human faculty and it represents the ability to behave in accord with goals, intentions, and rules, even when behavior runs counter to reflexive or highly competitive responses. One of the major characteristics of cognitive control is the flexibility that allows us to perform novel tasks with very little experience. Cognitive control is essential to modulate lower level sensory, memory and motor operations in order to drive goal-directed behaviors and constitute a crucial process for the human well-being. Indeed, even if often emotions play an important adaptive role for preparing to quickly respond to relevant stimuli in the environment, sometimes such fast, automatic emotional responses do not operate in accordance to our intentions and need to be overridden during goal-directed behavior. In this context, cognitive control can be defined as the best means to achieve what we recognize as intelligent behavior (Miller, 2000).

## 1.2 Neural correlates of emotions and cognition

An open debate in the field of emotion research concerns the existence of innate neural circuits dedicated specifically to emotions. If many authors attempted to define emotions, others devoted themselves to research of more specific and elaborated description of neural circuits underlying emotions. The work of Papez (1937) has been particularly influential in this regard. The network that he proposed as central neural circuit of emotion involved the hypothalamus, anterior thalamic nucleus, hippocampus, cingulate cortex and their interconnections. As explained by Papez "the sensory excitations which reach the lateral cortex through the internal capsule, receive their emotional coloring from the concurrent processes of hypothalamic origin which irradiate them from the gyrus cinguli (Papez, 1937)". Many of the pathways that Papez proposed are correct, although there is less evidence that all regions he specified are central to emotions. The anatomical model proposed later by Maclean (1949, 1952) and known as *Lymbic System*, is more broadly supported by current data. This model is an integration of previous models with the addition of crucial regions such as amygdala and prefrontal cortex and, it classified brain structures by an evolutionary architecture. The essential idea that Maclean proposed was that the emotional experiences come from the integration of sensations from the world with information from the body and proposed that events in the world lead to body changes. Information about these changes return to the brain where they are integrated with ongoing perception of the outside world. Emotional experiences constitute the by-product of this integration, which is the function of the limbic system. Despite some recent critics about the role of some regions of the *Lymbic System*, this concept survived to the current days as the dominant conceptualization of *emotional brain* and has been the focus of research in

affective neuroscience. Among the regions of the *Lymbic System* who have been confirmed to be consistently implicated in emotional processes there are the amygdala (Bechara et al., 1995; LeDoux, 1992) and the prefrontal cortex (PFC, Bechara et al., 1999), as well as anterior cingulate cortex. Interestingly there is evidence that the same brain regions are also implicated in cognitive processes (for review see Pessoa, 2008).
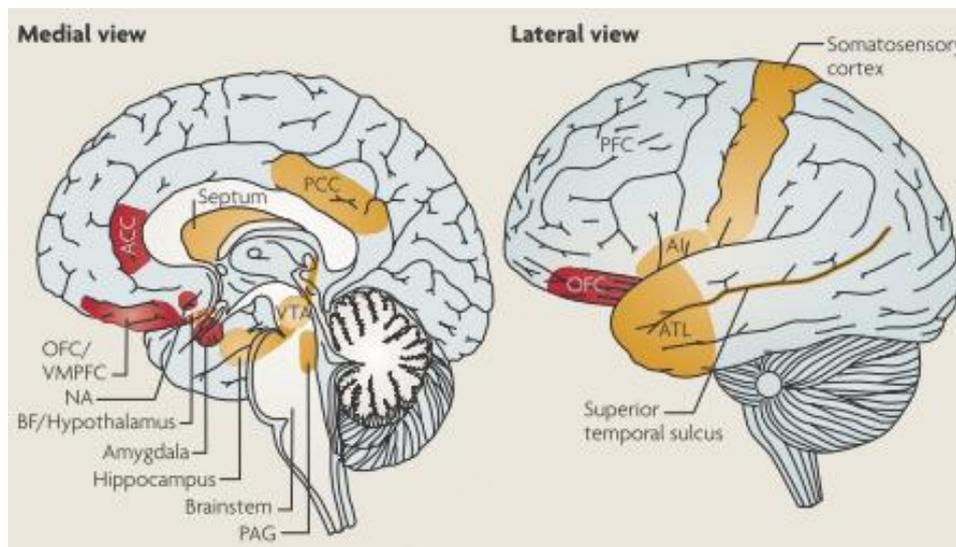


**Figure 1.1:**Set of brain regions that comprise the emotional brain, based on an informal assessment of the frequency with which they appear in the literature. The regions in red are those that appear with great frequenzy, while the yellow ones are found less frequently.Subcortical frequent regions are Amygdala, Hypothalamus and Nucleus Accumbens (NA); Cortical frequent regions are Ventro Medial prefrontal Cortex (VMPFC), Orbitofrontal Cortex (OFC) and Anterior Cingulate Cortex (ACC). Regions that appear less frequently are the brain stem, the ventral tegmental area (VTA), the hippocampus, the periaquaeductal grey (PAG), the septum and the basal forebrain (BF) at subcortical level; And, the anterior insula (AI), the prefrontal cortex (PFC), the anterior temporal lobe (ATL), the posterior cingulate cortex (PCC), superior temporal sulcus, and somatosensory cortex at cortical level. (Adapted from Pessoa, 2008)

**1.2.1 The amygdala**

The amygdala is a complex structure involved in a great number of normal behavioral functions. Like most of the brain regions, it is not a single mass but is composed of distinct subareas and nuclei that are distinguished on the basis of histological criteria and functions (LeDoux, 2012). Studies on brain lesions as well as neuroimaging and neurophysiology established the amygdala to be one of the most important brain regions for emotion, in particular for processing of social signal of emotion, emotional conditioning and consolidation of emotional memories (Dalgeish, 2004). Fear, meant as the ability to recognize and learn about dangers, has been the emotion most associated with the activity of amygdala. For instance, neuroimaging studies showed amygdala to be activated in response to induction of positive and negative emotional states during fear conditioning paradigm. Others lesions studies in humans indicated that lesions in this region led to emotional blunting and reduced fear conditioning (Feistein et al., 2011; for review see Phillips et al., 2003). Interestingly, several studies have focused on the perception of emotional cues, showing that activity of amygdala is highly linked to recognition of cues of threat or danger (Davidson et al., 2000). However, the amygdala has also been shown to be involved in a variety of other emotional functions. For example, it has been demonstrated to have a pivotal role in processing social signals of emotion. Previous literature in animals showed that neurons in the amygdala respond primarily to faces (Rolls, 1999) and that this response can be selective to dynamic social stimuli such as approach behavior (Brothers et al., 1990). Although discrete lesion of amygdala is rare, literature has reported specific impairment in recognition of facial expressions but not facial identity in patients with restricted amygdala damage (Adolphs et al., 1996; Calder et al., 1996; Young et al., 1995). A relatively body of research

focused on the role of the amygdala in processing of rewards to motivate and reinforce behavior. The lateral and central amygdala has been involved in various aspects of reward learning and motivation as well as drug addiction (LeDoux, 2012). The crucial involvement of this region in a multitude of functions is probably due to its great number of interconnections spread all over the brain, particularly with cortex.

### 1.2.3 The prefrontal cortex

The prefrontal cortex is a strip of gray matter located at the front of the brain just above the orbits of the eyes. It plays a crucial role among the many system of the brain, which are highly interrelated. Its location is strategic, with extensive anatomical connections to posterior cortical regions as well as subcortical regions. It is connected with regions that control motor and chemical responses and it receives signals from all the brain's sensory regions that control the states of the body, reason why it is involved in categorizing events as positive or negative. The orbitofrontal part of PFC has historically been linked to emotions. The first display of the involvement of PFC in emotion processing comes from the case of Phineas Gage in 1848, a man that miraculously recovered from an accident that damaged dramatically a big part of his prefrontal cortex. This lesion caused him a radical change in personality and emotional behavior. He became irreverent, impatient, quick to anger and unreliable and he could not manage his emotions anymore. To date, many are the evidence that confirmed the link between prefrontal cortex and emotions. The ventromedial prefrontal cortex has been extensively investigated by Damasio and colleagues (1994, 1996), who claimed that it provides a crucial substrate for affect-guided decision making. The somatic

marker hypothesis by Damasio suggested a key role of bodily feedback in emotions, especially implicating the ventromedial prefrontal cortex. According to this theory, PFC is crucial in processing "somatic markers", meant as physiological reactions that track previous emotionally significant events and provide signals that define current events with emotionally related consequences in the past. In situations where logical analysis is not sufficient the "emotional push" given by the somatic marker allows to make decisions. In support of this, Damasio and his colleagues reported cases of different patients with lesions in ventromedial prefrontal cortex (Damasio, 1994; Bechara et al., 1994) who tries and failed to deal with decisions in contexts of uncertainty. To date, this latter it is not the only function attributed to prefrontal cortex in emotions.

Studies by Rolls (1996, 1999) in monkeys suggested that orbitofrontal PFC works together with the amygdala to learn and represent the relationship between information about external sensory stimuli to interoceptive information that represents emotional significance. According to Rolls, neurons in PFC detect changes in the reward value of learned stimuli and change their response in accord with them. In addition, there are observations that medial prefrontal cortex is also involved in fear conditioning processing and particularly in extinction process: lesions of the medial PFC lead to a potentiating fear responses and retardation of extinction (Gewirtz & Davis, 1997; LeDoux & Phelps, 1993). Thus, medial PFC together with other neocortical regions may be related in regulating amygdala responses to stimuli based on their current affective value.

The dual system model by Davidson and colleagues (2000), proposes that PFC may function to guide behavior towards the most adaptive current goals (Davidson & Irwin, 1999). These authors suggest this region to promote adaptive responses competing with

alternatives that are linked to immediate emotional consequences. In this model, they argue a differential contribution of left and right side of PFC to positive and negative emotions, respectively. They divide two fundamental systems that underlie approach and withdrawal related to emotion and motivation: the approach system aimed at facilitating appetitive behavior and generating positive affects when close to a certain goal and, the withdrawal system aimed at encouraging retreat of an organism from aversive stimuli or organizations of appropriate response to threat. Left-sided PFC regions are involved in appetitive and positive goals, while right-sided PFC regions are involved in keeping negative goals that require behavioral inhibition and withdrawal. This system also generates withdrawal-related negative emotions such as fear or disgust. As reported by Davidson and colleagues (2004), evidence of the valence-asymmetry hypothesis is provided by both studies on patients with lesions and normal subjects (Morris et al., 1996; Davidson et al., 2000).
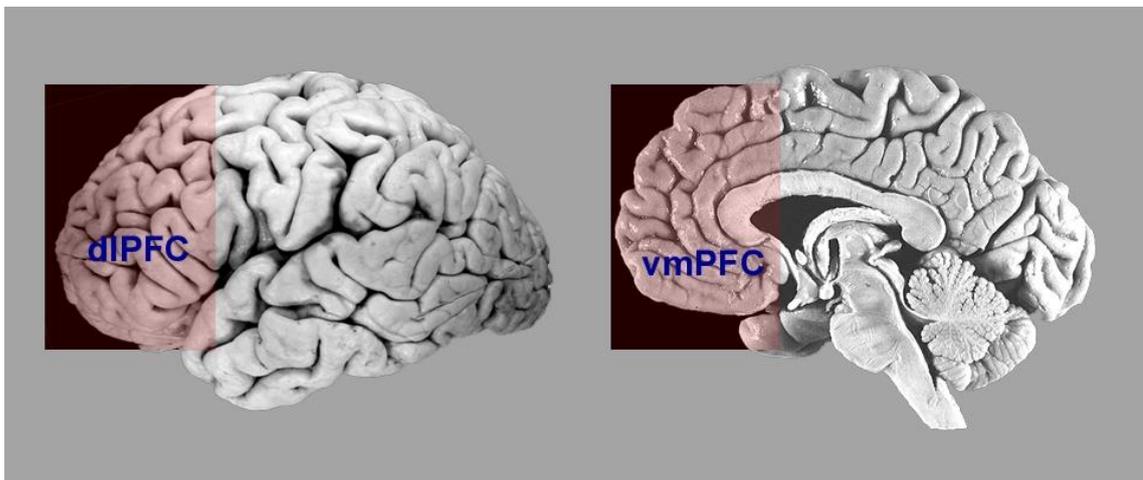


**Figure 1.2** This figure represents localization of dorsolateral (DLPFC) and ventromedial (VMPFC) prefrontal cortex in the brain.

The prefrontal cortex (PFC) is a crucial region not only for emotional but also for cognitive processes. While ventromedial (VMPFC) and orbitofrontal (OFC) parts of prefrontal cortex have been commonly associated to emotion, lateral regions of prefrontal cortex have been associated to cognition. Indeed, there is relative agreement that dorsolateral part of PFC may be considered as the most prominent and pure cognitive area in the brain. This area has a great number of connections that make of it an ideal region to process the wide range of information that we need for complex behavior and to exert top-down control on low sensory brain processes. Indeed, it is directly connected with higher-order sensory and motor cortex and indirectly (through VMPFC) with limbic structures that process internal information such as reward (Fuster, 2001). Studies on both monkeys and human lesions showed evidence of a functional organization of lateral PFC along a rostral-caudal axis as well as a dorsal-ventral axis (Petrides, 2005). On the one hand, the most caudal frontal region is more responsible for fine motor control and direct sensory-motor mapping, whereas the caudal lateral frontal region is implicated in higher order control processes aimed at regulating the selection among multiple contending responses and stimuli based on conditional operations. The most rostral lateral part of prefrontal cortex instead seems to be critical for more abstract role in cognitive control. Furthermore, considering a dorsal-ventral division of the lateral prefrontal cortex, dorsolateral region has been shown to relate to working-memory functions, while ventrolateral part to active judgment on information held in posterior cortical association regions (Petrides, 1994; for review see Petrides, 2005). Consistently, neuroimaging studies provided evidence that dorsolateral regions of prefrontal cortex (DLPFC) are responsible for monitor and

selection of goal-relevant information while ventrolateral is implicated in maintenance of this information (Wagner et al., 2001).

Studies in monkey showed that one of the most important functions of lateral prefrontal cortex is to extract information about rules across experience and use them to drive though and actions (Miller, 2000). Moreover, lateral PFC has been shown to be critical for learning of associations between sensory cues, outcomes and voluntary actions, ability required to make prediction and guide goal-directed behavior (Watanabe et al., 1992). In humans many are the examples of implication of lateral prefrontal cortex in a variety of cognitive processes such as working memory (Cohen et al., 1997; D'Esposito et al., 1998), abstract reasoning (Kroger et al., 2002) as well as general problem solving (Duncan et al., 2000). Anterior part of DLPFC has been shown to activate particularly in difficult problem-solving and reasoning tasks (Kroger et al., 2002). Kroger and colleagues (2002) for instance provided fMRI findings of greater activation of DLPFC by increasing complexity of the task as well as adding distracters during performance). Consistently, previous neuropsychological studies with patients with lesions in lateral prefrontal cortex showed dramatic impairment in the ability to solve matrix problems requiring integration of information at multiple dimensions (Waltz et al., 1999).

A fundamental cognitive mechanism whose dorsolateral PFC is responsible for is the inhibition and control of behavior. Indeed, successful behavior control requires the capacity to monitor ongoing actions to prevent responses when they would violate rules governing behavior. The so-called go-no go task has been widely used to investigate this function. In this task participants are asked to execute a motor response when presented the "go" stimulus but to withold the response when presented the "no-go" stimulus. fMRI and neuropsychological studies have provided evidence that lateral

prefrontal cortex has crucial implication in response inhibition (Aron et al., 2004; Sharp et al., 2010).

### 1.2.3 The anterior cingulate cortex

The cingulate cortex is another region crucially involved in both emotion and cognition. It is a thick strip of cortex encircling the corpus callosum and is one of the most prominent features on the mesial surface of the brain. From the functional viewpoint, findings supported the idea that anterior (rostral) cingulate cortex is specialized for affective processes, while midcingulate cortex (dorsal) is specialized for cognitive processes (for review see Bush et al., 2000). Consistently, the anterior part of this region is densely connected with the amygdala, the anterior and mediodorsal nuclei of the thalamus, and the orbitofrontal cortex, while dorsal is mainly connected with the posterior parietal and dorsolateral prefrontal cortices, as well as the medial pulvinar, lateroposterior, and laterodorsal nuclei of the thalamus.

Early studies showed that lesions of ACC produced a bunch of symptoms, including apathy, inattention, deregulation of autonomic functions and emotional instability (Tow & Whitty, 1953). Indeed, some contemporary studies pointed at the ACC as the center of generation of physiological and behavioral responses (Critchley, 2005), others implicate this region in the representation of the value of stimuli and actions and, in the monitoring of somatic states (Kalisch et al., 2006, Ocshner & Gross, 2005). Others studies attribute to cingulate cortex the integration of visceral, attentional and emotional information that is crucially involved in the regulation of affects and the top-down modulation of limbic and endocrine systems (Etkin et al., 2006; Schiller &

Delgado, 2010). However, the affective subdivision of ACC is routinely activated in functional imaging studies involving all kinds of emotional stimuli (Phan et al., 2003; Murphy et al., 2003).

Several studies suggested ACC to be important in both emotional and cognitive conflict. The Stroop task (Stroop, 1935) and its emotional variant have been extensively used to study conflict. Recent neuroimaging findings have shown that ACC monitors the conflict between functional states of the organism and any new information that has potential affective or motivational consequences (Dalgeish, 2004). Etkin and colleagues (2011) argued for a dorsal-ventral ACC functional dissociation, where the dorsal part of ACC is mostly involved in detecting emotional conflict whereas the ventral division, together with medial PFC and amygdala, is mostly involved in regulation of emotional conflict. Finally, studies on emotion regulation have shown activation of dorsal ACC in reappraisal, namely the modulation of emotional processing through deliberate and conscious application of top-down executive control (Gross, 2002) and activation of ventral ACC in affect labeling of emotional faces (Lieberman et al., 2007) or self-distracting from fear-conditioned stimuli (Delgado et al., 2008).

## CHAPTER 2 - Emotion affects cognitive processes

### 2.1 Emotion affects attention

The ability to detect information in the environment and process it based on its current relevance or salience is attributed to selective attention and executive functions (Driver, 2001). Attention can be defined as a set of neural mechanisms that reduce the inputs in an environment full of stimuli and facilitate perceptual processing of relevant aspects of the environment (Yantis, 2000). Consistently, neuroimaging and event related potential studies in humans have demonstrated that processing of attended information is greater compared to the processing of unattended information (Desimone & Duncan, 1995). Top-down signals coming from a network of frontal and parietal regions seem to be critical in the control of attention and in modulating activity within visual processing regions (Corbetta & Shulman, 2002). Nevertheless, visual system has limited processing capacity and paying attention to certain features of the visual field causes neglecting of others (Broadbent, 1958). Information must compete for processing resources (Desimone & Duncan, 1995). The competition between information can be modulated in different ways, by bottom-up stimulus-driven processes in the visual cortex (e.g. stimulus salience) or by attentional top-down processes in higher level regions of the brain (e.g. attending a particular location, for review see Pessoa et al, 2002). Thus, attention leads to increase the influence of behaviorally relevant stimuli at expenses of irrelevant ones and allows filtering information and according it priority to processing. Orienting of attention is herein a basic and fundamental process, but can the orienting of attention be modulated by certain kind of stimuli?

Attending information in the environment and selection of it could be critical for adaptive and survival behavior as it allows to react as quickly as possible to changes that occur around us and consequently to adjust our behavior. This is the case of emotional arousing stimuli. For instance, the sudden appearance of a threat in environment warrants immediate attention. In this perspective, a great number of empirical studies indicate that emotional or arousing images compared to neutral images affect performance of simple tasks, either when they are task relevant (targets) or task irrelevant (distracters), supporting the idea that emotional contents of stimuli influences mechanisms of selective attention.

In recent years, research has focused on emotional processing in general and on understanding how emotion and attention are related one to another in particular. Behavioral observations indicate that people more readily pay attention to emotional than neutral stimuli and that this happens in a reflexive and involuntary way. The preferential attention for emotional arousing stimuli has been widely demonstrated (for review see Vuilleumier, 2005), by means of many traditional paradigms already used in the study of selective attention. Some examples include the dot probe task (Armony & Dolan, 2002), the Eriksen flanker tasks (Fenske & Eastwood, 2003), the inhibition of return (Rutheford & Raymond,2010) and the spatial visual search (Eastwood et al., 2001; Fox et al., 2001; Öhman et al., 2001).

Richards and colleagues (2011) tested participants in an emotional variant of the Stroop task and showed that they were slower in naming the color of a word or picture when the stimulus has an emotional relevance, even though emotion is irrelevant to the task. Similar findings come from visual search tasks, where a unique target must be found among other distracters. In a classic visual search, the time to detect a specified target

typically increases in direct proportion to the number of irrelevant distracters, indicating serial attentive processing of every stimulus in the display. It has been shown that participants are faster in detection when the target has some emotional meaning, such as faces with positive or negative emotional expressions compared to neutral (Eastwood et al., 2001; Fox et al., 2001) or such as snake or spiders among flowers (Öhman et al., 2001). Interestingly, Eastwood and colleagues (2001) reported no such effect when emotional faces were presented inverted, ruling out the criticism that this emotional bias is due to differences in basic visual features, such as contrast or luminance.

Other studies have investigated the effects of emotional stimuli on temporal attention. For example, facilitation effect of emotion was found in attentional blink paradigms (AB, Raymond et al., 1992), where multiple stimuli are presented in rapid succession. Usually, when two targets are presented within about half second of one other, the second target is not detected. This impairment in detecting the second target of a stream of rapidly presented stimuli is reduced, when the second target is emotionally arousing (Anderson, 2005). However, in another study by Fox and colleagues (2005) the same effect was reported only in high anxious individuals. Phelps and colleagues (2006) focused on transient covert attention, automatically triggered by the sudden appearance of peripheral stimulus and investigated the possibility that emotion interacts with attention to further enhance even the earliest level of visual perception. In a rapid serial visual presentation paradigm (RSVP), they observed that the mere presence of a fearful face heightened contrast sensitivity and that the highest sensitivity was induced by manipulating emotion in conjunction with attention rather than separately. They concluded that people actually see better in the presence of emotional stimuli.

Although in a less extent, there is evidence that not only negative or threat-related emotions, like fear and anger, arise emotional bias but also pleasant and arousing stimuli can have similar effect, suggesting that arousal value rather than valence (negative or positive) plays a crucial role. Consistently, high level of arousal has been interpreted as indicative for relevant events in general (Lang et al., 1997).

In summary, a common conclusion of all these studies is that emotional visual stimuli automatically attract and hold attention more than neutral or novel stimuli and that this could be due to the fact that emotional value of stimuli is perceived by some rapid pre-attentive route that facilitate focal attention to the location of an emotional target more efficiently than to neutral target.

## 2.2 Emotion and attention: neural perspective

Researchers have started to investigate the effect of emotion on sensory processing and to wonder whether neural mechanisms may somehow explain the strict relationship between attention and emotion. Converging data indicate that selective attention mechanisms depend on a complex neural circuit that involves predominantly parietal, frontal and cingulate cortices with links to subcortical regions (Corbetta & Shulman, 2002; Posner & Petersen, 1990). Even if anatomically distinct, regions implicated in emotional processing show great overlaps with those implicated in attentional mechanisms. It has been shown, for instance, that fear, which is a crucial emotion for adaptive and survival behavior, it is likely to have links with neural networks of attention, guiding perception and action (Armony & Dolan, 2000).

Three are the important candidate structures involved in the relationship between emotion and attention. The anterior cingulate cortex is known to be related in selective attention, emotion evaluation and error monitoring (Bush et al., 2000; Yamasaki et al., 2002) and has numerous connections to visual processing regions of the brain. The orbitofrontal cortex is also a good candidate as it has been shown to play a vital role in affective evaluation (O'Doherty et al., 2003; Kawabata & Zeki, 2004) and value learning (Knutson et al., 2001) and it also sends and receives input from the primary visual areas of the brain (Rolls, 2000). Finally, because it sends large efferent pathway to primary visual cortex and receives signals from many cortical regions including OFC, amygdala has been designed as the most critical substrate of the modulation of activity evoked by emotional stimuli. This region has been shown to be involved in enhanced perception of emotional events (Anderson & Phelps, 2001) as well as in rapid response to emotional content of an event (LeDoux, 2002). It has been suggested that (LeDoux,

2002) amygdala facilitates perception of this stimuli by altering sensory cortical processing via feedback connections to visual cortex. Consistently, Morris and colleagues (1999) found a positive correlation between activity in amygdala and visual cortex, while participants viewed fearful faces compared to happy ones. Similarly, Pessoa and co-workers (2002) observed same kind of correlation between activity in amygdala and visual areas, such as superior temporal sulcus, middle occipital and fusyform gyrus. More evidence on the direction of the modulatory role of the amygdala come from neuropsychological studies (Anderson & Phelps, 2001), which showed that patients presenting bilateral amygdala damage, relative to normal subjects, were impaired in the usual advantage in detecting aversive word stimuli. This view suggests that in emotional contexts the amygdala may affect attentional processing by modulating early visual regions. On the other hand, Pessoa and colleagues (2004) propose a second way through which emotional modulation can be implemented, via amygdala projections to frontal regions, involved in control of attentional resources, such as anterior cingulate cortex (ACC) and dorsolateral prefrontal cortex (DLPFC). In this latter case, emotional modulation would correspond to a sort of attentional modulation, in which the valence of a stimulus aims at informing cognitive regions of a potentially relevant event (Pessoa et al., 2004). Thus, responses to visual stimuli of amygdala would be modulated by attention.

In spite of the emphasis on the role of amygdala in the modulation of attentional processes evoked by emotional stimuli, it is worthwhile to repeat that also other brain regions, such as orbitofrontal cortex, play a role in responding to emotional contents and that together with amygdala could determine behavioral and social relevance of stimuli. In conclusion, it is interesting to note that all these regions that show enhanced neural

responses for different emotional events compared to neutral are also implicated in attentional and cognitive processes.

## 2.3 Emotion and attention: the problem of awareness

As reported above, the relationship between emotion and attention raised great interest in research. There is good evidence that the processing of emotional information is prioritized relative to other kind of information and interferes with ongoing processing of other information. In particular, a question that raised considerable attention is whether the processing of emotional stimuli is automatic or requires attentional resources. Many behavioral and neurophysiologic observations suggest that the advantageous processing of emotion-laden stimuli occurs in an automatic manner, outside of attention (Öhman, 2002; Vuilleumier et al., 2001a) and awareness (Öhman et al., 1995). Nevertheless there is evidence both for and against automaticity and the debate is still open. Findings in favor of automatic emotional processing derive from fMRI studies, which showed that amygdala responds to fearful stimuli even when they are masked and participants are unaware of their occurrence (Whalen et al., 1998). In a famous fMRI study, Vuilleumier and colleagues (2001a) tested participants instructed to fixating a central cue and matching either two faces (fearful and neutral) or two houses presented eccentrically. Results showed no evidence that attention modulated responses in the amygdala, regardless of the stimulus valence.

On the other hand, Pessoa and colleagues (2002) argue that processing of emotional contents is not automatic but instead requires attention, at least at a certain extent. Moreover, they conjecture that attentional failure in modulation of emotional stimuli

processing, showed by previous literature, is imputable to an insufficient engagement of attentional resources by competing tasks. In their fMRI paradigm, participants were presented with neutral and emotional faces expressions while attention was focused on them (attended) and while it was directed to a sufficiently demanding bars orientation task (unattended). Results presented that attended stimuli evoked enhanced activity in amygdala for facial emotional expressions but that only in the attended stimuli condition responses to stimulus valence was significantly different. Contrarily to the previous results, these ones demonstrate that expression of a valence effect is not automatic but requires attention instead. Consistent with this view, interesting findings are presented in other studies that used techniques such as magnetoencephalography (MEG, Luo et al., 2010) and intracranial recording (Pourtois et al., 2010), that compared to fMRI are considered more sensitive in terms of time and spatial resolution. Recently, Luo and colleagues (2010) showed that the degree of automaticity in processing of emotional facial expressions is a matter of time. Their results demonstrated an early (40-140 ms) amygdala response to visual emotional information independent of attention modulation but also a later (290-410 ms) amygdala response to emotional information that on the contrary was modulated by attention. Similarly, Pourtois and colleagues (2010), recording intracranial focal field potential from amygdala in fearful faces presentation, found both an early emotional effect in the amygdala arising prior to, and independently of attentional modulation and, a significant modulation of attention on differential emotional responses at a later latency. Taken together these results suggest separate influences of emotion and attention on amygdala responses as function of time and they could be considered as an explanation of the discrepancy in previous literature. Nevertheless, other possibilities could be taken into account. One of these

possibilities concerns individual differences as important predictors of neural and behavioral sensitivity to emotional stimuli. Indeed, previous literature reported that personality traits have a great impact in detection and recognition of emotions.

## 2.4 Emotion and attention: the role of personality

As previously reported the ability to recognize an emotion has a critical adaptive function and may affect our social relationships. Recognizing emotions as quickly as possible allows reacting to incoming events from the environment. Consistently, emotional stimuli summon preferential attention compared to neutral stimuli (Vuilleumier et al., 2004), and evoke fast and involuntary autonomic responses (Globish et al., 1999). An issue that generated considerable interest is whether and how individual differences, such as personality or dispositional affect, may modulate emotional attention. For instance, people usually differ from each others in the amount of anxiety they experience, or in the degree of extraversion they exhibit. These individual differences may influence behaviors and sensitivity to emotional stimuli. Findings in favor of this claim come from behavioral and neuroimaging studies on both clinical and non clinical populations (for review see Calder et al., 2011), indicating that negative mood (Hepworth et al., 2010), anxiety (Fox et al., 2002), personality disorders (Domes et al., 2009) or simply personality traits (Hamann & Canli, 2004) all constitute possible explanation for the modulation of neural bases of emotional processing and consequent behavior. The relationship between anxiety and emotional stimuli processing has been extensively investigated by means of different paradigms as visual search task, dot-probe task or backward masking procedure. A number of studies, that

used a visual probe task, where threat-related and neutral stimuli are replaced by a probe and participants are instructed to respond as quickly as possible to the probe, have shown that anxious individuals are relatively faster to respond to probe replaced threat compared to non-threat ones (McLeod et al., 1986; Bradley et al., 1998, Bar-Haim et al., 2007). Similar evidence is provided by a modified version of spatial cuing paradigm used by Fox and colleagues (2001). This work showed that participants with higher level of anxiety were slower in shifting attention from the spatial location of the threat cues. Another study by Georgiou and co-workers (2005) indicated that high-trait anxious individuals, compared to low-trait anxious individuals, needed longer to classify peripheral targets when fearful faces were presented at fixation relative to other emotional expressions such as happy, sad or neutral ones. Converging data on the important role of individual differences in emotional processing concerns also personality disorders, such as Borderline Personality Disorder (BPD). Enhanced emotional sensitivity and increased emotional reactivity are thought to be characteristics of BPD patients (Linehan, 1993). Thus, it has been assumed that these patients should show a lower detection threshold and increased accuracy in the detection of emotion. Although there is evidence showing BDP patients to exhibit improved facial recognition and greater sensitivity for fearful faces (Wagner & Linehan, 1999; Lynch et al., 2006), there are also contrasting findings, indicating less accuracy of BDP patients and no enhanced sensitivity in recognizing expressions of emotions, such as anger, disgust and fear (Bland et al., 2004; Domes et al., 2008). However, as suggested by Domes, divergence in results of these studies could be attributed to differences in the paradigms that have been used.

In spite of the controversial results in this domain, there is general agreement that a given emotional stimulus can evoke a wide range of emotional responses across individuals and that this variability can elucidate the neural bases of emotional processing in general. It has been observed previously that amygdala is a key region for emotional processing but that its activity exhibits also a certain degree of variability, for example for happy faces (Canli et al., 2002). However, this variability was shown to be strongly correlated to participants' extraversion traits, resulting in the more extraverted the subject was, the more their amygdala responded to happy faces. Recent studies have investigated the extent to which amygdala responds to threat-related distracters, depending on individual anxiety levels (Bishop et al., 2004). Low-anxious individuals only showed increased amygdala responses to attended fearful faces, while high-anxious individuals showed increased amygdala responses to both attended and unattended threat-related stimuli. Likewise, in men with elevated trait anxiety scores, trait anger was demonstrated to correlate positively with bilateral amygdala reactivity to angry facial expressions (Carré et al., 2010). Moreover, by presenting emotional (faces expressions) and neutral (houses) stimuli to a non clinical population of individuals and asking participants to attend or not to the stimuli, higher anxiety level produced increased activity in right amygdala to attend direct angry facial expressions, compared to neutral or fearful ones, whereas increased activity in left amygdala was associated to unattended fearful faces (Ewbank et al., 2009).

In conclusion, these findings suggest that, although emotional attention is important in general, it is also possible that the salience and the value of stimuli vary as function of personality, mood or other individuals characteristics (Fox et al., 2005; Vuilleumier, 2005; Bishop et al., 2007).

## 2.5. Emotion and attention: the motivation value of stimuli

Stimuli incoming from the environment can be considered as affective also depending on what impact they have on the perceiver's eye. A scary image, for instance, can be considered as negative by virtue of its ability to make the perceiver feel momentarily unpleasant. In this perspective, we can argue that visual selection processes are accompanied by affective evaluation and value prediction based on the current and future goals of the individual and that this might affect allocation of attention. Indeed, *attention* can be defined as a set of neural mechanisms aimed at facilitating perceptual processing of relevant stimuli and at inhibiting processing of stimuli that could interfere with the achievement of our goals. Another critical system that acts in interaction with attention is called *motivation* and it has the task to specify current goals for an individual, to direct attention consequently. This system monitors internal emotional states as well as external conditions and appraises possible outcomes of actions. It strictly relies on previous learning and it is widely guided by our idea of what we consider as rewards or punishments (Raymond, 2009). Attention and motivation are heavily connected. Indeed, it is often assumed that pursuing a goal leads to the voluntary allocation of attention to goals–relevant stimuli and places (Yantis, 2000).

We have already reviewed the strong literature about the automatic attentional orienting to certain classes of stimuli, such as emotional stimuli that have potentially important adaptive and evolutionary functions. Nevertheless, there are not solely stimuli relevant to our evolutionary motives but also stimuli that are relevant because they fit with our temporary goals or because they acquire a certain value with experience. There is evidence supporting the possibility that motivational drives contribute to visual selection and enhances selective attention (Della Libera & Chelazzi, 2006).

In a spatial cuing task, Vogt and colleagues (2010) examined whether words relevant to a person current goal influence orienting of attention even when there is no intention to attend to these goal-relevant stimuli, and found that goal-relevant stimuli delayed disengagement of attention more than other types of stimuli. These results are similar to previous ones showing difficulties in disengaging attention from threat-related stimuli (Fox et al., 2001). As suggested by previous literature (Lang et al., 1997), attentive orienting is not a response confined only to emotional stimuli but is also prompted by stimuli that are motivationally relevant – either appetitive or defensive. Thus, as human behavior widely relies upon people's goals and motivations, it is essential that automatic allocation of attention is guided by people's goals and motivation to relevant stimuli. This hypothesis is perfectly in line with results provided by studies on attentional bias for food-related stimuli and food deprivation. For example, using visual probe task, it has been found that attentional bias towards food words was associated with self-reported hunger (Mogg et al., 1998), and that fasting increased attentional bias to high-calorie food-related words (Placanica et al., 2002). Similarly, deprivation of food delayed the naming of the color of food words in a modified Stroop paradigm (Dobson & Dozois, 2004). In addition, neuroimaging and event-related potential studies provide evidence that hunger and satiety affect stimulus perception. Stockburger and co-workers (2009) used event related brain potentials to examine the effects of food deprivation on visual attention to food stimuli and observed that hunger enhances late positive potentials to food pictures, revealing that variations in motivational state enhances visual attention processes at the level of stimulus processing. Moreover, it has been demonstrated that food deprivation increases neural activity in higher level visual associative regions and amygdala when processing food pictures (LeBar et al., 2001).

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An interesting similarity comes from studies on addiction and drug dependence, which showed attentional bias for cigarette-related cues in smokers and alcohol-related cues in drinkers (Bradley et al., 2003; Field et al., 2004).

The value attributed to an object may fluctuate depending on our current needs and preferences. Indeed, research has demonstrated that alterations in the participants' internal state or needs (e.g., hunger-satiety) can influence the deployment of visual attention to motivationally significant stimuli (i.e., food). For example it has been observed that affective state of the perceiver may influence visual processes and attention orienting (for review see Barrett & Bar, 2009).

Research has started to explain how the brain codes and stores information about the value of visual stimuli acquired through association with reward and punishments (O'Doherty, 2004). The evidence suggests that value prediction is coded using dopaminergic circuit involving orbitofrontal cortex (OFC) and the ventral striatum (Knutson, 2001, O'Doherty et al., 2002; O'Doherty, 2004). In addiction Amygdala conduces to coding and updating value prediction (Paton et al., 2006). In line, animal and human studies on food devaluation indicate that the orbitofrontal cortex (OFC) may be critical for signaling changes in the reward value of food stimuli (for review see Murray et al., 2007). From the OFC, signals indicating the current reward value of foods may be conveyed to attention regions of the brain, such as the dorsolateral prefrontal cortex and the posterior parietal cortex (Cavada & Goldman-Rakic, 1989), thereby directing visual attention selectively to food targets that can best satisfy current needs (Mohanty et al., 2008). These findings suggest that value coding system could have important modulatory effects on visual cognitive processes such as selective

attention. To summarize, recent studies on humans showed that the attention and emotional evaluation interact to determine visual selection.

**Introduction to experiments One, Two and Three**

This chapter reviewed the state of art regarding the relationship between attention and emotion. Taken together, results from behavioral and neuroimaging studies showed that emotional processing is prioritized and it may affect cognitive processing as perception and selective attention. Because of their importance for adaptive and survival functions, emotional stimuli such as facial expressions of anger and fear were shown to preferentially draw attention even in a automatic way, when compared to neutral stimuli. These findings come from diverse paradigms, including those employing peripheral emotional stimuli and those in which affective and neutral stimuli are spatially separated. Thus, emotion and attention are strictly related as explained also by the overlaps of neural regions implicated in both processes. The crucial neural regions involved in this relationship are the amygdala, because of its role in emotion perception and its links to the primary visual cortex; the anterior cingulate cortex, related to selective attention and emotion evaluation and, the orbitofrontal cortex, related to affective evaluation and value learning. Although the importance attributed to processing of emotions, there is discrepancy between studies suggesting that emotional perception is automatic and those indicating that, on the contrary, emotional perception is not immune to the effects of cognitive processes and it depends on the availability of attentional resources.

Expanding about the relationship between emotion and perceptual and attentional processes, in the next three chapters, three studies will be reported that investigate some aspects, such as personality, motivational value of stimuli and social context that may influence perception of and attention towards emotions.

To date, some aspects of personality have received more attention than others. While anxiety is one of the most studied traits of personality in relation to attention to and discrimination of emotion, the influence of aggression traits still remains unclear. Moreover, the few studies to have investigated aggression concern mainly clinical populations. Behavioral evidence on whether aggression personality traits in normal subjects affect the ability of discriminate emotion is still lacking. Thus, this will be the focus of the study presented in chapter 3.

Chapter 4 and 5 will be more specifically dedicated to attentional processes.

Motivation may be considered critical for the relationship between emotion and attention. It has been suggested that attentive orienting does not preferentially respond only to emotional stimuli but rather to stimuli that are motivationally relevant for individuals. The experiment in chapter 4 aimed at investigating whether modulation of motivational value and pleasantness of a stimulus may influence visual selective attention. Finally, it should be noted that emotional enhancement of attention has often been investigated in isolated contexts with no consideration for the social nature of human beings. The study reported in chapter 5 examines whether and how the phenomenon of enhanced attention for emotional pictures is modulated by the presence of others.

# CHAPTER 3 - EXPERIMENT ONE

## Personality affects how we discriminate facial emotional expressions

### 3.1 Introduction

Emotions play an adaptive function and are critical in influencing our social interactions (Hext & Lunsky, 1997). Recognizing an emotion allows us to react promptly to external stimuli and to modulate our behavior accordingly. Each emotion or group of emotions can influence behavior in different ways, and have a different impact on our state and on how we organize perception, cognition and action (Izard, 1992).

It has been reported that individuals recognize emotions in others not only by using clues from facial expressions but also from the posture of the body, language and tone of voice (Loveland, 1997). However, the majority of studies on emotion recognition used facial expressions as stimuli, because the face is considered to be the primary reservoir of information about biological and other social characteristics (gender, identity, age and emotional state, Fox et al., 2007).

 Some emotions, such as joy, fear or anger emerge during the earliest stages of life. They have their own distinct characteristics and serve specific functions. Fear, for example, has been described as a stimulus that allows to quickly communicating to co-specifics the presence of a negative or dangerous stimulus that should be avoided (Mineka & Cook, 1993). Anger plays a similar adaptive role, by providing clear information on the source of the threat. Moreover, we can consider anger as a negative signal that discourages socially inappropriate and unexpected behavior (Averill, 1983).

The expression of joy, on the contrary, provides a positive sign of cooperation and affiliation during social interactions (Schmidt & Cohn, 2001) and has been shown to be the most easily recognized emotion, followed by sadness and anger (Walz & Benson, 1996; Matheson et al., 2005). This result, however, is in contrast with other studies showing that facial expression of anger were more easily recognized compared to expressions of joy and neutral expressions (Eastwood et al., 2001, Ohman et al., 2001).

In spite of these divergences, all available literature agrees in sustaining the critical importance of emotions in life, from the adaptive role they hold, to their influence in development of personality, and in shaping cognitive processes and social interactions. There is proof that the processing of emotions is influenced by several aspects, including personality. A large number of studies have shown that personality differences can influence the processing of emotions (for review see Calder et al., 2011). Studies that have used threat-related stimuli in individuals diagnosed with anxiety disorders (Mogg et al., 2004) and in non-clinical populations of individuals with low and high levels of anxiety (Bar-Him et al., 2007) concluded that anxiety may influence the behavioral responses to cues that communicate threat. Similarly, Fox and colleagues (2001, 2005) have investigated the role of anxiety, measured by using self-reported questionnaires, as determinant factor in the selective processing of emotional expressions. Their results showed that attention was biased towards expressions of fear only in subjects with high levels of anxiety. Accordingly, Mogg and Bradley (1999) showed that participants with high levels of anxiety had a greater propensity to direct their attention to expressions of fear and anger.

Evidence regarding the influence of personality in the processing of emotions also comes from brain imaging studies (fMRI), which show that some personality

dimensions may explain differences in neural responses to emotional stimuli. For instance, Canli and colleagues (2001) found that, in response to positive and negative emotional facial expressions, extroversion and nervousness traits correlated with the variability in activity of the amygdala, a key region for the processing of emotions, especially negative ones.

Aggression, defined as overt behavior with the intention of inflicting physical damage to another individual (Nelson & Trainor, 2007), is another important trait of personality, the influence of which has been less investigated compared to anxiety. Indeed, many studies concerning processing of emotions have investigated mainly anxiety and depression (Williams, 1997), omitting the fact that aggression might be associated with a greater sensitivity to negative stimuli as threat-related ones. In this regard, one must note that traits of aggression in personality may lead to respond differently to threatening stimuli, according to personal interpretation (Beck, 1976). Van Honk and colleagues (2001) tested subjects with low and high levels of aggression/anger in a version of a masked and unmasked emotional *Stroop* task and found that individuals with low levels of aggression/anger were facilitated in the task while subjects with a higher level of anger suffered an interference effect. They found no difference between the masked and unmasked conditions. In another study in which authors used a pictorial emotional *Stroop* task, an attentional bias to masked angry faces only in individuals with traits of high aggression was shown (Van Honk et al., 2000). Further findings on the link between aggression traits and personality come from clinical populations. For instance, Matheson and colleagues (2005) have investigated the ability to identify emotions in frequently aggressive and non-aggressive individuals with intellectual disability. Their results demonstrated that more aggressive participants had more

difficulties, compared to less aggressive ones, in labeling emotions. Another study on the same type of patients has found that aggressive individuals with intellectual disabilities had a tendency to interpret facial expressions more negatively when compared to non-aggressive individuals with the same disability (Walz & Benson, 1996).

The interaction between anxiety and aggression traits of personality in the reactivity to emotional facial expressions has also being investigated at the neural level through imaging techniques. Carré and colleagues (2010) have shown that features of aggression are correlated with the activation of the amygdala but only in men with high levels of aggression and not in women. Consistently, other evidence shows that individuals with high levels in expression of aggression showed an amplification of amygdala activity in response to crude representations of expressions of fear (Carlson et al., 2010).

The current study tested healthy subjects with high and low levels of aggression in two different tasks of recognition of basic emotions such as anger, fear and joy. The aim of the study was to investigate whether and how personality differences in the level of aggression may affect the ability to process distinct types of emotions. Two hypotheses are equally plausible: the first is that people that are more aggressive are also more used to experiencing anger, so they could be facilitated in recognizing negative emotions, such as anger, in others. In this case, we would expect participants with more aggressive personalities to be faster and more accurate in recognizing facial expressions of anger compared to other emotions. On the contrary, a second possibility is that people that are more prompted to aggression develop a form of insensitivity to emotions and to the expression of anger in particular. In this latter case we would expect impairment in recognition of facial expressions, in particular for angry faces.

Most of the literature on emotion recognition based its findings on a static presentation of emotions such as photographs of emotional facial expressions (e.g. Ekman & Friesen, 1976). However this has attracted criticism, because static stimuli are considered to be too simple type of stimuli, lacking the dynamic and contextual cues of natural stimuli (Moore et al., 1997). In addition, some studies have found that dynamic facial expressions of emotion have a facilitating effect on perceptual/cognitive processing (Sato et al., 2004, Sato et al., 2008). To avoid this problem, here we used two different tasks, a backward masking task (Williams et al., 2004; Phillips et al., 2003, 2004), featuring static images of emotional facial expressions followed by a neutral mask, and a morphing task, presenting emotional expressions that changed dynamically.

## 3.2 Materials and Methods

**Participants**

34 subjects (14 females; mean age = 25.15, range: 19-32; mean years of education = 15.2, range: 8-18), recruited through posted advertisements, participated in the experiment. None of the participants reported neurological or psychiatric disorders. They had normal vision or corrected to normal vision. Participants remained naïve as to the purpose of the study until debriefing. All procedure conformed to national and institutional guidelines and to the Declaration of Helsinki.

In order to assess the social level of each participant, we used the French self-report version of the NEO PI-R created in 1990, branching off the NEO PI (Costa & McCrae, 1985). Indeed the NEO PI-R is a well-established and standardized instrument to assess personality traits. The NEO PI-R (also called Big Five) features five broad dimensions of personality, each one composed of six facets:

*Neuroticism (N)*, including anxiety, angry, hostility, depression, self-consciousness, impulsiveness, vulnerability; *Extraversion (E)*, including gregariousness, assertiveness, activity, excitement-seeking, positive emotion, warmth; *Openness (O)*, including ideas, fantasy, aesthetics, actions, feelings, values; *Agreeableness (A)*, including trust, straightforwardness, altruism, compliance, modesty, tender-mindedness; *Conscientiousness (C)*, including competence, order, dutifulness, achievement striving, self-discipline, deliberation.

Each facet score is obtained by adding the scores (0, 1, 2, 3 or 4) on eight items. Thus, the NEO PI-R is composed of 240 items, and the scores on its six facets compose each

dimension score. Thus, the possible range of scores for each facet is 0-32, whereas the possible score range for each dimension is 0-192.

In order to assess the level of aggression of participants, we used the 34-item Aggression Questionnaire (AQ) by Buss and Perry (1992). This is a validated measure of aggression, divided into four scales: Physical aggression, a measure of the tendency to use physical force when expressing anger or aggression; Verbal aggression, a measure of the tendency to be verbally argumentative; Anger, a measure of anger-related arousal and sense of control and Hostility, a measure of feelings of resentment, suspicion and alienation. The total score is the sum of the overall level of anger and aggression reported by the subject. Participants responded to each item by indicating on a scale from 0 (not at all like me) to 5 (completely like me) how much the sentence corresponded to her/him. Before starting the experiment, the tests were explained to participants. Indeed they were informed that they had to give an answer to each item, that there was no right nor wrong answer, and finally that there was no time limit for filling in the questionnaire.

**Tasks**

*Morphing task* - The stimuli used in the experiment were standardized color digital photographs of 16 faces (8 females and 8 males) selected from the NimStim Stimulus Set (Tottenham et al., 2009). Images included the following expressions, displayed by a variety of models: anger, happy, fear and neutral. For each expression, images were manipulated with Fantamorph5 software in order to create 30 intermediate images starting from neutral and progressively changing to a given emotional expression. This allowed us to create the morphing task in which participants were initially presented

with a neutral face and each click of the subject corresponded to a slight change in the expression of the face. Participants were instructed to stop clicking as soon as they thought they could recognize an emotion, and were instructed to choose (forced-choice) among six possible alternatives: anger, fear, happiness, sadness, and surprise. Each of these emotions corresponded to a number on the keyboard. Stimuli were displayed one at a time on a computer screen using Presentation software that also recorded the responses provided by participants. As dependent variables, the number of clicks that each emotion needed to be recognized (click %), and the number of correct responses (accuracy %) were recorded.

*Backward Masking task* – Stimuli were standardized photographs of six different individuals (three men and three women) depicting fear, anger, happiness and neutral expressions (Ekman & Friesen, 1976). In this procedure, participants were presented with target-mask pairs of images, depicting different emotional and neutral facial expressions. Fearful, angry, happy targets and neutral control expressions were presented followed by a mask neutral expression. Following each target/mask trial, subjects made a forced-choice decision about the target face expression (choosing among fear, anger, happy and neutral) by pressing a button, and a corresponding confidence rating (1–9 scale; 1 = 'not at all confident' to 9 = 'extremely confident'). The latter served as a strict criterion for confirming the target face duration necessary for fully conscious (overt) perception of facial expressions. Time of target duration varied, while mask duration was stable during the experiment. We determined the point at which participants did not perform significantly differently from chance in discriminating fear from neutral, anger from neutral and happy from neutral.

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Each experimental session comprised 9 blocks of 24 target/mask pairs, randomized within subjects. Thus, the emotional target-mask pairs included fear-neutral, anger-neutral, and happy-neutral pairs. Moreover, a neutral-neutral pair was added as a control pair. Emotional targets and neutral controls appeared with equal frequency. The time interval between onset of the target and mask (SOA) was manipulated between blocks (23, 36, 50, 63, 76, 90, 103, 116 or 130 ms) with an inter-stimulus interval between target and mask of 0 ms, so that mask onset was immediate. The duration of mask stimuli was fixed and lasted 220 ms and each trial was preceded by a fixation cross. The interval between successive target– mask pairs was 1sec. Dependent variables recorded in this task were response time (ms) and accuracy (%) for emotion recognition.

## 3.3 Results

**Morphing task**

*Percentage of clicks* - First a general one-way ANOVA on percentage of clicks necessary to recognize each emotion was conducted. We found a strongly significant difference between emotions [$F_{(3, 99)} = 9.85$, $p < .001$]. Post hoc analysis showed that the easiest expression to be recognized was the happy facial expression (41%), followed by angry ones (47%). Fearful facial expressions resulted to be the most difficult with 57% of clicks necessary for recognition.
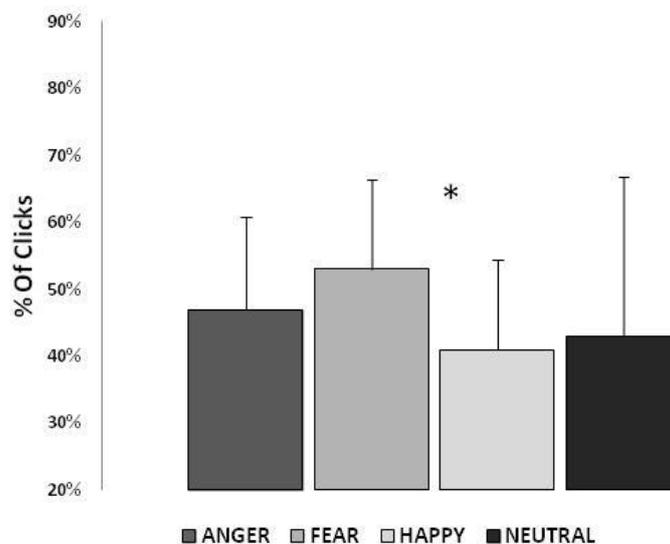


**Figure 3.2** Percentage of clicks necessary to discriminate anger, fear, happy and neutral facial expressions.

Successively, we explored the possibility that response patterns varied among participants, based on their traits of aggression. Therefore, we divided participants in high and low traits of aggression based on their score in the Aggression Questionnaire

(Buss & Perry, 1992). Thus, we calculated the median score (70): all of the participants who obtained a score higher than median value were assigned to the high AQ group and those who had a score lower than the median value were assigned to the Low AQ group. Participants who obtained a score equal to the median value were excluded from this analysis. A 2 (Group: Low vs. High) x 3 (Emotion: Anger vs. Fear vs. Happy) ANOVA on percentage of clicks showed a significant main effect of Group [F (1, 29) = 7. 60, p = .01], a significant main effect of Emotion [F (2, 58) = 33.55, p< .0001] but no significant interaction Group x Emotion (p=.09).
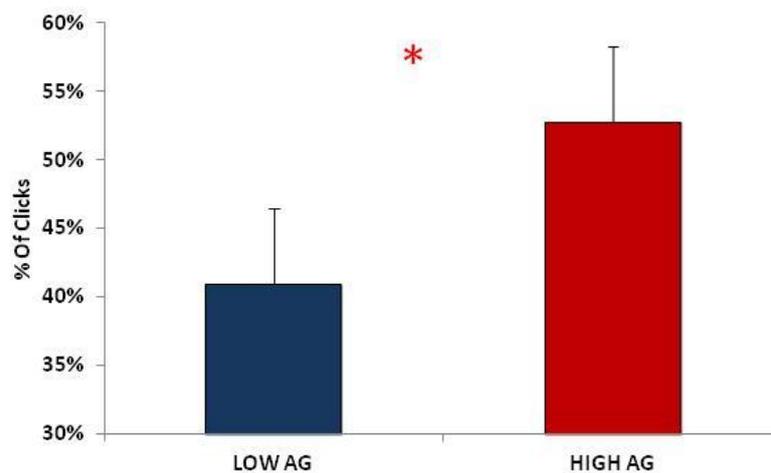


**Figure 3.3** This figure shows that High AQ compared to Low AQ participants need more morphological features to recognize emotional facial expressions (*p* < .01).

Post hoc analyses showed that participants in the Low AQ group needed significantly less morphological features to recognize emotions compared to participants in the High AQ group (40% vs. 52% of clicks, *p* = .01). Moreover, as in the general analysis, Newman-Keuls test on the main effect of emotion showed that fear required more facial characteristics (53%) to be recognized compared to anger (47%) and happiness (40%)

expressions (p < .001 in both cases). Angry and happy facial expressions also differed from each other (p < .01). These results indicate that aggression traits of personality make people less sensitive to discriminating emotional expressions.

*Percentage of Correct responses (Accuracy)* - We performed the same pattern of analyses as above for the participants' performance accuracy. The general one way ANOVA on Emotion (Anger vs. Fear vs. Happy vs. Neutral) showed a significant difference [F (3, 99) = 42. 78, p< .00001] in accuracy in detecting the three emotions. Specifically, the Newman-Keuls test found that the highest accuracy concerned happy facial expressions (91%), followed by expressions of Anger (82%), and Fear (65%). All of the expressions showed significant differences from each other (all *p<.01*) and from neutral.
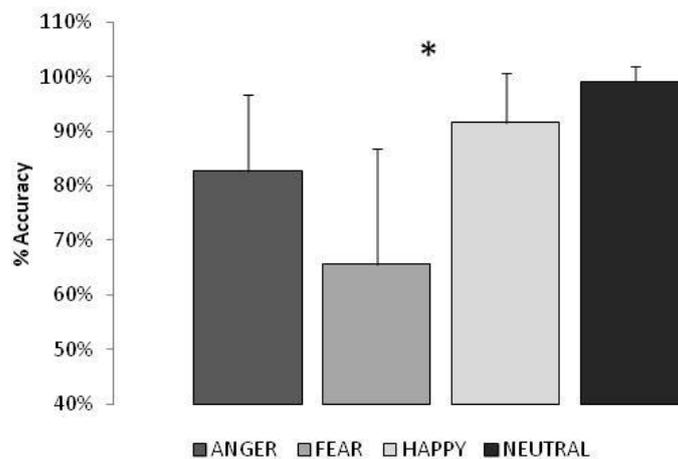


**Figure 3.4** Percentage of accuracy in discriminating facial emotional expressions.

As before, we conducted an analysis that compared accuracy in the Low and High AQ groups. Results showed a main effect of emotion according to which participants had the highest accuracy in detecting happy faces followed by anger and fear expressions.

Accuracy for fear expressions showed to be significantly lower compared to anger and happy expression ($p<. 01$), while anger and happiness did not differ from each other. There was a marginally significant main effect of group ($p = .05$). Participants in the High AQ group resulted to be slightly more accurate in recognizing emotions compared to those in the Low AQ group (84 % vs. 77 %). Interestingly, the analysis showed a strongly significant Emotion x Group interaction [$F (2, 58) = 6.95$, $p = .001$]. Post hoc comparisons indicated that Low and High AQ groups differed only in detecting fear facial expressions with significantly lower accuracy for fear recognition in Low AQ participants compared to all other conditions ($p< .001$ in all cases).
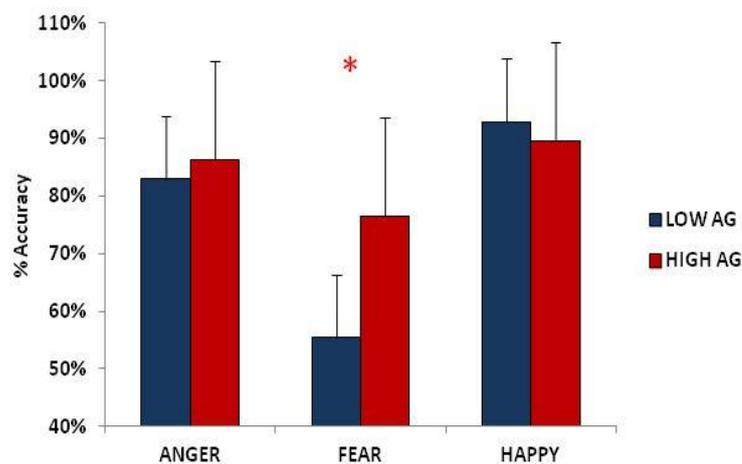


**Figure 3.5** This figure illustrates the significant interaction Emotion X Group ($p = 0.001$). Post hoc analysis showed that low and high AQ participants were significantly different only when identifying facial expressions of fear.

In addition, the five scales of the NEO-PR and the score of AQ were entered in a multiple regression as predictors with percentage of clicks and accuracy for recognition of each emotional expression as dependent variables. We found only a positive correlation between AQ score and percentage of clicks in recognizing happy faces ($\beta =$

.46, p <. 01), indicating that the more individual are aggressive, the more happy morphological features they need. No others significant correlations were found.

**Backward Masking Task (BM task)**

Because of some technical problems in the recording of responses during the BM task, one subject was discarded from the analysis, so the analysis was performed on 33 subjects.

*Percentage of correct responses (Accuracy)* - We observed that target expression recognition accuracy was not significantly above chance at 36–ms SOA (p = .13) for anger and at 50 – ms SOA (p = .17) for fear discrimination. The mean correct detection percentage for anger expressions at 36 ms was 55 % (SD= 0.27), while the mean correct detection percentage for fear expressions at 50 – ms SOA was 56% (SD= 0.35). Performance was clearly above chance level (p < .0001) for SOAs 76-130 ms for both anger and fear discrimination. Participants' performance for happy expressions and neutral control expressions showed a ceiling effect as accuracy for recognition of both these expressions resulted to be significantly above chance for all SOAs ( <.0001). The mean correct percentage discrimination for happy expressions at 23-ms SOA was 79% (SD= 0, 22). The corresponding value for neutral control expressions was 94%.

A general ANOVA on accuracy in recognizing emotions revealed that participants had significantly lower correct response percentage in discriminating negative emotional expressions compared to positive and neutral expressions [F(3, 96) = 34.40, p < .0001]. In particular, no significant difference between anger (67%) and fear (67%) and

between happy and neutral expressions emerged, while discrimination of happiness (92%) significantly differed from anger (p<.0001) and fear (p<.0001). A general 9 (SOA: 23, 36, 50, 63, 76, 90, 103, 116, 130 ms) x 4 (Emotion: Anger vs. Fear vs. Happy vs. Neutral) ANOVA comparing discrimination of different emotional expressions as function of SOA resulted in significant main effects of both Emotion (p<.00001) and SOA (p<.00001) and a significant interaction SOA x Emotion [(F= 3, 118) =, p< .0001]. Results showed that only accuracy for discrimination of negative emotional expressions varies as function of time presentation of the target stimulus. This variation is clearly explained in the Figure below.
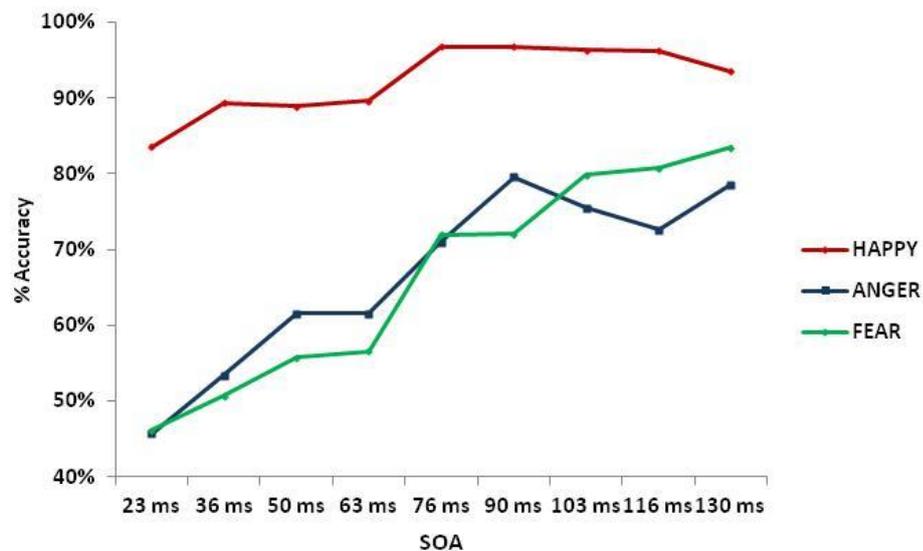


**Figure 3.6** Percentage of accuracy in BM task as function of SOA. Interaction SOA x Emotion $p < .0001$.

As for the morphing task, we conducted an ANOVA 2 (Group: Low AQ vs. High AQ) X 3 (Emotion: Anger vs. Fear vs. Happy) comparing accuracy in recognition of facial expressions of emotions in the Low and High AQ participants. The analysis showed a main effect of emotion [F (2, 56) = 39.14, $p < .0001$] reflecting, as in the general

ANOVA, higher accuracy for happy facial expressions (93%) compared to fear and anger (respectively 68% and 69%). No main effect of group appeared. Interestingly, the analysis revealed a significant Emotion X Group interaction [F (2, 56) = 3.605, $p < .05$]. Planned comparisons showed significant difference between Low and High AQ groups only in detection of fearful facial expressions ($p < .05$). High AQ participants were significantly more accurate than Low AQ participants in detection of fear expressions. Accuracy for happy and angry expressions was not affected by the aggression level of participants.
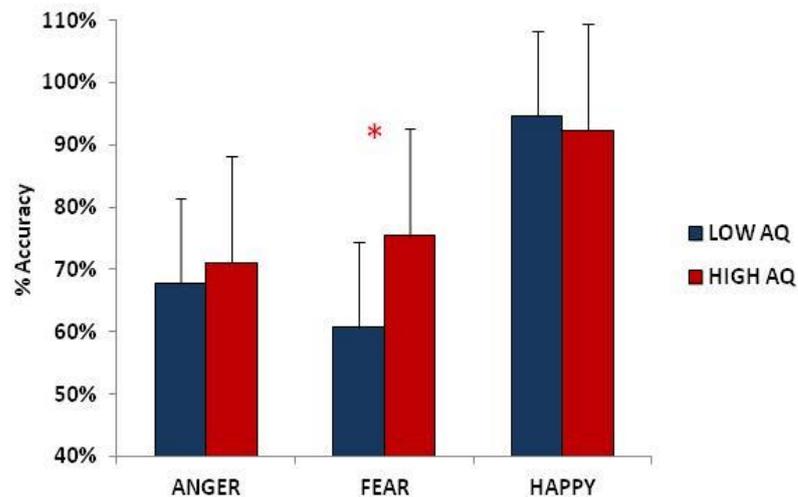


**Figure 3.7** Significant interaction Emotion x Group. The Low and High AQ groups differ only in recognition of fear with significantly less accuracy in the Low AQ group compared to the High AQ group.

*Response times (RT)* - A one way ANOVA on response time (RT) showed significant differences in recognizing anger, fear and happy emotional expressions [F (3,96)= 54.23, $p < .00001$]. Post hoc comparisons showed that participants were significantly slower in recognizing Anger (2415 ms) compared to fear (2191 ms, p< .01) and happy

(1684 ms, *p*< .001) emotional expressions. Fear and happiness also resulted to be significantly different from each other (*p* < .001).
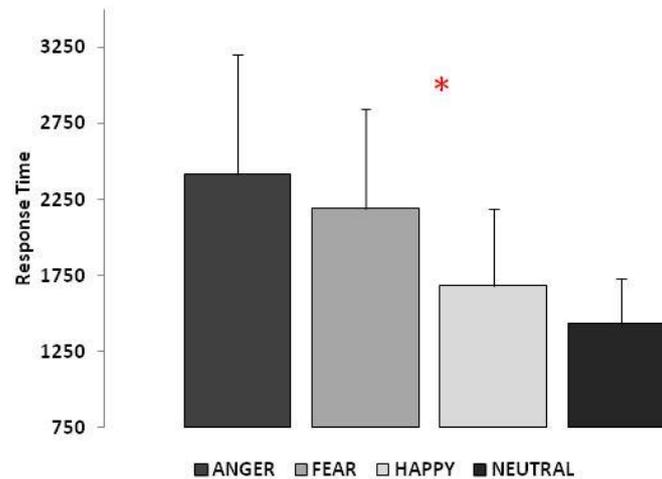


**Figure 3.8** Response time in discrimination of emotional facial expressions

Aiming to investigate whether time responses for each emotion varied as function of SOA, we performed a general 9 (SOA) x 4 (Emotion) repeated measures ANOVA. The analysis reported significant main effects of Emotion (*p*< .0001), with slower response time for negative expressions compared to positive (anger and fear did not differ each other) and a main effect of SOA (*p*<.0001), with slower response time for unconscious (23, 36, 50, 63 ms) compared to conscious (76, 90, 103, 116 ms) SOA. Nevertheless, no significant SOA x Emotion interaction was found.

Importantly, we investigated the relationship between personality traits and time response for recognition of emotional expressions. Again, we performed an ANOVA 2 (Group: Low AQ vs. High AQ) X 3 (Emotion: Anger vs. Fear vs. Happy) on response times. This analysis showed only a main effect of emotion, indicating significantly

longer response times to recognize anger facial expressions (2291 ms) compared to fear (2090 ms) and happy (1614 ms, *ps* < .01 in all cases).

In addition, the five scales of NEO-PR and the score of AQ were entered in a multiple regression as predictors with RT and accuracy for each emotional expression as dependent variable. The analysis yielded no significant results.

**3.4 Discussion**

A relationship between personality and emotion has been previously demonstrated in many ways. For instance, studies on emotional attention showed that traits of anxiety correlate with a bias toward fear and anger expressions (Mogg & Bradley, 1999); evidence from neuroimaging studies reported correlation between personality traits and activity in amygdala, when participants were exposed to positive and negative emotional facial expressions (Canli et al., 2001).

Facial expressions typically contain cues that allow to quickly understanding others' emotional states (Fox et al., 2007). This makes the ability to recognize emotions from facial expressions critical in processing socially relevant information (Heuer et al., 2010). Nevertheless, there are no as yet clear behavioral evidence regarding the influence of specific personality traits, such as aggression, on identification of facial expressions and, which are the individual characteristics that may influence this important ability is still a matter of concern. The aim of the current study was to investigate the role of traits of personality, in particular aggressive traits, in modulating how people recognize facial emotional expressions. We tested participants in two different tasks of emotion recognition that used both static and dynamic stimuli,

expressing fear, anger or happiness. Measures of personality by self-report questionnaires were collected.

For what concerns recognition of emotion in general, using dynamic stimuli paradigm (morphing task), we showed that happiness was the easiest emotional facial expression to be recognized, followed by anger and fear, as the most difficult. Indeed, less morphological characteristics were needed to identify happy facial expressions and participants were significantly more accurate in recognizing this emotion compared to others, such as fear and anger. Results from the static stimuli paradigm (BM task) confirmed these results, showing that happy faces were still the easiest to be recognized even at a level of unawareness. Indeed recognition of happy faces seemed not to be influenced by the time of presentation. On the contrary, only recognition of facial expressions of negative emotions such as fear and anger resulted to vary as function of the time presentation. Moreover, recognition of happy faces required shorter response time, followed by fear and anger.

These findings are in line with previous results indicating happiness to be the easiest emotion to be identified (Waltz & Benson, 1996; Matheson et al., 2005), whilst fear the most difficult (for review see Adolphs, 2002). Early studies on universality of emotion facial expression (Izard, 1971; Ekman, 1972, Ekman et al., 1987) showed that happy faces reached the highest score in recognition across cultures. Neuropsychological studies also reported interesting evidence: Adolphs and colleagues (2003) observed that after extended bilateral temporal damage only recognition of happy static faces was preserved, suggesting that recognition of positive and negative emotions draw upon anatomically separable brain regions. In our study, negative and positive facial expressions of emotions significantly differed in response time and accuracy. This,

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however, is not necessarily consistent with the hypothesis of dissociable anatomical and functional processes for pleasant and unpleasant emotional facial expressions (Adolphs, 2002), but rather may suggest that negative emotions are more difficult to recognize, as compared to positive emotions, and therefore are more easily disrupted after brain damage.

In an interpersonal perspective, the expression of joy has been interpreted as a sign of cooperation and affiliation (Schimdt & Cohn, 2011) and provides important information to interact with others, which is indispensable for human well-being (Insel & Fernald, 2004). Moreover, it is noteworthy that, developmentally, happiness is the first emotion to be recognized, followed by sadness (Izard, 1971).

Expressions of fear and anger were shown to be more difficult to be recognized, in both tasks, as they required more morphological features and longer time. We can find an explanation of this data in how conceptual knowledge of emotions might be organized. Russel (2003) proposes a continuum of emotional valence that stretches from "happy" to "unhappy", where happiness and sadness are the two extremes of the line. These two emotions should be therefore categorized as basic emotions and should be easily detectable. On the other hand, fear and anger should fall in between of the continuum, requiring more information to be identified. Thus, valence should be the main dimension along which facial expression are evaluated (Russel, 2003). Nevertheless recognition of sadness was not included in this work, so this remains only a pure speculation that would require further empirical evidence to be demonstrated.

More important for the purpose of the present study, we found that different level of aggression in personality may affect individuals' ability to recognize emotional facial expressions. We focused on the influence of aggression traits as it has been less

investigated in the past compared to other personality traits such as anxiety. The overall effects of experiencing anger are enormous. While anger is an emotional, physiological and cognitive internal state, aggression is considered as the tendency to action. Traditionally, aggression has been defined as overt behavior with the intention of inflicting physical damage to another individual (Nelson & Trainor, 2007). It is a complex social behavior that evolved in the adaptive context of defending or competition for resources (Berkovitz, 1993) but when expressed out of these contexts may have disastrous consequences such as uncontrolled impulsivity and impaired recognition of social cues. Accordingly, our results showed that higher traits of aggression impair recognition of emotional facial expressions in general. Indeed individuals with aggressive tendencies exhibited less sensitivity to dynamic stimuli and need more morphological features in order to recognize facial expressions of emotions. This is also consistent with previous studies indicating that patients diagnosed with intermittent explosive disorder (IED ) which are characterized by aggressive impulsivity (Best et al., 2002), perform poorly on facial emotion recognition tasks as well as aggressive patients with mental disability (Matheson et al., 2005; Walts & Benzon, 2006). Nevertheless, accuracy was not influenced. Interestingly, our results on accuracy showed that individuals with greater tendency to aggression were significantly more accurate in labeling fear facial expressions compared to individuals with lower tendency to aggression. This result is in some way in accordance with previous studies that found aggressive individuals to be equal, or better than, non-aggressive peers at labeling anger emotional expressions (McKenzie et al., 2000). Indeed, it is likely that people that often experience negative emotion such anger (which is also strictly related to fear), are biased towards this kind of expressions, despite their general impairment in recognition

of emotions. Consistent with this latter hypothesis, we found that more aggressive individuals had difficulty in identifying happy facial expressions. The results from the backward masking task strongly confirmed the facilitation in recognition of fearful expressions in more aggressive individuals. Interestingly, the results from accuracy in the backward masking task mirrored exactly those from accuracy in morphing task, indicating that, despite a general impairment in discrimination of emotions, aggressive people were more accurate in recognizing fear facial expressions compared to non aggressive people. This result may be explained by the complementarities between fear and aggression. It is likely indeed that aggressive people, which have the tendency to dominate and to attack, are also more used to detect fear in the others during their social interactions. This hypothesis is in line with previous neuroimaging observations that showed individuals high in anger expression to have amplified left amygdala response to representations of fearful faces (Carlson et al., 2010) and suggested this to be a trigger for aggressive behavior. Previous studies specifically implicate amygdala and prefrontal cortex in aggression (Davidson et al., 2000): for instance, it has been shown that amygdalar dysfunction lead to impulsive aggressive behavior (Van Elst et al., 2000), and that specific damage of OFC is also associated with aggression, impulsivity and scant control of emotions (Damasio et al., 1994; Anderson et al., 1999). One possibility is that aggressive individuals suffer from a lack of prefrontal control on subcortical regions. This hypothesis is in line with theoretical models proposing that humans possess a cognitive mechanism that mediates suppression of aggression and predispose to withdraw in distress contexts (Blair, 1995). Absence or impairment of this mechanism would lead to aggressive behavior and to a dysfunctional development of morality. Accordingly, additional studies showed that psychopats, which are usually

marked by aggressive reactivity, are also impaired in inhibitory control and have impaired functioning of prefrontal cortex (Blair, 2001; 2010).

In sum, we showed that personality and tendency to aggression in particular may affect recognition of emotions ability. Since facial expression of emotion is an important cue of social relevant information, we confirmed and expanded on the idea that individual differences in personality are critical aspects for good functioning of social and interpersonal behavior.

## CHAPTER 4 – EXPERIMENT TWO

## Food pleasantness affects visual selective attention

### 4.1 Introduction

Visual selective attention is an adaptive mechanism that allows fast and accurate perception of the environment by focusing processing resources on relevant objects (e.g., Corbetta & Shulman, 2002; for review see Yantis, 1997). In recent years, abundant research has suggested that the emotional significance of sensory events can determine how visual attention is allocated (see Lang et al., 1997; Vuilleumier, 2005). Convergent studies in social cognition, cognitive and clinical psychology (e.g., Bradley et al., 1997; Fox et al., 2002; Pratto & John, 1991; Öhman et al., 2001; Williams et al., 1997) have shown that people more readily pay attention to emotional stimuli such as snakes, spiders, and angry faces than neutral stimuli, suggesting that emotional information has a special propensity to attract and/or hold visual attentive processing. Consistent with this, brain imaging studies in human subjects have revealed enhanced responses to emotional stimuli relative to neutral stimuli in several brain regions (Sabatinelli et al., 2005; Vuilleumier et al., 2001), thus providing a plausible substrate for their greater competitive strength in attracting attention, as observed behaviourally. Furthermore, emotional effects in visual attention are greatly enhanced in individuals with high levels of trait- and state-anxiety (Bradley et al., 1998; Fox, 1993; Fox et al., 2001; Williams et al., 1996), which may play a role in the development and/or maintenance of clinical anxiety disorders (Mogg & Bradley, 1999;).

Although much of the past research on emotional attention has concentrated on negative or threat-related emotions (e.g. fear or anger), also pleasant or rewarding stimuli (e.g. food, addictive drugs) can sometimes show similar advantage in the competition for attentional resources. Hunger-satiety manipulation has provided a model system to explore the influence of motivationally significant stimuli (i.e., food) on the deployment of visual selective attention. For example, Channon and Hayward (1990) found, using the modified Stroop task, that fasting subjects were slower in naming the colours of food-related words than control stimuli, in comparison with non-fasting subjects, which was consistent with a hunger-related processing bias. Piech and colleagues (2010) reported that food pictures were more powerful distractors when participants detecting targets within a continuous stream of images were hungry, than when they were sated. Likewise, studies with the visual probe task (see below) in a non-clinical sample revealed that food deprivation is associated with increased attentional bias for food-related words (Mogg et al., 1998; Placanica et al., 2002), compared to satiated state. More direct evidence that hunger increases selective attention to food pictures has also been obtained using neuroimaging measures (Mohanty et al., 2008), and event-related brain potentials (Stockburger et al., 2009). Finally, recent research has shown that attentional bias to food-related cues is exacerbated in people who report a predisposition to eat in response to external food cues (Brignell et al., 2009), and in obese individuals (Nijs et al., 2009), who retain an enduring tendency to orient to food stimuli despite feeding and decreased self-report of hunger (Castellanos et al., 2009).

Thus, ample evidence suggests that food-related attention is modulated by transient motivational states of hunger and satiety both in normal and clinical samples. Crucially, however, previous studies assessed the effects of hunger and satiety on visual selective

attention in different groups or sessions (held days or weeks apart), without addressing how attention is allocated to different foods as their relative motivational/hedonic value transiently changes during the course of a meal.

To examine this issue, we exploited the fact that the pleasantness of the sight and of the taste of a food eaten to satiety decreases temporarily relative to other foods not eaten in the meal (Rolls et al., 1981). In this case, one is still motivated to eat other unconsumed foods, particular those with different orosensory characteristics. This phenomenon has been termed sensory-specific, or selective satiety (Rolls et al., 1981), and provides a useful technique to manipulate the pleasantness and reward value of a stimulus, without modifying its physical characteristics (Kringelbach et al., 2003). Accordingly, any differences observed between behavioural responses to a particular food stimulus before and after satiety can be attributed to the change in the motivational/hedonic value of that food. Furthermore, by measuring responses to another food that is not eaten in the meal, it is possible to control for nonspecific confounds, such as increases in thirst, gastric distension and levels of glucose and lipids after feeding. This technique has been used in functional magnetic resonance imaging (fMRI) studies to determine brain regions involved in representing the reward value of olfactory stimuli (Gottfried et al., 2003), and the subjective pleasantness of food (Kringelbach et al., 2003). However, this technique has never been used before to examine incentive-based control of visual selective attention.

In the present study, one of two palatable foods was devalued by feeding participants to satiety on that food. Both before and after the selective satiety procedure, participants tasted and rated the pleasantness of the two foods and then viewed the same as stimuli on a computer screen while attentional selection was assessed by means of a visual

probe detection paradigm, a common test of attentional bias (MacLeod et al., 1986; see also Bradley et al., 1997; Mogg et al., 1995). In this task, two pictures were presented simultaneously on the computer screen, one on each side of a central fixation point. One of these pictures depicted one of the tasted foods, and the other a control stimulus unrelated to food or eating. Each picture pair was presented for either a relatively brief (200 ms) or long (700 ms) duration, and was followed by a probe which appeared in the location of one of the preceding pictures. Participants were required to detect the location of the probe by pressing one of two response keys. An attention bias for food images would be indicated by faster response times to probes replacing food rather than control pictures, as response times are typically faster to probes which appear in attended, rather than unattended, locations.

To sum up, we examined attentional bias towards food stimuli before and after subjects were fed to satiety on one of those foods (selective devaluation). Our main hypothesis was that attentional bias for food eaten (devalued) would decrease significantly from pre- to post-satiety, parallel to the subjective pleasantness for the consumed food. By contrast, we expected that attentional bias for food not eaten (valued) would not show any such decrease.

## 4.2 Methods and Materials

### Participants

Twenty-six healthy right-handed volunteers (15 females, 11 males) participated in the experiment. The average age of the subjects was 25.1 (range 19-34). All participants were free of current or past psychiatric or neurological illness as determined by history. The eating attitudes test (EAT-26) (Garner et al., 1982) was administered and indicated no eating disorders in any of the subjects (mean score, 3.6; range, 0 –14; all scores were under the 20 point cut off).

Participants were instructed to fast for at least 6 h prior to arriving in the laboratory, but were permitted to drink water. Prior to participation in the experiment, subjects were pre-screened to ensure that they found both solid foods (i.e., Ritz crackers and Canestrelli cookies) to be pleasant, and to ensure that they were not overweight, on a diet, or planning to go on a diet. Participants remained naïve as to the purpose of the study until debriefing.

The experiment was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki (International Committee of Medical Journal Editors, 1991), and was approved by the Ethical Committee of the Department of Psychology, University of Bologna.

**Stimuli**

Solid food stimuli included Ritz crackers (Kraft, Italy) and Canestrelli cookies (La Sassellese, Italy). These foods were selected because they are consistently identified as appetizing and are distinguishable in their flavour (one is savoury and the other is sweet) and texture, thereby facilitating sensory-specific satiety and minimize the likelihood of the subjects developing a generalized satiety to all solid foods. To assess possible order (i.e., practice or fatigue) effects across sessions (since the post-satiety session was always completed after the pre-satiety session), we also included oat bran biscuits (Molino Chiavazza, Italy) as hedonically neutral food stimuli.

Visual stimuli were 4 digitized colour photographs depicting the three foods and a telephone token, used as a distracter stimulus. The images were approximately 4.5 cm wide by 4.5 cm tall. The mean luminance and contrast levels of the 4 photographs were slightly adjusted with the Adobe Photoshop™ 7.0 program to achieve uniform values for the different pictures.

**Procedure**

All testing took place between 11 a.m. and 2 p.m. The experiment consisted of two sessions: pre-satiety and post-satiety. There was a break between sessions during which participants were fed to satiety on one of the two palatable foods (selective satiety treatment). More specifically, subjects were presented with a tray containing three transparent bowls, each containing one kind of food (Ritz crackers, Canestrelli cookies and oat bran biscuits, respectively), and were invited to eat either Ritz crackers or Canestrelli cookies for their lunch, and to stop eating when they felt pleasantly satiated.

The subjects were not informed in advance which solid food they would be invited to consume. The specific food used for devaluation was fully counterbalanced across subjects, such that thirteen subjects were fed to satiety on Ritz crackers, and thirteen subjects were fed to satiety on the Canestrelli cookies. This selective food devaluation procedure served to devalue one of the food stimuli, although leaving the motivational value of the other stimulus relatively intact. Note that subjects viewed all three types of foods (valued, devalued and neutral) during feeding, thereby minimizing the possibility that attentional effects were simply due to overexposure to one type of food (rather than to change in the subjective pleasantness) during the selective satiety procedure.

At the beginning of each session, we collected behavioural ratings, including hunger level (0, full; +10, starving), pleasantness (-5, very unpleasant; +5 very pleasant), and intensity (-5, very weak; +5, very intense) of the taste of the three foods (Ritz crackers, Canestrelli cookies, and oat bran biscuits) presented in random order. In each session, participants completed first the hunger rating task, followed by pleasantness and intensity rating tasks, which were administered in counterbalanced order across participants.

After the behavioural rating tasks, participants performed a computer-based visual probe task similar to that used by Bradley and colleagues (1998, 2003). The trial sequence is illustrated in Figure 1. Participants initiated each trial by pressing the space bar. A fixation point appeared at the center of the screen for 800 ms. Next, two colour pictures were presented side by side, flanking the central fixation point. The pictures were separated by approximately 14 cm from center to center. One photograph depicted one of the three foods, and the other a telephone token of comparable size and luminosity. These task-irrelevant images were presented for either 200 or 700 ms and

then removed. Next, the probe (@ sign) was presented for 100 ms at the location previously occupied by one of the two images. Participants were told to respond immediately to the left or right location of the probe by pressing one of two response keys (left and right arrow keys of the keyboard). They were instructed to look at the fixation point at the start of each trial. The duration of the inter-trial interval (ITI) varied randomly between 1000 and 1500 ms.
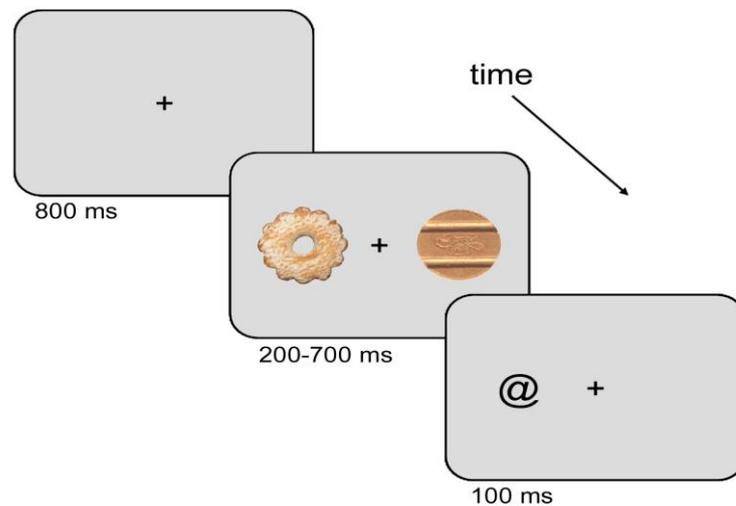


**Figure 4.1**. Schematic illustration of the experimental paradigm.

Participants completed 24 practice trials and one block of 144 trials in each session. Each block was composed of six repetitions of 24 randomly intermixed unique trials, resulting from the factorial combination of 3 food types (devalued, valued or neutral), X 2 food locations (left or right), X 2 exposure duration (200 or 700 ms), X 2 probe positions (left or right). Thus, nothing about the design of the experiment allowed subjects to predict which image would be probed.

## 4.3 Results

***Effects of selective satiety on behavioural ratings*** - Participants showed a significant reduction in experienced hunger ratings after the selective satiation procedure, $t(25) = 20.01$, $p < .0001$). Mean hunger ratings were 7.46 ($SD = 1.47$) before satiety, but dropped to 1.85 ($SD = 0.73$) after satiety.

Subjective pleasantness and intensity ratings for the three different food rewards before and after feeding to satiety with one of the foods are plotted in Figure 2. Mean subjective ratings were analysed by a 3 (food: devalued, valued or neutral) X 2 (session: pre- or post-satiety) X 2 (rating type: pleasantness or intensity) repeated-measure analysis of variance (ANOVA). The analysis showed main effects of food, $F(2,50) = 85.27$, $MSE = 2.06$, $p < .001$, $\eta_p^2 = .77$, session, $F(1,25) = 37.38$, $MSE = 1.7$, $p < .001$, $\eta_p^2 = .47$, and rating type, $F(1,25) = 31.15$, $MSE = 2.07$, $p < .001$, $\eta_p^2 = .55$, which were qualified by a significant food X session X rating type interaction, $F(2,50) = 11.14$, $MSE = 0.82$, $p < .001$, $\eta_p^2 = .31$. Post hoc Newman-Keuls tests showed that the subjective pleasantness of the foods eaten (devalued) decreased markedly from pre- to post-satiety, $t(25) = 9.23$, $p < .0001$, whereas the pleasantness of the foods not eaten (valued) and the neutral foods did not show any such changes (both $ps > .05$), reflecting the efficacy of the selective satiation procedure in lessening the value of the food eaten. On the other hand, no significant changes were observed for the subjective intensity of taste of the food stimuli when comparing pre- to post-satiety ratings (all $ps > .05$), confirming that it is the perceived pleasantness and not the perceived intensity of taste of the devalued food that decreases following satiation (Rolls et al., 1981).
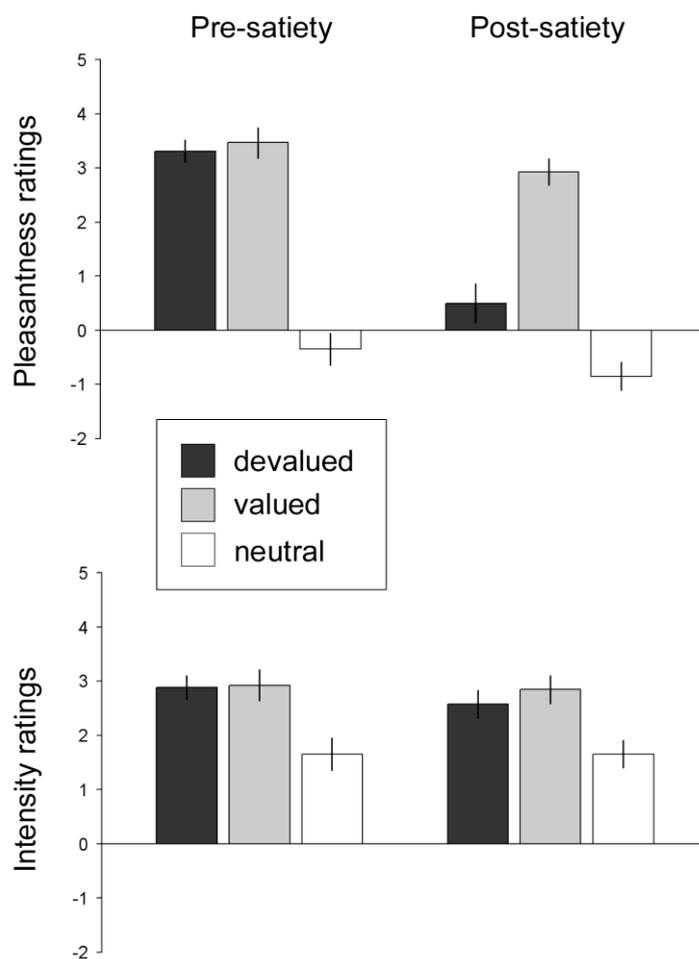
**Figure 4.2** Upper panel: Subjective pleasantness ratings on a scale of -5 (very unpleasant) to +5 (very pleasant) for the food eaten (devalued), the food not eaten (valued) and the neutral food, before and after the selective satiety procedure. Lower panel: Subjective intensity ratings on a scale of -5 (very weak) to +5 (very intense) for the food eaten (devalued), the food not eaten (valued) and the neutral food, before and after the selective satiety procedure.

*Effects of selective satiety on response times in the visual probe task* - Response latency above 1,500 ms or below 200 ms were deleted from the data set, as were all incorrect responses, resulting in the removal of 1% of the data. Table 4.1 presents mean probe detection latencies for each experimental condition.

| Session and exposure duration | Devalued | | Valued | | Neutral | |
|---|---|---|---|---|---|---|
| | *Probe replacing food stimulus* | *Probe replacing control stimulus* | *Probe replacing food stimulus* | *Probe replacing control stimulus* | *Probe replacing food stimulus* | *Probe replacing control stimulus* |
| Pre-satiety session | | | | | | |
| Short duration (200 ms) | 347 (31) | 375 (43) | 345 (28) | 373 (40) | 353 (24) | 371 (52) |
| Long duration (700 ms) | 342 (20) | 364 (31) | 345 (20) | 366 (42) | 352 (40) | 360 (36) |
| Post-satiety session | | | | | | |
| Short duration (200 ms) | 359 (54) | 365 (39) | 339 (41) | 373 (39) | 347 (37) | 354 (45) |
| Long duration (700 ms) | 363 (30) | 357 (37) | 335 (25) | 361 (34) | 349 (37) | 351 (41) |

**Table 4.1** Mean response times (and standard deviations) to probes for each experimental condition of the present study. Response time is in milliseconds (ms).

To examine our prediction directly, however, attentional bias scores were calculated for each participant by subtracting the mean response time to probes replacing food images from the mean response time to probes replacing control images. Greater bias scores indicate greater attention to food stimuli, relative to control stimuli (i.e., an attentional bias towards food images). Bias scores were calculated separately for each type of food

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picture (valued, devalued and neutral) and exposure duration (200 and 700 ms), in the pre- and post-satiety session.

Attentional bias scores were subjected to a 3 (food: devalued, valued or neutral) X 2 (session: pre- or post-satiety) X 2 (exposure duration: 200 or 700 ms) repeated-measure ANOVA. The analysis revealed a significant main effect of food, $F(2,50) = 10.05$, $MSE = 992$, $p < .001$, $\eta_p^2 = .29$, indicating that attentional bias was greater overall for probes on valued food than for probes on devalued and neutral food (both $ps < .05$), while bias scores between these two latter conditions were not different from each other ($p > .05$). There was also a marginally significant main effect of session, $F(1, 25) = 3.84$, $p = .06$, $MSE = 1793$, $\eta_p^2 = .13$. More critically, there was a significant two-way interaction between food and session, $F(2, 50) = 7.32$, $p < .01$, $MSE = 866$, $\eta_p^2 = .23$, which is summarized in Figure 3. Post hoc Newman-Keuls tests showed that the attentional bias for probes at the location of the devalued food was significantly reduced in the post-satiety relative to the pre-satiety session ($p < .001$), whereas there was no such decrease for probes at the location of the valued food, ($p = .6$). No significant difference was also found between attentional bias for probes replacing neutral foods in the pre- *vs.* post-satiety session ($p = .16$), indicating no significant order effect. Furthermore, attentional bias was greater for probes on valued food than for probes on devalued food in the post-satiety session ($p = .001$), whereas there was no significant difference between these conditions in the pre-satiety session ($p = .8$). There were no other significant results.

Next, we conducted post hoc one-sample t-tests to assess whether or not the attentional bias was significant within each condition (Bonferroni corrected alpha level for these post hoc tests was .008). Results showed that mean bias score (averaged across exposure durations) for valued food was significantly greater than zero in the pre-satiety

($t$ (25) = 3.62, $p$ = .002), and post-satiety session ($t$ (25) = 4.97, $p$ = .001). In contrast, bias score for devalued food was significantly greater than zero in the-pre-satiety ($t$ (25) = 4.61, $p$ = .001), but not in the post-satiety-session ($t$ (25) = .03, $p$ = .9). There were no other significant results.
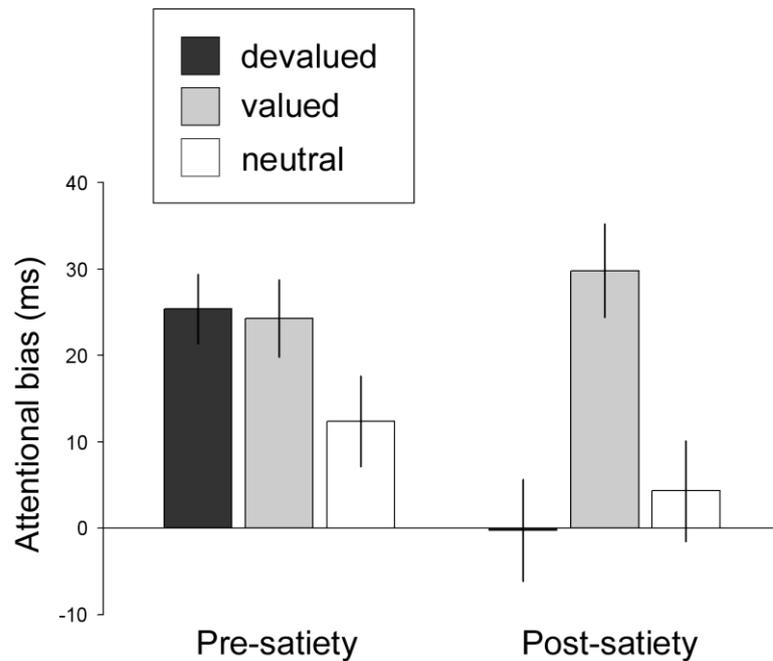


**Figure 4.3:** Mean attentional bias (collapsed across delays) for probes presented at the location of the devalued, valued and neutral food, in the pre- and post-satiety session. Error bars indicate standard errors.

Finally, to explore the relationship between attentional effects and subjective reports of the pleasantness of food, changes in attentional bias scores were calculated by subtracting the attentional bias score in the pre-satiety session from the attentional bias scores in the post-satiety session, separately for each type of food (data averaged across exposure durations). Negative values of these scores indicate reduced attentional bias for food pictures after the satiation procedure. Pearson correlations were calculated between changes in bias scores and changes in rated pleasantness (calculated by

subtracting the pre-feeding rating of the pleasantness of the taste of a food from the post-feeding rating of the pleasantness of the same food) for each type of food. These analyses revealed that changes in bias scores for devalued food were significantly associated with changes in the pleasantness ratings, $r(24) = .67$, $p < .001$, indicating greater decrease in attentional bias for consumed food in those participants who reported greater change in the pleasantness of that food. There was no other significant result.

## 4.4 Discussion

This study provides behavioural evidence that a transitory decline in the pleasantness of the taste of a food plays an important role in modulating the functioning of covert mental processes, such as visual selective attention. Using a visual probe task as an index of attentional bias, we found that a food-specific devaluation treatment induced a considerable reduction in the attentional bias for devalued foods, parallel to the perceived pleasantness of those foods, whereas visual selective attention to valued foods did not change significantly. In the protocol employed in the present study, the relative pleasantness of two palatable foods was varied during the course of the experiment by allowing hungry subjects to feed to satiety on one of those foods (Kringelbach et al., 2003; Rolls et al., 1981). Indeed, rated pleasantness for the consumed food showed a marked decrease after the selective satiety procedure, in the absence of relevant changes for the unconsumed food. As such, these effects are distinct from alliesthesia, a change in the hedonic evaluation of food and food related stimuli produced by fluctuations in homeostatic needs (Berridge, 1991; Cabanac, 1971), which, unlike selective satiety, is

not specific to the external sensory stimulation received (such as the taste of a particular food eaten during satiation). In this regard, it is unlikely that the selective decrease in attentional bias for the consumed food is simply a result of extensive exposure or familiarity with that food during the selective satiety procedure because participants viewed all food stimuli during feeding (see Method). Furthermore, the significant correlation between change in attentional bias and subjective pleasantness of the food eaten also supports the contention that the attentional effects seen here were indeed modulated by the hedonic value of stimuli rather than by their degrees of familiarity.

Another result of the present study is that the attentional bias for food pictures did not exhibit a significant degree of variation over the two picture durations examined here, namely, 200 and 700 ms. This finding therefore suggests that a bias for food pictures operates in both initial orienting and the maintenance of attention. This observation is consistent with evidence from previous visual probe studies of attentional biases for food (Brignell et al., 2009), and drug-related cues (e.g., biases for cigarette-related cues in smokers, and alcohol-related cues in heavy drinkers, e.g. Bradley et al., 2003; Field et al., 2004), which have used relatively longer exposure durations (2000 ms) than those used here. Finally, the present findings were observed while participants were required to make a speeded discrimination judgment on the probes, and there was no advantage gained from paying more attention to food than control stimuli, since food cues were unpredictive as to the location of impending probes. These results, then, support the conclusion that the motivational regulation of visual attention is to a certain degree a spontaneous and involuntary process (Bargh, 1997; Piech et al., 2009 Stockburger et al., 2009), operating even when people are not explicitly required to assess the affective value of stimuli, and these are completely task-irrelevant. More generally, our findings

suggest that mechanisms of visual selective attention are flexibly regulated to optimize interaction of the individual with the environment, depending on current motivational state (Lang et al., 1997). Such a feature may be fundamental in providing attentive processes with both flexibility and self-regulation properties (Della Libera & Chelazzi, 2006).

Previous evidence revealed that the deployment of visual attention in humans can be modulated by external financial reinforcers, such as monetary rewards (Della Libera & Chelazzi, 2006; Small et al., 2005). Here, we report that short-term changes in the hedonic evaluation of the food's taste during a meal may also influence visual selective attention. The present findings are perfectly consistent with several earlier studies (Channon & Hayward, 1990; Mogg et al, 1998; Mohanty et al., 2008; Piech et al., 2009; Placanica et al., 2002; Stockburger et al., 2009) showing that selective attention to food stimuli is sensitive to hunger-related motivation. However, unlike the present study, a selective satiety design was not used in previous research so that attention effects could reflect the subjects' overall level of satiety (or other nonspecific confounds) rather than hedonic and motivational changes that occur to different foods when one is eaten to satiety. Critically, the present study provides clear evidence that the motivational guidance of attentional resources is not an all-or-none mechanism (Vuilleumier & Huang, 2009) but rather reflects accurate on-line assessment of the hedonic value of the various stimuli present in the environment.

Animal and human studies of food devaluation indicate that the orbitofrontal cortex (OFC) may be critical for signalling changes in the reward value of food stimuli (see Murray et al., 2008). For instance, monkeys with OFC lesions fail to alter learned responding after reinforcer devaluation (Murray et al., 2008). Moreover, fMRI evidence

reveals a significant correlation between OFC activity and decrease in subjective pleasantness when a food is eaten to satiety (Kringelbach et al, 2003). From the OFC, signals indicating the current reward value of foods may be conveyed to attention regions of the brain, such as the dorsolateral prefrontal cortex and the posterior parietal cortex (Cavada & Goldman-Rakic, 1989), thereby directing visual attention selectively to food targets that can best satisfy current needs (Mohanty et al., 2008). Importantly, the present findings raise the possibility that signals that have been attributed exclusively to representation of reward in the OFC and other reward-related brain areas might be, at least in part, signals of motivation-related modulation of attention (Maunsell, 2004).

Two potential limitations of this study deserve mention. First, the current study examined the effect of only changes in subjective palatability on visual selective attention to food cues. We found that changes in food liking scores related closely to attentional effects. However, Berridge and Robinson (1998) have suggested that reward representation entails distinguishable psychological and functional dimensions –"liking" (pleasure/palatability) and "wanting" (appetitive/incentive salience). Thus, we cannot rule out the possibility that incentive motivation (i.e., the non-hedonic process of wanting) may also play a role in guiding visual selective attention to food pictures. It must be said, however, that explicit, self-report measures of liking and wanting are highly correlated, and that subjects often find difficult to make this distinction explicitly (Finlayson et al., 2009). Furthermore, both animal and human studies (Havermans et al., 2009; Rolls et al, 1981) indicate that food-specific satiety reflects a selective reduction in both food liking and food wanting. Nonetheless, additional studies are needed to

examine whether liking and wanting contribute differently to visual attention to food stimuli.

Second, the visual probe task permits evaluation of attentional bias to food cues, relative to control cues, but it seems less effective in distinguishing whether such bias reflects the orienting component of attention (e.g., a food stimuli attracts attention to its location), or the hold or disengage component of attention (e.g., once a food stimulus has been detected attention tends to dwell in that location; e.g., Fox et al, 2001). This is relevant because several studies (Compton, 2000; Fox et al, 2001, 2002; Yiend,, 2001) indicate that negative emotions, such as fear and threat-related emotion, specifically affect the disengage component of visual attention in anxious individuals. Notably, these studies have commonly used exogenous cuing tasks, which allow a more direct assessment of the attentional disengagement mechanism by examining delay to re-orient from invalid emotional cues compared to invalid neutral cues. Recently, however, Koster and colleagues (2004) have proposed that a visual probe task may be used to examine orienting and disengagement components of attention by comparing responses to probes in emotional-control pairs to probes in control-control pairs. The present study did not include control-control pairs and used a small set of food stimuli, thereby precluding a detailed analysis of the critical components of attention that are influenced by motivational cues. Additional research is needed to uncover the cognitive mechanisms of motivated attention, and to identify exactly which of these mechanisms are common (or distinct) across different kinds of emotional (e.g., fear) and motivational (e.g., food) stimuli.

Finally, the findings of this study have potential clinical implications. Research has found attentional biases in patients with eating disorders (Nijs et al, 2009; Lee &

Shafran, 2004; Shafran et al, 2007), and has suggested that such biases may play a role in causing and/or maintaining dysfunctional eating (Lee & Shafran, 2004). Interestingly, a recent study (Castellanos et al, 2009) found that obese adults maintain an increased attention to food images regardless of reported hunger/satiety, indicating disregulated responses to food cues in obesity. It would be important to clarify whether transitory changes in the subjective pleasantness of food (after selective satiety) affect attentional bias to food cues in overweight individuals, as reported here in normal-weight people.

To conclude, the control of food intake requires the coordination of motivational and higher cognitive processes. The present findings suggest that the allocation of visual attention is flexibly and rapidly adjusted to reflect temporary shift in relative preference for different foods. Shifting the balance of attention away from consumed may serve to optimize exploitation of available food resources and to increase the variety of food consumed.

# CHAPTER 5 - EXPERIMENT THREE

## Presence of others affects how we look at emotional scenes

## 5.1 Introduction

A primary adaptive function of emotion is to influence our interaction with environmental events that are potentially harmful, threatening, or beneficial to our well-being under certain conditions (Lang et al., 1997). One means of achieving this is by emotion enhancing attention, leading to increased detection of emotional stimuli. Several behavioral studies indicate that people more readily detect emotional than neutral stimuli, suggesting that emotion exerts a powerful influence on attention (Vuilleumier & Huang, 2009). Typically, emotional enhancement of attention has been investigated in single individuals performing their task in isolated settings. Humans, however, are intensely social beings. In everyday life, most of our thoughts, feelings, and behaviors are deeply influenced by the presence of other people. Moreover, beyond their function at the individual level, emotion reactions evolved to serve social functions and have interpersonal consequences (Van Kleef, 2009). Therefore, our aim in the present study was to examine whether and how the phenomenon of enhanced attention to emotional pictures is modulated by the presence of others. To this end, we used eye-movement recordings to assess overt attention to pleasant (sexual) and unpleasant (threat/injury) emotional visual scenes and compared participants' performance when they act in the presence of others and when each individual is alone.

Previous research has established that the emotional significance of sensory events can determine how visual attention is allocated. For instance, in visual search tasks, in

which a unique target must be found among distracters, detection times are faster when the target has emotional value, such as an angry or happy face among neutral faces (Fox et al., 2000; Öhman et al., 2001; Tipples et al., 2002), or a snake or spider among flowers (Öhman et al 2001). Similarly, in the visual probe paradigm, viewers are faster at detecting probes replacing either pleasant or aversive than neutral stimuli, suggesting an attentional bias toward emotional stimuli (Mogg et al., 1998; Mogg & Bradley 1999; di Pellegrino et al., 2010). Consistent with this, brain imaging studies in human subjects have revealed enhanced responses to emotional stimuli relative to neutral stimuli in several brain regions (Sabatinelli et al., 2005; Veulliemier et al., 2001), thus providing a plausible substrate for their greater competitive strength in attracting attention, as observed behaviorally. Particularly important for the present purposes, eye-movements recordings, used as an index of overt behavioral manifestation of allocation of attention (Henderson, 2003), have been recently applied to study preferential attention to emotional pictures. The eye-tracking method is particularly valuable in that it provides an online record of the time course of the initial orienting and the subsequent maintenance of attention (Calvo & Lang, 2004). When unpleasant, neutral, and pleasant photographic scenes were presented simultaneously with neutral control pictures under free viewing conditions, the probability of first fixating the unpleasant and pleasant picture, and the frequency of subsequent fixations, were greater than those for the neutral picture (Calvo & Lang, 2004; Nummenmaa et al., 2006). This suggests that an emotional bias to emotional pictures is seen both in initial orienting and subsequent engagement of attention. Moreover, there is also evidence indicating that such attentional capture might operate in a reflexive or involuntary manner. In a task in which emotional and neutral pictures are presented concurrently, emotional pictures are

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more likely to be fixated first, even though participants are explicitly instructed to attend to the neutral pictures (Nummenmaa et al., 2006). Thus, several observations indicate that the emotional salience of stimuli affects the allocation of attention. Here, we hypothesized that such an effect is susceptible to social influences. Previous research provided several line of evidence for this possibility. One category of studies has documented that the social presence of others has strong impact on the expression of emotion, even though the direction in terms of social facilitation versus inhibition and the interpretation thereof is still intensely debated. For example, Brightman and colleagues (1977) demonstrated great differences in expression to sweet versus salty sandwiches when with others but not when alone; also, Dale and co-workers (1991) found greater emotional expressiveness to humorous videotapes in women who were in dyads than in women who viewed the videotapes alone. There is, however, also compelling evidence indicating social inhibition of emotional reactions. Yarczower and Daruns (1982) showed that children were more expressive when they viewed a series of affective slides alone than in the presence of others; Kraut (1982) found that people presented with pleasant versus unpleasant smells showed less emotional expressiveness when with another subject than when alone; finally, Kleck and colleagues (1976) reported that subjects who knew they were being observed showed reduced levels of expression to painful stimuli.

A second kind of evidence reveals that performing a task in the presence of others can lead to changes in arousal, autonomic activity (e.g., cardiovascular, electrodermal) and cortisol responses. For instance, Zajonc's (1965) theory of social facilitation maintains that the *mere* presence of social others can increase physiological activity, and this, in turn, could facilitate dominant responses (e.g., enhanced performance on easy tasks,

impaired performance on difficult ones). More recent evidence indicates that emotional and physiological responses are stronger when participants believe that others are evaluating them, namely in situations in which the social self is or could be negatively judged by others (i.e., social-evaluative threat; Bond et al., 1983; Dickerson & Kemeny, 2004; Dickerson et al., 2008; Mullen et al., 1997).

Finally, a third line of evidence from cognitive neuroscience has documented a close relationship between neural mechanisms underlying social and emotional information processing (Adolphs et al., 2002; Norris et al., 2004). For instance, when participants process socially inappropriate embarrassing events, activations in brain areas associated with emotion (e.g., amygdala, medial prefrontal cortex) are strongly modulated by the presence of others (Finger et al., 2006).

In sum, several observations appear consistent with the idea that emotional and physiological responses are influenced by social context. However, previous research did not specifically address whether the presence of other individuals affect preferential attention to emotional pictures. To test this hypothesis, pictures of either pleasant (nude and erotic content), unpleasant (threat and injury) or emotionally neutral scenes were paired with neutral control pictures and presented simultaneously, while eye fixations and pupil diameter were monitored. Participants were asked to freely look at the pictures and instructed to choose the most interesting image of a pair, either when they were alone or in the presence of a confederate, of same or opposite gender. Preferential attention was determined by the probability of first fixation, the frequency of subsequent fixations, and viewing time on the emotional stimulus in comparison with the neutral stimulus, whereas the level of arousal and autonomic activation was determined by pupil diameter (Bradley et al., 2008).

The following predictions can be derived for the two different conditions. For the Alone condition, we expected to replicate previous findings of preferential attention to both pleasant and unpleasant, relative to neutral, pictures. Likewise, we predicted greater arousal, as indexed by pupil diameter, when viewing emotional than neutral stimuli (Bradley et al., 2008). For the Confederate condition, there are three possible outcomes. First, according to the distraction hypothesis (Klauer et al., 2008; Wühr & Huestegge, 2010), the presence of another person only disturbs performance on cognitively demanding tasks, probably due to a competition for limited attentional resources. Because emotional pictures appear to capture attention in a reflexive and automatic manner (Nummenmaa et al., 2006), we would expect them to be unaffected by the presence of a person in the environment. Second, the social facilitation hypothesis, advocated by Zajonc (1965), argues that the presence of others increases arousal and enhances the habitual, dominant response to a stimulus. As a consequence, since preferential attention to emotional stimuli is the dominant response, social presence might facilitate this habitual tendency, thereby increasing preferential attention to emotional pictures, regardless of their hedonic valence. Finally, according to the social evaluation hypothesis (Dickerson et al., 2004), conditions that threaten to demean the social self (e.g., one's social image, acceptance or standing) may engender psychological, physiological, and behavioral changes necessary to coordinate an appropriate response to the situation. On this perspective, only attention to erotic stimuli should be affected by social presence, particularly when subjects viewed stimuli in presence of an opposite –gender confederate. Indeed, erotic images can be deemed as high arousing, attention-grabbing and pleasant stimuli, when viewed in isolation (Bradley et al., 2001; Buodo et al., 2002) or with a romantic partner. However, in our

culture, erotic stimuli can also be embarrassing and shame-inducing, when viewed in the presence of an unfamiliar other. Emotions like shame and embarrassment are usually considered as self-conscious emotions, evoked by self reflection and self evaluation. They usually arise from public exposure or disapproval of some transgression, when individuals fail to behave in accordance with social norms and rules (Tangney, 1996). Costa and colleagues (2001) collected self-report data and assessed non-verbal behaviors during erotic and neutral pictures viewing, either when participants were alone or in company of two unfamiliar individuals. They found that erotic stimuli were effective in inducing feelings of embarrassment and shame, with greater responses in the presence of others. Therefore, in the current study only viewing erotic stimuli entails violation and transgression of social rules, thereby meeting the requirement for a situation of social-evaluative threat. Accordingly, we expected to find modulatory effects of social presence on visual attention to erotic scenes only, and particularly when audience involved peers of opposite-gender to the observer.

## 5.2 Methods and Materials

### Participants

Thirty two male subjects, aged between 22 and 36 years (mean age = 26.8 years, S.D. = 3.6), took part in the experiment. All of them were right-handed, and were pre-screened to verify that they were heterosexual (self-reported as having only opposite-sex sexual desire and sexual experiences). They had normal vision or corrected to normal vision. None of the participants reported neurological or psychiatric disorders. Participants remained naïve as to the purpose of the study until debriefing. For ethical reasons, the participants had been informed prior to the experiment that they would be presented with photographs of which some could be pleasant or unpleasant in content, and that they could refuse to participate in or withdraw from the experiment at any time if they wished. Because previous research (Codispoti et al., 2008; Hamann et al., 2004; Lykins et al., 2008) has documented gender differences in processing visual sexually arousing stimuli, we restricted our study to male participants to maintain homogeneity of the subject sample. All experimental procedures were approved by the Bologna Department of Psychology ethics board and conformed to national and institutional guidelines and to the Declaration of Helsinki.

**Stimuli**

The stimuli used in the experiments were 160 digitized color photographs selected from the International Affective Picture System (IAPS, Lang et al., 2005, reported in Appendix A). They included three categories of target pictures, classified as a function of their emotional or affective valence: pleasant (n = 20), neutral (n = 20), or unpleasant (n = 20), and one category of control neutral pictures (n = 100). All target pictures depicted *people*. Specifically, pleasant (erotic) pictures portrayed women positioned provocatively with facial expression communicating high sexual receptivity and heterosexual couples in sexual behavior; neutral pictures portrayed people in daily, non emotional activities; unpleasant pictures depicted threatening people or people suffering from a serious threat or harm (violent attacks or dead people and expressions of pain, crying, and despair). Control pictures represented various inanimate scenes and objects and were neutral in affective valence.

Means (M) and standard errors (SE) of emotional valence and arousal ratings, luminance level, contrast level, complexity value, and color saturation for the red, green and blue channels of the four picture categories are reported in Table 5.1. Valence ratings, ranging from 1 (most pleasant) to 9 (most unpleasant), and arousal ratings, from 1 (most calm/relaxed) to 9 (most agitated/aroused), for each picture were obtained from previous norming studies (Lang et al., 2005). Valence (pleasantness vs. unpleasantness) reflects the dominant motive system activated (avoidance or approach). Arousal reflects the intensity of the motive system activation, from calm to tension. The luminance and color saturation (red, green, and blue) values were derived from the histogram/luminance function of Adobe Photoshop™ in RGB-mode (mean luminance in RGB-mode ranges from 0 for completely black pictures to 255 for completely white

pictures). Average luminance levels and of the pictures were slightly adjusted with the Adobe Photoshop™ program to achieve uniform values for the different picture categories. In addition to average luminance values, we analyzed standard deviation values, as an index of contrast (Calvo & Lang, 2005). The complexity of the pictures was assessed in terms of the number of Mbytes of the image file size in BMP format, with the assumption that the more complex the image is, the larger the file (Buodo et al., 2002).

**Table 5.1.** Means and (standard errors) of stimulus characteristics of the unpleasant, neutral, pleasant, and control stimuli used in the study.

|  | Unpleasant | Neutral | Pleasant | Control |
|---|---|---|---|---|
| Valence | 2.48 (0.17) | 5.37 (0.16) | 6.33 (0.14) | 5.60 (0.10) |
| Arousal | 6.12 (0.16) | 3.30 (0.13) | 6.07 (0.14) | 3.26 (0.09) |
| Luminance | 101.06 (7.28) | 102.52 (6.26) | 106.07 (4.21) | 108.94 (2.85) |
| Contrast | 73.74 (2.40) | 75.15 (1.77) | 72.01 (2.38) | 68.09 (1.55) |
| Red channel saturation | 113.18 (7.69) | 111.76 (5.64) | 124.70 (3.85) | 118.58 (2.76) |
| Green channel saturation | 97.23 (7.56) | 100.09 (6.79) | 101.68 (4.75) | 107.49 (3.06) |
| Blue channel saturation | 88.59 (6.88) | 89.84 (7.28) | 86.14 (5.41) | 90.47(3.86) |
| Complexity | 2.25 (0.10) | 2.05 (0.11) | 2,28 (0.15) | 2.29 (0.14) |

Valence and arousal ratings (1-9), stimulus luminance (0 –255), stimulus contrast (0-255), color saturation for the red, green and blue channels (0-255), stimulus complexity value (image size in Mbytes).

The stimulus characteristics of the four picture sets were compared using a series of one-way analyses of variance (ANOVAs). These analyses revealed significant differences in arousal ($p < .0001$), and valence ratings ($p < .0005$). Post hoc analysis (Newman-Keuls test) showed no significant differences between mean arousal rating scores of pleasant and unpleasant pictures, and between neutral and control pictures (all

*ps* > .05). However, arousal ratings were significantly higher for pleasant and unpleasant images than for neutral and control images ($p < .0001$ in both cases). Regarding valence, the mean rating was higher for pleasant than for neutral, control and unpleasant pictures ($p < .0005$), whereas the mean rating for control and neutral pictures was higher than for unpleasant pictures (*ps* < .0001). Mean valence rating score for neutral and control pictures did not differ from each other ($p > .05$). As for the low-level properties of the images, the analyses revealed no significant differences in mean luminance level, contrast level, red, blue and green saturation, and complexity value between the all four categories of pictures ($p > .05$ in all cases). Thus, the analysis of the stimulus properties demonstrates that we were reasonably successful in selecting stimulus pictures that differ only with respect to arousal and valence but not with respect to low-level visual features.

In each trial, two pictures were presented on the screen: a target picture (involving pleasant, unpleasant or neutral stimuli) and a control picture. The target and control pictures were randomly paired, thus producing three groups of experimental trials: 20 pleasant-control trials, 20 unpleasant-control trials, and 20 neutral-control trials. Additionally, there were 20 filler trials (pairs of control images), which were included to balance the number of emotional and neutral displays (Nummenmaa et al., 2006). The size of the pictures was 140 mm wide x 100 mm high when displayed on the screen, which equals to 12.3° x 8.8° of visual angle at a viewing distance of 73 cm. The pictures in each trial were presented side by side, flanking a central fixation point, over a dark gray background. The distance between their inner edges of the two pictures corresponded to a minimum visual angle of 2° (at least one visual degree between the central fixation cross and inner edge of the picture). The left and right locations of the

target pictures were balanced across trials. The randomization of stimulus pairs and picture locations ensured that participants were not able to successfully use any preset scanning strategy.

**Apparatus**

The experiment was performed in a windowless and dimly lit room. Stimuli were displayed on a 15-inch (38 cm) computer screen at a resolution of 1024 x 768 pixels. The viewing distance from the participants' eyes to the screen on which stimuli were displayed was 73 cm. Stimuli were delivered and controlled via a PC running E-Prime (Psychology Software Tools, Pittsburgh, PA, 2002) stimulus presentation software. Eye position and pupil diameter were recorded using a table-mounted infrared video–based eye-tracker (Eye-Track ASL-6000) at a 60-Hz sampling rate. Viewing was binocular, although only the subject's right eye was illuminated by an invisible infrared light, and the reflections were recorded by a video-camera positioned 63 cm from the eye. The eye-tracker was connected to a second PC, positioned in a separate room. Event markers transmitted to the eye-tracking computer by the stimulus presentation computer allowed coordination between behavioral events and eye data for analysis. Moreover, the experimenter monitored on-line the position of the subject's eye gaze that was projected on a second screen.

**Procedure**

Participants were tested individually. Upon arrival at the laboratory, they received general information about the experiment and gave written consent. Next, they were seated in front a computer screen with their chins positioned in an adjustable chinrest, and their forehead rested against a rounded bar to allow minimal movement and keep the distance from the stimuli constant.

One armchair was positioned behind the participants' chair, at the approximate distance of 1.5 m. For half of the participants, the chair was located to the right in the back of the participant, approximately 220° with regard to the participants' line of sight; for the other half of the participants, the chair was located to the left in the back of the participant, approximately 140° with regard to the participants' line of sight.

Prior to the actual experimental task, participants were asked to perform a color discrimination task; actually this was the eye calibration session. Eye calibration consisted of having the participant fixate and verbally report the color of nine markers arranged on the display area, whilst their position of gaze was recorded for each marker. Once the eye-tracker was successfully calibrated, subjects were acquainted with the experimental procedure and the practice session began. They were told that they were going to see pairs of pictures, and their task was to indicate, by pressing the left or the right button of a mouse, which image of each pair was the most interesting. In the practice session, the participant was presented simultaneously with two images depicting landscapes, and was instructed to look at the pictures as he normally would, and then report the most interesting image by pressing the mouse button correspondent to the image's side. Once the practice session was completed (5 trials), the experimental session began.

At the beginning of each trial, a central fixation cross (0.5° x 0.5° of visual angle) was displayed on the screen, and the participant had to focus his gaze at the centre of the cross. When the participant's eye was fixated on the cross, the trial started. After a variable delay of 200-600 ms, introduced to prevent anticipatory saccades, a pair of pictures positioned to the left and right side of the fixation cross appeared, remaining on the screen for 3500 ms. Successively, the pictures and the fixation cross were replaced by a question ("Which picture was the most interesting?"). Subjects had to answer this question by pressing the mouse button correspondent to the preferred image's side within a time window of 3000 ms. Thus, the task involved an interest judgment which ensured that participants had to look at both images at least once in order to indicate which of the two they found more interesting. Finally, after a blank short interval, a new trial began.

**Experimental Design**

Each subject performed the experimental task in two separate conditions: alone (Alone condition) and with another unfamiliar individual in the room (Confederate condition). In both conditions, exactly the same procedure was followed and subjects viewed the same set of 160 images, randomly paired. The only difference was the presence/absence of a stranger, during one of those conditions. Half of the participants were paired with a same-sex (male) confederate, henceforth referred to as the Same-sex group (N = 16, mean age=26.6 ± 4.35; mean years of schooling = 15 ±.39), while the other half were paired with a opposite-sex (female) confederate, henceforth referred to as the Opposite-sex group (N = 16, mean age = 27.25 ± 2.69; mean years of schooling=14.81, ±.39). There was no difference among the 2 groups with respect to age (p =.59), and education

(p=.74). Participants were told this person to be a student, doing her/his project thesis in the lab and getting acquainted with the task. When the confederate was present, she/he was asked to sit on the chair behind and outside the field of view of the participant, to look at the computer screen where pictures were presented, and to pay attention to the participant's performance for the whole duration of the session without making verbal comments. The experimenter was never present during the task.

In each condition, participants performed 80 trials (20 erotic-control trials, 20 unpleasant-control trials, 20 neutral-control trials and 20 control-control trials) administered in a random order. Target and control stimuli appeared once in each condition. In order to minimize habituation effects, the two conditions were separated by two weeks from one another. After completion of both experimental conditions, participants were probed for suspicion, and debriefed. No participants guessed the hypotheses of the study or reported attempts to control their emotion during the experiment.

**Measures and data preparation**

*Eye-movements* - Eye movement data were analyzed using the Eyenal Data Analysis Program (Applied Science Group 2000). If eye movements were stable within 1° of visual angle for 100 ms or more, this was classified as a fixation to that position, the duration of which was recorded. Fixations were classified as being directed at the left or right pictures if they were 1° wide of the central position on the horizontal plane (this visual angle corresponds to the distance between the fixation cross position and the inner edge of each picture). Three types of eye-movement measures were collected: a) direction of first fixation, b) total number of fixations, and c) total viewing time. The

direction of first fixation following the onset of the two pictures display on each trial was determined as the first location of the eyes after leaving the fixation point. First fixation proportion was calculated for each participant by expressing the number of trials when initial fixations were directed to the target picture as a proportion of the total number of trials in which an initial eye movement was made to either the target or control picture. Proportion scores > 0.5 means that first fixations landed more frequently on the target than on the control picture. This measure was assumed to assess initial orienting of attention and attentional capture (Calvo & Lang, 2004; Nummenmaa et al., 2006). Total number of fixations was a count of the different times the eye landed on any given image, with each new fixation requiring that the eye gaze moves from outside the picture in the preceding fixation. Total fixation proportion was calculated for each participant by expressing the number of gaze fixations directed to the target picture as a proportion of the total number of fixations made to either the target or control picture on each trial. Proportion scores > 0.5 reflect a tendency to look more frequently at target than control images. Finally, total viewing time examined how long, rather than how likely, a given image was fixated during each trial. It was calculated by summing up the duration of fixations made to target and control pictures during the whole 3.5-s exposure period. Total viewing time proportion was obtained by computing the time spent gazing at target pictures as a percentage of the total amount of time looking at either image recorded per trial. Proportion scores > 0.5 reflect a tendency to look longer at target than control images. Total fixation and viewing time proportions were assumed to index maintenance of attention on a particular image (Calvo & Lang, 2004; Lykins et al., 2008). Note that although each trial lasted 3500 ms, due to tracker loss and the exclusion of blinks, only some of this time was recorded for some trials.

Since a partial recording may not be representative, trials with excessive missing data (where fixations to the pictures accounted for less than 20% of the total picture presentation time, e.g., less than 700 ms) were excluded from the analysis. This resulted in the exclusion of 5% of all trials. After trials with missing data had been excluded, gaze fixations accounted for 81% of the time when pictures were presented, with no fixations recorded during the remaining 19% of the time due to eye movements (saccades), eye blinks, and failures of the eye-tracker to record data. These percentages did not differ as a function of target type (neutral, pleasant, or unpleasant), or condition (Alone or Confederate), or their interaction, ($F < 1$ in all cases).

*Pupil responses* - A single measure in pixels of pupil diameter was computed by averaging the horizontal and vertical diameters of the pupil ellipse, and then converting the obtained value in millimeters. Pupil responses during picture viewing were baseline corrected with a 200-msec pre-stimulus baseline; those containing eye-blinks or for which data were missing were discarded. Two measures of pupil responses were gathered: a) mean pupil diameter change of first fixation on the target picture, following the onset of the two-picture display on each trial (first pupil diameter change), and b) mean pupil diameter change during the whole viewing of a target picture in each trial (mean pupil diameter change). Previous studies support the view that considers pupil diameter as a valid measure of emotional arousal, and they indicate that pupil changes are significantly affected by pictures emotionality (Bradley et al., 2008).

*Interest score* - Finally, in order to gather an explicit measure of interest and ensure that participants looked at both images at least once, we asked them to indicate, in each trial,

the picture that they felt was the most interesting to them personally. An interest score was computed by calculating the percentage of trials in which the participant selected the target picture as the most interesting of a stimulus pair. This score was considered an explicit measure of the participants' interest. Proportion scores > 0.5 reflect a tendency to find more interesting target than control pictures.

*Subjective Measures* - Subjective feelings of embarrassment, shame, anxiety, surprise, sadness, and disgust were informally assessed at the end of each experimental condition.

## 5.3 Results

Data from practice and filler trials were discarded. Means and standard errors of the eye movement measures, interest scores and pupil responses for the three different target types in two task conditions, for both Same-sex and Opposite-sex groups, are presented in Figure 5.1 and Figure 5.2. Because observed variables were normally distributed (Kolmogorov-Smirnov test for normality), data analyses were conducted using repeated measurement ANOVAs, with target type (three levels: neutral, pleasant and unpleasant) and condition (two levels: alone and confederate) as within-subject factors, and group (two levels: same-sex and opposite-sex) as between subject factor. Post hoc examination of significant interaction effects was conducted using Newman-Keuls tests. A $\alpha$-level of 0.05 was used for determining statistical significance.

*First fixation proportion* - Analysis yielded a statistically significant main effect of target type on first fixation proportion, $F(2, 60) = 16.18$, $p < .001$. Planned comparisons showed that, overall, the probability of first fixating a pleasant picture (.76), or an unpleasant picture (.74) was greater than that of first fixating a neutral picture (.64), $p < .05$ in both cases; whereas first fixation proportions were not significantly different for the pleasant and unpleasant pictures, $p = 0.3$. These results are in line with prior studies (Nummenmaa et al., 2006), indicating that initial orienting of overt attention is biased towards emotional stimuli (both pleasant and unpleasant) compared to neutral stimuli. The analysis also showed a significant interaction between target type and condition, $F(2, 60) = 6.50$, $p < .01$.

More important for the present purposes, the three–way interaction between target type, condition, and group proved significant, $F(2,30) = 3.13$, $p < .05$. In order to identify the

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source of this interaction, we conducted two separate ANOVAs, one for each group, with the factors target type and condition. In the Opposite-sex group, there was a significant main effect of target type, $F$ (2, 30) = 5.42, $p<$ .01, as in the main ANOVA. Critically, the interaction between target type and condition was significant, $F$ (2, 30) = 8.46, $p<$ .01. The interaction reflects the fact that the proportion of first fixations on pleasant pictures decreased significantly in the Confederate (.67) relative to the Alone condition (.79), whereas presence of female peer had no effect on the probability of first fixating an unpleasant picture (means were .72 and .74 in the Alone and Confederate condition, respectively) or a neutral picture (.61 and .65 in the Alone and Confederate condition, respectively). Moreover, pleasant (sexual) pictures were more likely to be fixated first than neutral pictures when participants were alone ($p$ = .002). Also, the proportion of first fixation was similar for both pleasant and unpleasant images (and higher than neutral images) in the Alone condition, whereas, in the Confederate condition, pleasant pictures attracted marginally less first fixations than unpleasant pictures ($p$ = .053).

A rather different pattern of results was found for the Same-sex group. There was a main effect of target type, $F$ (2, 30) = 14.53, $p<$ .001, again revealing that first fixation probability was higher for erotic (.78) and unpleasant pictures (.74) that neutral pictures (.66). However, neither the main effect of condition $F$ (1, 15) = 0.64, $p$ = .43, nor the interaction between target type and condition, $F$ (2,30) = .33, $p$ = .71, were significant. This clearly indicates that the presence of a same-sex (male) confederate had no effects on the pattern of first fixations on emotional and neutral pictures.

***Total fixation proportion -*** There was a significant main effect of target type on total fixation proportion, $F$ (2, 60) = 21.76, $p$ = .0001, with higher gaze fixation probability on pleasant (.66) and unpleasant pictures (.65) than on neutral pictures (.56), and no significant difference between pleasant and unpleasant pictures. However, neither the main effect of condition, nor other interactions involving this factor were significant, *ps* < 1, thereby indicating that the proportion of total fixations on pleasant, unpleasant and neutral pictures were independent of the presence of a confederate, either female or male, in the room.

***Total viewing time proportion -*** The analysis showed that target type significantly affected total duration proportion, $F$ (2, 60) = 16.23, $p$ < .001. Post hoc analyses showed that pleasant (.63), and unpleasant (.62) pictures were gazed longer than neutral (.54) pictures, $p$ <.05 in all cases, with no significant differences between pleasant and unpleasant images. There were no other significant results.
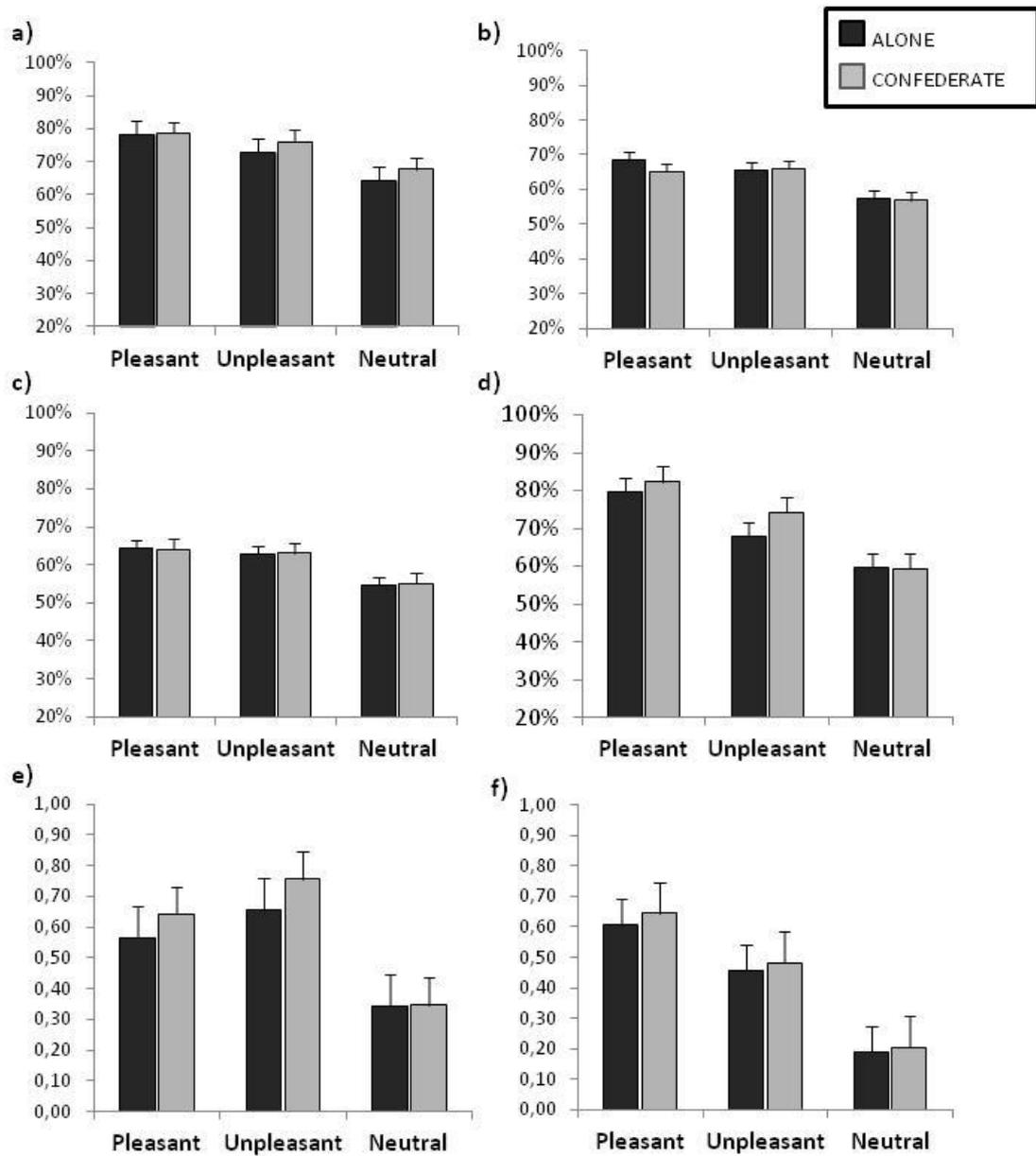
**Figure 5.1 Eye movement data, interest scores and pupil diameter**. Proportion of first fixations (a), total fixations (b), total viewing time (c) interest scores (d) first pupil diameter (e) and mean pupil diameter (f) for pleasant (sexual), unpleasant (threat/injury) and neutral target pictures, in Alone and Confederate – same sex condition.
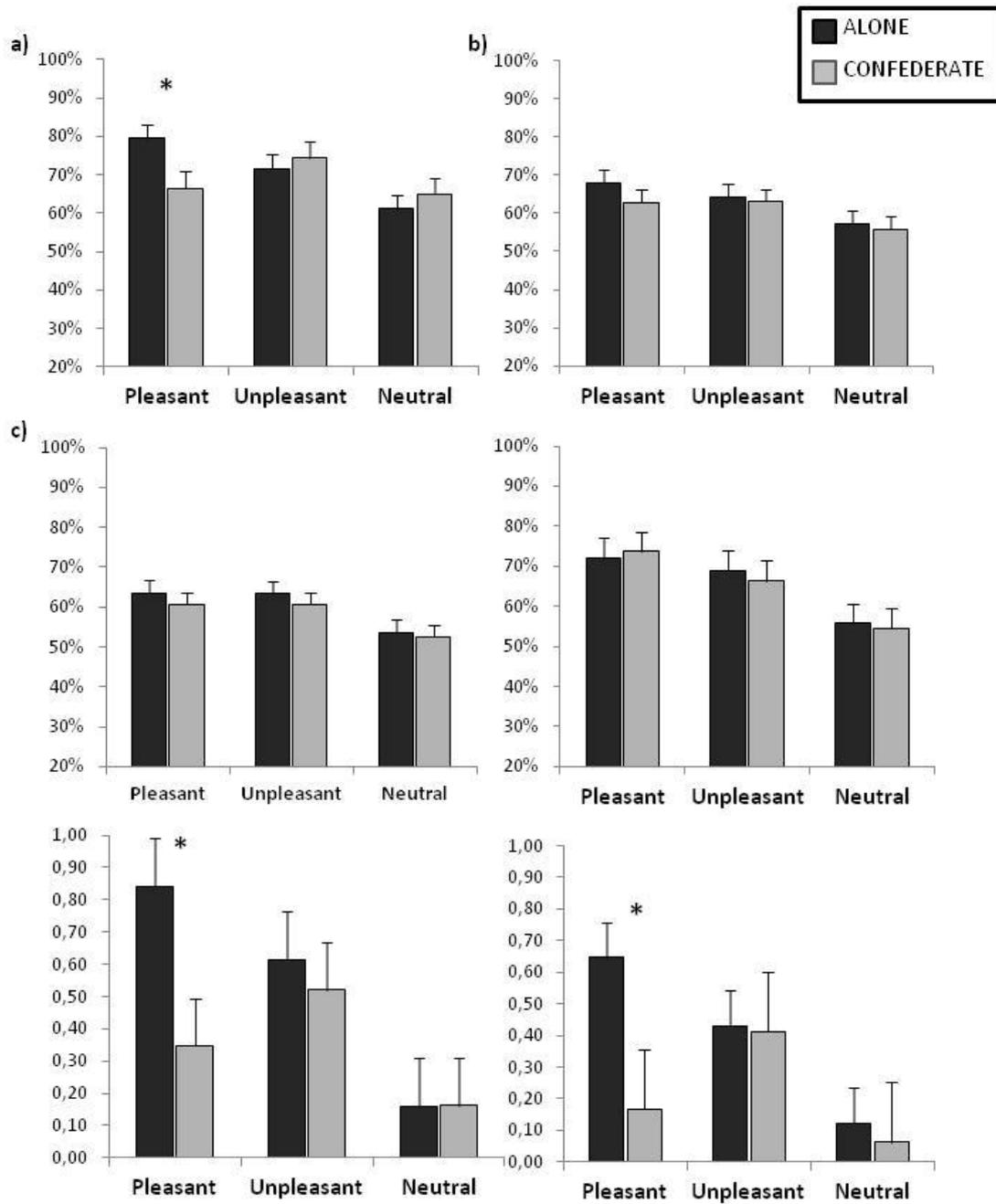
**Figure 5.2 Eye movement data, interest scores and pupil diameter**. Proportion of first fixations (a), total fixations (b), total viewing time (c) interest scores (d) first pupil diameter (e) and mean pupil diameter (f) for pleasant (sexual), unpleasant (threat/injury) and neutral target pictures, in Alone and Confederate – opposite sex conditions.

*Pupil responses* - Change of pupil diameter of first fixation (first pupil response) was affected by target type, $F(2, 60) = 10.49$, $p < .001$ such that highly arousing erotic targets and unpleasant targets prompted equivalent pupillary changes (M = 0.60 mm and 0.64 mm, respectively, $p = .72$), with both types of picture eliciting larger changes than when participants gazed first at neutral pictures (M = 0.25 mm), both $ps < .01$. The three-way interaction between target type, condition and group approached significance, $F(2, 60) = 2.82$, $p < .07$. This marginally significant three-way interaction was tested by running two separate ANOVAs on the Opposite-sex and Same-sex groups. In the Opposite-sex group, the relationship between target type and condition just missed statistical significance, $F(2, 30) = 3.09$, $p < .06$. Planned contrasts revealed that mean pupil changes when viewing pleasant pictures were significantly smaller in the Confederate (M = 0.35 mm) than in the Alone (M = 0.84 mm) condition, $p = .012$, whereas there was no difference between conditions for unpleasant (M = 0.52 mm and 0.61 mm, for the Confederate and Alone condition, respectively, $p = .53$) and neutral target pictures (M = 0.16 mm and 0.16 mm, $p = .99$).

In the Same-sex group, the main effect of target type was significant, $F(2, 30) = 3.98$, $p < .03$. However, neither the main effect of condition nor the condition X target type interaction was significant, $Fs < 1$, suggesting that pupil responses to emotional pictures were independent of the presence of a same-gender confederate.

Similarly, change of pupil size averaged across the whole exposure period (mean pupil response) was significantly modulated by target type, $F(2,60) = 10.49$, $p < .001$, due to the fact that pupil dilation proved greater for both pleasant and unpleasant than neutral pictures, $p < .01$ in both cases, with no overall difference between pleasant and unpleasant target pictures, $p = .41$. More critically, a statistically significant three-way

interaction between target type, condition, and group was found, $F (2, 30) = 3.28$, $p$ <.05. To uncover the source of the significant three-way interaction, two separate ANOVAs, one for each group, with the factors target type and condition, were conducted. In the Opposite-sex group, a significant two-way interaction between target type and condition was found, $F (2, 30) = 3.48$, $p$ <.05. This interaction reflected the fact that pleasant (erotic) pictures elicited larger pupil dilation in the Alone relative to the Confederate condition, $p < .01$, whereas such difference between conditions was immaterial for unpleasant and neutral target pictures, all $ps > .05$. Furthermore, erotic pictures showed larger pupil changes compared to neutral pictures when participants viewed them alone, $p < .001$, but not when they gazed at erotic pictures in the presence of a female confederate, $p = .44$. In stark contrast, in the Same-sex group, the interaction between target type and condition was not significant, $F<1$, thereby revealing that viewing emotional pictures with a same-sex confederate did not affect mean pupil response.

*Interest scores* - Interest scores were analyzed in a separate ANOVA. The results showed a main effect of target type, $F (2, 60) = 13.81$, $p = .001$. Pairwise comparisons indicated that the interest score for pleasant (erotic) (.77) and unpleasant (.70) images was significantly greater than for neutral (.57) images, both $ps < .05$, whereas interest scores for pleasant and unpleasant pictures were not different from each other, $p = .08$. Both the main effect of condition, and the interactions involving this factor were not significant, $Fs < 1$. Thus, results revealed that participants found both pleasant and unpleasant pictures more interesting than neutral stimuli, and that such explicit interest was unaffected by the presence of a peer.

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Finally, participants reported more embarrassment in the Confederate than in the Alone condition, particularly when paired with an opposite-gender confederate than a same-gender confederate.

## 5.4 Discussion

Behavioral studies provide strong evidence that emotional pictures are more likely to draw and hold visual attention that neutral pictures (Vuilleumier & Huang, 2009). The current study empirically tested whether such emotional enhancement of attention is modulated by social presence. Participants freely inspected two (one emotional – one neutral) simultaneous pictures under instruction to indicate the most interesting image of the pair, either alone or in the presence of a stranger of same or opposite gender. Eye-movements monitoring was used to assess overt attentional orienting to, and maintenance on, emotional visual pictures, whereas pupil size was included as an indicator of autonomic arousal. As predicted, participants performing the task alone were not only more likely to attend first to the emotional pictures, but these were also attended to for longer time and with more fixations than neutral pictures. Initial orienting and maintenance of attention were similarly biased toward both unpleasant and pleasant target pictures. Furthermore, pupil changes were larger when participants viewed pleasant or unpleasant pictures, compared to neutral pictures, indicating increased physiological activity for emotional scenes (Bradley et al., 2008). Overall, the present data converge with earlier results (Calvo & Lang, 2004; Nummenmaa et al., 2006) in supporting the hypothesis that both initial orienting and subsequent

maintenance of attention are biased toward highly arousing emotional pictures of both pleasant and unpleasant valence.

More importantly, the pattern of eye movements and autonomic responses to emotional pictures was affected by the presence of another person in the environment, even though this person remained outside the field of view of the participant. This effect, however, crucially depended on the specific content of pictorial stimuli as well as on the nature of the social-evaluative context. The probability of making the first fixation on pictures conveying sexual information was reduced in the presence of an unfamiliar peer of opposite gender. However, being watched by an unfamiliar individual of the same gender had no effect on first fixations to erotic images. Also, first fixations to unpleasant or neutral pictures were not influenced by the presence of an invisible audience, regardless of gender. Moreover, autonomic physiology data showed that pupil diameter in response to erotic, but not unpleasant and neutral, pictures was smaller in the Confederate than in the Alone condition, provided that an opposite-gender peer was present in the environment. Interestingly, the maintenance of attention on emotional pictures, as measured by total viewing time and frequency of fixations, were unaffected by the presence or absence of a stranger in the room. Finally, social context of the viewing situation did not alter self-reported interest.

Taken together, our findings indicate that social presence selectively decreases early attentional capture and emotional arousal prompted by pleasant erotic stimuli, while it leaves unaltered behavioral and physiological responses to equally arousing (salient) unpleasant pictures. To unfold its effects, however, social presence must possibly be threatening to one's social self-evaluation, for only the presence of a female peer selectively impairs male' performance on erotic pictures. Thus, potentially negative

social evaluation, but not mere social presence, is responsible for determining the attentional changes observed.

Overall, the pattern of our results is neither compatible with the distraction hypothesis (Klauer et al., 2008; Wühr & Huestegge, 2010), nor with the social facilitation hypothesis (Zajonc, 1965), which predicted that the presence of another person modulates the processing of highly emotional stimuli, regardless of their valence or content, at least when there are no arousal or salience difference between pleasant and unpleasant stimuli, as was the case in the present study. The present evidence for a selective effect of social presence on the allocation of attention to pleasant (erotic), but not unpleasant stimuli, is not in line with either account. Furthermore, the classical social facilitation framework (Zajonc, 1965) assumes that the presence of others should increase arousal, thereby facilitating the dominant response to a stimulus. In fact, our results point the other way, showing an attenuation of arousal when male participants viewed erotic pictures in the presence of a female stranger.

The current findings quite nicely fit with the social evaluation hypothesis (Dickerson et al., 2004) that predicted specific behavioral and physiological responses to specific conditions in which an aspect of the self is, or could be, negatively judged by others. In our study, the crucial difference between processing erotic images and threat/injury images in social context is that only the former provides the potential for negative social evaluation and rejection (social-evaluative threat). In Western culture, indeed, watching erotic material in public, especially in a formal setting, it is deemed highly inappropriate and shameful. Shame and related negative emotions are preferentially elicited when one's social image is threatened, namely when a disapproving other, either real or imagined, negatively evaluates the self (Lewis, 1971). Consistent with this, earlier

research (Costa et al., 2001) has demonstrated that watching erotic pictures in the company of an unfamiliar person increases the subjective experience of embarrassment and shame. Although assessed informally, our participants experienced increased feelings of embarrassment during the presentation of erotic picture in the presence of another individual of opposite gender.

An interesting question is through which mechanism social-evaluative threat reduced overt attention to erotic pictures. One first possibility is that the social-evaluative threat depletes participants' cognitive resources, which in turn limits the amount of attention paid to erotic pictures in social context (Dreisbach & Böttcher, 2010). It is important to note, however, that social presence only disrupted initial orienting of attention to erotic pictures, while had no consequences on maintained attention. If social-evaluative threat reduces attentional capacity and increases distractibility, then one would expect equal or stronger effects on maintained attention (i.e., proportion of total fixation and viewing time), which relies more on (limited) attentional resources than initial orienting (Nummenmaa et al., 2006).

An alternative explanation of our findings is that, in social context, individuals automatically regulate their reactivity to emotionally evocative, but socially inappropriate, sexual stimuli, to conform to socio-cultural norms, and avoid social exclusion and unfavorable evaluation of others (Mesquita & Albert, 2007). Emotion regulation refers to a set of processes that dampen, intensify or simply maintain emotion, depending on an individual's goals and contexts (Gross & Thompson, 2007). Although typical examples of emotion regulation are conscious and deliberate (Ochsner & Gross, 2005) , such as when subjects are instructed to voluntarily decrease the intensity of the sexual arousal felt in reaction to erotic stimuli (Beauregard et al., 2001),

recent empirical work indicates that unconscious regulatory processes may be crucial in controlling physiological reactions and emotional impulses incompatible with one's current goals (Fujita & Han, 2009; Mauss et al., 2007; Williams et al., 2009). Unconscious emotion control can occur without subjective awareness and thus consume little or no attentional resources (Bargh & Williams, 2007). Moreover, unconscious emotion regulation processes may be activated efficiently and quickly, that is they can operate before full-blown emotional and physiological responses are generated (i.e., antecedent-focused). In the present study, neither subjects reported making conscious attempts to control their emotions in the Confederate condition, nor were they instructed to do so, thus making unlikely the possibility of deliberate emotion regulation in the social presence condition. The fact that pupil diameter was reduced in the Confederate condition further distinguishes this type of emotion regulation from deliberate or willful type of emotion control, which has been associated with larger pupil diameter (Urry et al., 2009), reflecting the effortful nature of conscious control of emotion. Thus, we suggest that social presence implicitly activated unconscious emotion regulation processes, effectively dampening the emotional salience and autonomic arousal of erotic pictures and thus their propensity to capture visual attention in the presence of others.

Why would social-evaluative threat affect initial orienting but not maintained attention to erotic scenes? Several evidence suggest that initial orienting toward an emotional stimulus is to a significantly degree driven by the affective properties of a stimulus, whereas maintained attention is more susceptible to voluntary control (Corbetta & Shulman, 2002; Egeth &Yantis, 1997), reflecting the participant's conscious motivations, interests and desires. On this perspective, our findings suggest that social presence exerts a subtle impact on attention to erotic images, blunting the incentive

salience and attention-grabbing characteristic of sexual pictures, without changing the controlled, elaborative processes that subserve the maintenance of attention on them. Presumably, once emotional impulses and physiological responses towards sexual pictures had been cooled down by the social-self threat, participants could look and explore the content of sexual images from a detached and non-emotional perspective. Of course, this is a currently speculative interpretation that will need to be confirmed in future studies.

Several limitations that characterize the present study warrant comments. First, all the participants were males. It will be important for future investigations to examine the extent to which these findings generalize to women, and, further, if there are gender differences in attentional responses to sexual and non-sexual images in social contexts. Second, the present studies featured just one index of physiological reactivity (changes in pupil size across experimental stimuli and conditions), and the use of other autonomic (skin conductance, heart rate), and subjective (self-report) measures could shed additional light on the role of social presence in modulating emotional reactivity. In conclusion, the present study provides evidence that social context can modulate the physiological and attentional responses to emotional stimuli, depending on their specific content. The presence of an unfamiliar and invisible other reduced early attentional capture and emotional arousal elicited by pleasant erotic stimuli but did not affect behavioral and physiological responses to equally arousing, but unpleasant pictures. We suggested that the social evaluative context implicitly instigates unconscious emotional regulation processes, lessening the emotional salience and autonomic arousal elicited by erotic pictures and, in turn, their propensity to capture visual attention in the presence of others. Above all, our findings indicate that the reactivity to emotional stimuli reflect

not only intra-individual psychological tendencies but is also flexibly shaped by the interpersonal, sociocultural environment.

# CHAPTER 6 - Cognitive processes affect emotion

In the past two decades, research has witnessed a shift from a separated view of emotion and cognition toward a more interactive and integrated view of these two domains. There is great increasing interest on how emotion and cognition interact and on what are the mechanisms underlying this interaction. The idea of a bidirectional relationship between affective and cognitive processes has developed, also supported by neuroimaging and neurophysiologic data. The previous chapters of this thesis report evidence that emotion influences cognitive processes. In an evolutionary frame, it has been shown that certain kind of stimuli, emotionally and motivationally valenced, may automatically drawn attention compared to neutral ones. Attention is not the only domain that has been investigated to highlight the importance of emotion in cognition. Further examples come also from studies on memory and reasoning (for review see Dolan, 2002). For instance, the benefit of emotion on autobiographical or explicit memory is extensively reported in studies that showed enhanced memory for events that are emotionally charged or for material that include personal information (Phelps et al., 1997) as well as in studies with amnesic patients, which show spared mnemonic abilities for emotional materials, despite memory deficits (Hamman et al., 1997). Furthermore, the emotional influence on reasoning and decision-making is reported in studies on patients with VMPFC damage (Bechara et al., 2000) and is explained by the somatic-marker hypothesis, according to which evocation of past feeling states biases decision-making processes toward or away from a particular behavior (Damasio et al., 1996).

If on the one hand the contribution of affective processes on cognition domain is well documented, there is as much evidence of the influence of cognitive processes on emotion domain. A critical example is the fundamental adaptive ability of individuals to override automatic, "irrational", emotional responses when they are not consistent with current intentions (Cohen, 2005). But how does this happen? What are the neural mechanisms involved in this kind of control?

The general idea is that behavior might be determined by a competition between brain systems that lead to different evaluations of the same circumstances. Neuroimaging findings indicate the prefrontal cortex, in its anterior and dorsolateral regions, to be a crucial area for the resolution of this competition. Studies on emotion regulation and decision-making could provide a great example of how high-level cognitive processes compete and interact with emotion in the brain to produce behavior. This chapter will delve into this topic.

**6.1 Cognitive control of emotion**

A fundamental question about the relationship between cognition and emotion concerns the neural substrate underlying emotional self-regulation. One of the primary functions attributed to emotion is providing individuals with important information coming from the environment and preparing them to quickly respond to external opportunities and challenges (Frijda, 1986). Nevertheless, sometimes the emotional responses are not appropriate to the situations people face, and often they are not appropriate to achieve long terms purposes (Gross, 1998). Sometimes emotional responses need to be modulated and overridden by means of higher-order cognitive functions. Emotion regulation serves this important role. Usually, we refer to emotion regulation as a set of strategies by which individuals influence their emotions, when and how they experience and express these emotions (Gross, 1998). These strategies may be automatic or controlled, unconscious or conscious and may affect emotion generative processes at early or later stages. Given the increasing hint of complex interdependency of cognitive and affective processes, lately cognitive psychology and neuroscience committed to elucidate behavioral and neural substrates of emotion regulation. On the basis of various evidence from experimental lesion studies in animals and clinical neuropsychological, psychophysiological, and functional brain mapping studies in humans, Davidson and colleagues (2000) have proposed that emotional regulation may be normally implemented by a neural circuit consisting of several regions of the prefrontal cortex (orbitofrontal, dorsolateral and anterior cingulate cortex), and of subcortical limbic structures, such as the amygdala and the hypothalamus. Functional neuroimaging studies have been used to investigate neural systems implicated in different type of regulative strategies. Two in particular have been examined: controlling attention to,

and cognitively changing the meaning of, emotionally evocative stimuli. Cognitive change is used to regulate an existing or an ongoing emotional response and, consistent to Davidson hypothesis, has been shown to rely on interaction between prefrontal and cingulate control networks and cortical and subcortical emotion generative system (for review see Ochnser & Gross, 2008) with differences in the time occurrence (Goldin et al., 2008).

Among cognitive change strategies, reappraisal has received particular attention. It consists of cognitively transforming a situation so as to alter its emotional impact. Experimental evidence previously confirmed reappraisal to be effective. For example, it has been shown that reappraisal of negative valence films led to a decrease in experience of negative emotion (for review see Gross, 1998). Neuroimaging results suggested that processing dynamics similar to those implicated in other forms of cognitive control are recruited in cognitive control of emotion. Using fMRI, Ochsner and colleagues (2002) presented participants with aversive photos and instructed them to increase, maintain, or decrease (post experimental debriefing suggested that participants reappraised) their emotional reactions. Two conditions were employed: ''Attend trials,'' where participants were asked to let themselves respond emotionally to each photo by being aware of their feelings without trying to alter them and, ''Reappraise trials'', where participants were asked to interpret photos so that they no longer felt negative in response to them. Results showed that reappraisal implicated activation in the regions of lateral PFC and medial PFC, essential for working memory and cognitive control (Knight et al., 1999; Miller & Cohen, 2001), and decreased activation in medial OFC and amygdala, two regions involved in emotion processing (Bechara et al., 1999; Davidson & Irwin, 1999). In addition, the magnitude of ventral

LPFC activity during effective reappraisal was inversely correlated with activation in both emotion-processing regions.
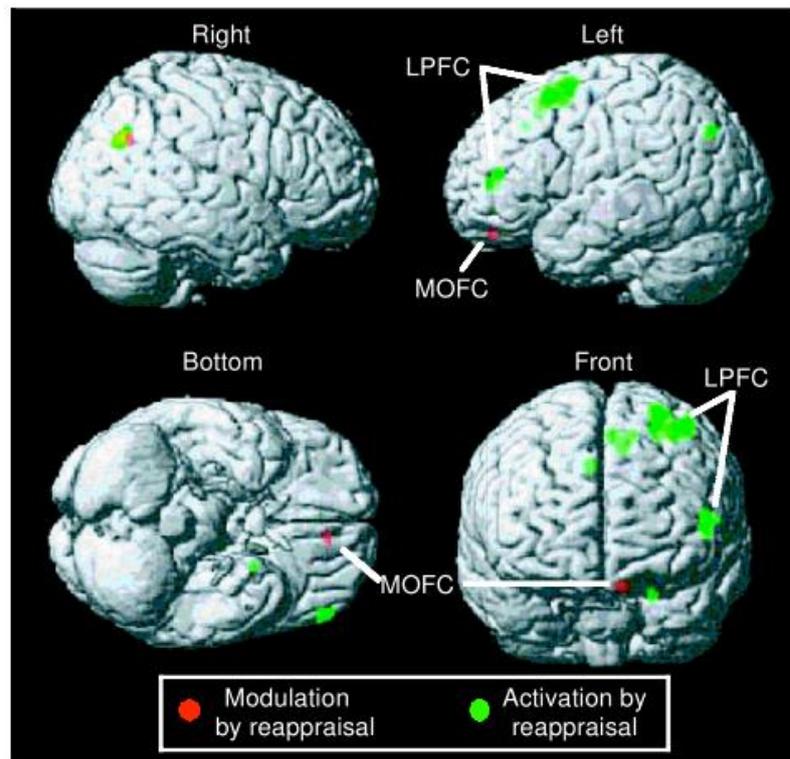


**Figure 6.1:** Group averaged brain activation when reappraising or attending to feelings in response to the most negative photos. The "modulation by reappraisal" in red shows regions important for emotion processes that are modulated by reappraisal. The "activation by reappraisal" in green shows regions exerting cognitive control over emotion activated by reappraisal. (Adapted from Ochsner et al., 2002)

Moreover, additional experiments found the same patterns of activity for both up- and down- regulation of emotion (Ochsner et al., 2004). The authors concluded that reappraisal recruits lateral PFC to maintain the selection and application of the regulative strategy and, in accordance with the current goal, modulate emotion processes implemented in cortical and subcortical regions involved in evaluating the

affective salience and contextual relevance of a stimulus (Ochsner & Barrett, 2001; Phelps et al., 2001; Rolls, 1999).

In another study by Beauregard and co-workers (2001) brain activation was measured in normal male subjects while they either responded in a normal manner to erotic film excerpts or voluntarily attempted to inhibit the sexual arousal induced by viewing erotic stimuli. Results demonstrated that the sexual arousal experienced in response to the erotic film excerpts was associated with activation in limbic and paralimbic structures, such as the right amygdala, right anterior temporal pole, and hypothalamus. On the contrary, the attempted inhibition of the sexual arousal generated by viewing the erotic stimuli was associated with activation peaks in the right dorsolateral PFC (superior frontal gyrus) and the right ACC. Contrary to the pattern of brain activity seen in the sexual arousal condition, no significant loci of activation were noted in the limbic regions in attempted inhibition condition. These findings reinforce the view that emotional regulation is normally implemented by a neural circuit comprising various prefrontal regions, implicated in top-down processes that monitor and control the information processing necessary to produce voluntary action and, subcortical limbic structures, implicated in the evaluative processing of the stimuli. Importantly, these findings report that cognitive control of emotion implicates the same neural network involved in other forms of control, useful to resolve cognitive conflict between two simultaneous responses that compete for limited resources. Indeed, in cognitive demanding tasks ACC has been shown to correlate with level of conflict and to predict subsequent increases in prefrontal cortex and execution of control in lateral PFC (Botvinick et al., 2001, 2004).To better understand this mechanism and how it might fit

to emotion-cognition competition, in the next paradigm a classic example of "cold" cognitive conflict will be explained.

## 6.2 An example of Cognitive Conflict

We can talk about cognitive conflict every times cognitive processes go in competition with each other. The Stroop task (Stroop, 1935) and its many variants can be considered as the experimental task most extensively used to study competition between processes. In its traditional form, it consists of presenting a visual display of a word (e.g. the name of a color) and asking either to read the word or to name the color in which the word is displayed.
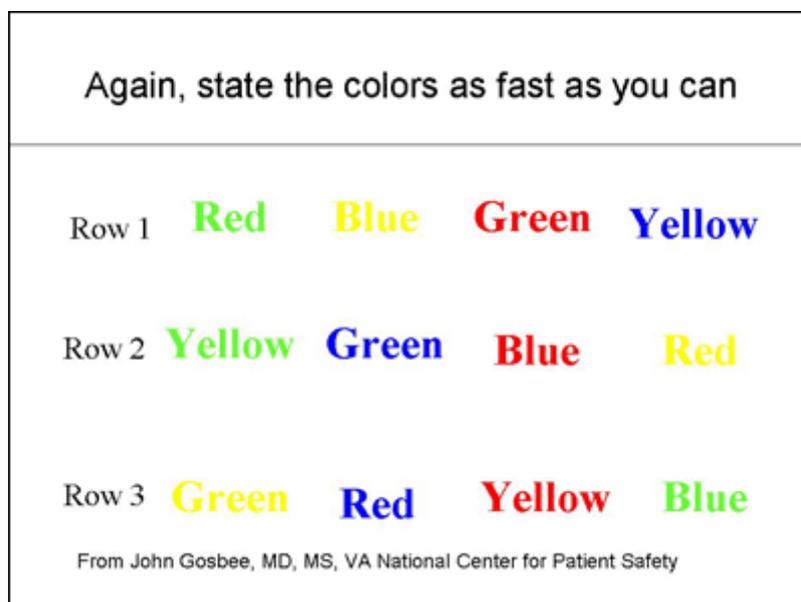


**Figure 6.2**: Example of incongruent trial in the Stroop Task (Stroop, 1935)

Typically, neither accuracy nor speed is affected by the color in which the word is presented when the subjects are required to simply read the word, for example saying "Red" to the word red presented in green. Contrarily, when subjects are required to name the color, response is not always equally simple. If the word itself and the color of the word disagree, as in the example above (incongruent trials: the word red presented in green) the response times significantly decrease, compared to if the color of the word and the word itself agree (congruent trials: the word red presented in red). This effect has been explained as a consequence of the competition between the strong automatic process of word reading and the process of color naming (Kahneman & Treisman, 1984; MacLeod & Dunbar, 1988). Neural network models have been proposed to clarify the dynamics of this competition and its relationship to behavior. The existence of two pathways has been suggested (Cohen et al 1990). The word reading pathway would serve encoding the orthographic form of visual stimulus into its corresponding verbal representation, whereas the color naming pathway would serve encoding the color of stimuli into the same set of verbal representation. Each pathway consists of a set of input units, intermediate units, and output units. Conflict is defined as the product of the activity of competing processing units and can be reduced by increasing activity of the unit that provide top down control (e.g. Color naming unit). This will augment activity in the task-relevant unit and inhibit activity in the other unit, reducing conflict. This model of the Stroop task suggest that differences in practice lead to differences in the strength of processing, so that the much more considerable experience that adults have in reading words than in naming colors makes connections in the word reading pathway stronger than those in the color naming pathway. This clarify why when presented with a word and asked to respond, usually people tend to invariably read the

word and not to name the color in which the word is displayed. However, even if the reading word is easier and more automatic, people are ever able to respond correctly in incongruent trials when they are asked to name the color. According to the Stroop model, this is possible because there are units that represent the knowledge about the two dimension of the stimulus and about the two different task demands (color naming and word reading). In the case of naming the color, top down processes are necessary to activate the correct task demand unit and to proceed in the corresponding pathway. This top down support strengthen information in the color naming pathway to make it competitive against the usually stronger information coming from word reading pathway and allows producing a correct response, consistent with the demand of the task. The Stroop task is variously described as exploiting the cognitive functions of selective attention, behavioral inhibition, working memory or goal-directed behavior. Miller and Cohen (2001) proposed that all these functions rely on representation of goals and rules in the form of patterns of activity in PFC, which configure processing in other parts of the brain in accordance with current task demands. According to the theory of cognitive control the PFC serves the function of active maintenance of patterns of activity that represent goals and the means to achieve those (Miller & Cohen, 2001). These representations bias signals throughout the rest of the brain and guide the flow of neural activity along pathways that establish the proper mapping between inputs, internal states and outputs needed to perform a given task. This is especially important whenever stimuli are ambiguous or when multiple responses are possible. Thus, cognitive control has been frequently conceptualized as the top-down flow that supports the task-relevant processes and resolve cognitive conflict.
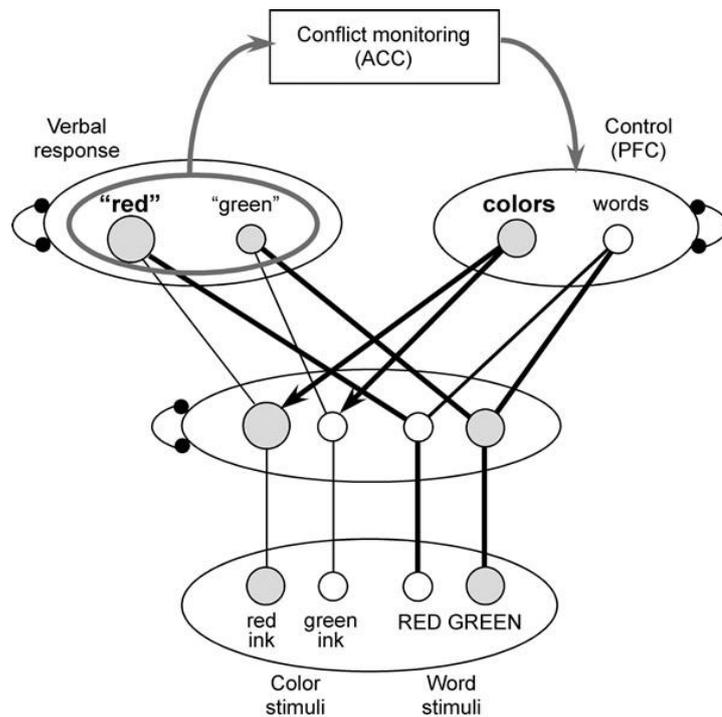
**Figure 6.3:** Response conflict and Stroop task (1935). This figure shows a model developed to capture the notion of response conflict and to adaptively adjust cognitive control to improve performance. The input layer reflects sensory input in the form of the ink color (color stimuli, either Red (R) or Green (G) and word meaning (word stimuli). These two inputs then bias responding with greater strength given to the word meaning to reflect the greater automaticity of this process. Cognitive control, derived from PFC activity helps to improve performance by selectively biasing sensory inputs based on whether the task is to do color-naming (C) and word-reading (W). Control is gated by the detection of response conflict in ACC. (Adapted from Cohen, 1994).

Neuroimaging studies provided contribution in specifying neural correlates of cognitive conflict and execution of control. Anterior cingulate cortex (Brodmann's areas 24 and 32) and dorsolateral prefrontal cortex (Brodmann's area 9 and 46) seem to be two regions closely related to cognitive conflict and executive control. For instance, studies on working memory (Cohen et al., 1997) increased activity in these prefrontal regions

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during tasks that required holding long sequences of items or while performing two tasks at the same time. However, functional dissociation of these two regions has been reported. For instance, Fletcher and colleagues (1998) found DLPFC activity in absence of ACC activity when participants were engaged in maintaining and manipulating information in working memory. On the contrary more activity in ACC was shown in tasks of divided attention, as the traditional Stroop task (Pardo et al., 1990), in monitoring performance and in errors detections (Carter et al., 1998). MacDonald and colleagues (2000) suggested that DLPFC may be involved in representing and maintaining the attentional demands of the task and implementation of control, while ACC may be involved in evaluative processes and detection of conflict. Consistently, these authors showed that only activity in DLPFC, during a modified version of the Stroop task, increased in response to instructions to name the color but not to read the word, while no-instructions related activity was observed in ACC. Moreover, they showed that the most activation in left DLPFC after color-naming instruction showed the smallest Stroop interference effect. These findings contribute to the idea that DLPFC exerts a top-down control function and that more activity in this region corresponds to conflict decrease. Furthermore, consistent with the role of ACC in conflict monitoring, greater activity of this region was more related to response period for color-naming incongruent trials than for congruent ones and was associated with greater Stroop interference.

## 6.3 Emotion and cognition in decision making

Conflict has been well studied in contexts where cognitive control is necessary to avoid erroneous or prepotent responses within cognitive tasks. It has been previously shown that increase in anterior cingulate cortex (ACC) activity is related to level of conflict and can predict subsequent increase in lateral prefrontal cortex activity and exertion of control (Botvinick et al., 2001). Although the mechanisms described above concern the competition between different cognitive processes, it is possible that similar mechanisms can be applied to other circumstances where the competition is not between two different cognitive processes but between simultaneous emotional and cognitive processes that conflict with each other and that have opposing effects on behavior. Decision-making is a good field to investigate this possibility.

Sometimes we find ourselves in situations where strong emotional responses are place in competition with the outcome supported by cognition. In these cases, conflict may serves as a neural measure indicating whether emotion regulation is necessary to override emotional responses and cognitive control processes should be recruited to guide behavior in favor of long-term intentions. A variety of decision-making tasks, such as moral judgments (Greene et al., 2004), economic decision-making (Sanfey et al., 2003) or inter-temporal choices (McClure et al., 2004), have been explored in this direction, suggesting that decision-making may include both emotional and cognitive aspects and that our choices may be the product of the competition between these two processes.

Furthermore, sometimes behavior can create, not only reflect, people's attitude. Indeed several studies have shown that decisions can alter our preferences (Izuma et al., 2010). Difficult decisions which occur when we are forced to choose between equally

attractive options may generate a negative emotional states and conflict may serve to indicate inconsistency between our attitudes and behavior. In this case cognitive control might be recruited to justify and provide coherence to behavior. An example of this can be found in studies that investigate changes of preferences and attitudes. Most of these contexts reflect situations that we easily meet in our everyday life. In the next paragraphs neural systems that underlie these competitive and regulative mechanisms will be discussed.

## 6.3.1 Cognitive control in moral judgment

Historically, the debate concerning moral decision process was dominated by the assumption that maximization of the self-interest is the main force driving human behavior. Economists have used this assumption to identify conditions under which self-interest leads to the common good. However, it is evident that everyday decisions not always follow rational and utilitarian principles but instead present many inconsistencies. The two versions of the trolley problem (Thomson, 1986) are good instance to highlight this inconsistency:

"A runaway trolley is headed for five people who will be killed if it proceeds on its present course. The only way to save them is to hit a switch that will turn the trolley onto an alternate set of tracks where it will kill one person instead of five. Should you turn the trolley in order to save five people at the expense of one?"

Most people say yes (Greene et al., 2001).

"A trolley threatens to kill five people. You are standing next to a large stranger on a footbridge spanning the tracks, in-between the oncoming trolley and the hapless five. This time, the only way to save them is to push this stranger off the bridge and onto the

tracks below. He will die if you do this, but his body will stop the trolley from reaching the others. Should you save the five others by pushing this stranger to his death?"

Most people say no (Greene et al., 2001).

What is the difference between these two scenarios? Why people are willing to accept one action but not the other even if they both bring to the same outcome? Philosophers and ethicists have struggled to solve this issue. A possibility to answer these questions is considering that often people take decisions not only relying on universal rational principles but rather on their intuitions. In many everyday life situations, human behavior reflects separate emotional and cognitive aspects. Indeed, recently the role of intuitive and emotional processes in human decision making (Damasio, 1994) and sociality (Bargh & Chartrand, 1999; Devine, 1989) has been emphasized, fanning the debate about the bases of morally relevant decisions. The inconsistency of human decision-making may be the mirror of the existence of separated affective and cognitive aspects, and our behavior could be the result of the interaction and the competition between these aspects. The investigation of the situations in which cognitive and emotional processes countervail may help to understand if and how affective and cognitive processes, and their neural substrates, separately influence our behavior. fMRI works on moral decision-making provided an attempt to unveil these mechanisms and solve out a longstanding debate.

An account suggested by Greene and Haidt (2002) is that some circumstances, such as those presented in the dilemmas above, elicit stronger emotional responses compared to others. Flipping a switch can be less emotionally engaging that pushing a worker off a bridge to his death. The negative emotional response aroused by this latter action may elicit an automatic feeling of wrongness and consequently lead to condemn the action

itself. Greene and his colleagues tested this hypothesis using fMRI (Greene et al., 2001) while participants were presented with different types of moral dilemmas, with the prediction that dilemma requiring the infliction of direct and serious body harm on another individual to achieve some good (Personal) compared to dilemma including the infliction of harm in a less direct fashion (Impersonal), would evoke greater emotional response that influences participant's moral intuitions. Consistently, contemplation of personal moral dilemmas was shown to activate brain regions, such as medial prefrontal cortex, previously and strongly associated with emotional processing and social cognition (Damasio, 1994; Davidson & Irwin, 1999). On the contrary, activation of the dorsolateral prefrontal cortex (DLPFC) consistently associated with cognitive processes such as abstract reasoning, working memory and problem solving (Cohen et al., 1997), was found while participants were contemplating impersonal dilemmas. Moreover, behavioral results showed longer reaction times for "incongruent" trials in which participants, contrasted emotional automatic response and accepted moral violations of personal dilemmas. Interestingly, these findings suggest a pattern of interference similar to that observed in cognitive tasks, such as Stroop task, in which automatic processes compete with higher order processes and can influence responses (MacLeod, 1991).
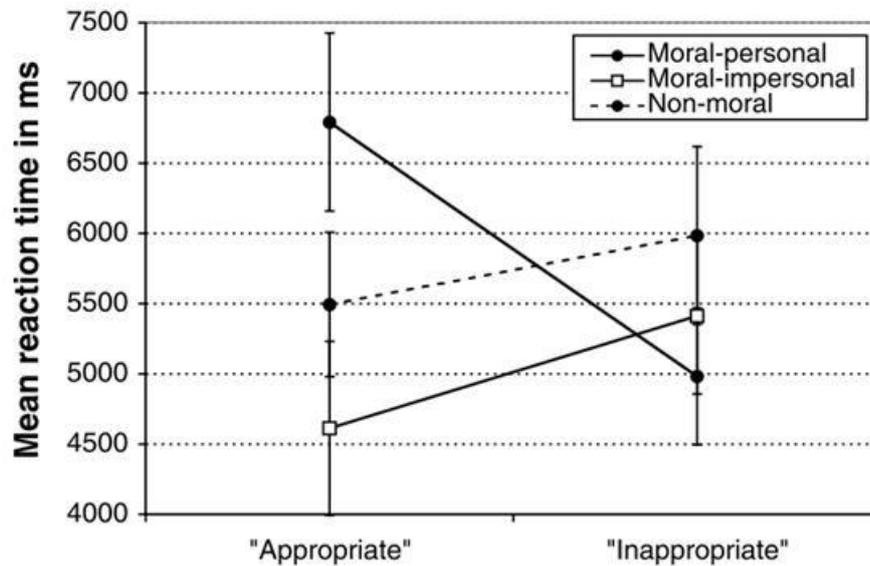
**Figure 6.4:** Mean reaction time by condition and response. Reaction times differed significantly between response of "appropriate" and "inappropriate" in the moral-personal condition but not in the moral-impersonal condition and in non-moral condition (Adapted from Greene et al., 2001).

These findings can find an explanation from an evolutionary point of view. While our common ancestors used to live mainly guided by emotions such as anger, jealousy, empathy, joy, love and sense of fairness (De Waal, 1996), in apparent absence of reasoning, humans developed also abilities of abstract reasoning and problem solving that may contrast emotions in order to guide behavior and achieve long term goals. Accordingly, the work by Greene and colleagues suggest that in order to accept moral violations eliciting strong emotional and automatic response, humans must engage higher order cognitive processes, such as cognitive control that lead to the resolution of the conflict. To support this hypothesis, Greene and colleagues (2004) tested participants with a class of dilemmas that require longer time to answer because the negative social-emotional response strongly conflicts with a more abstract, cognitive

reasoning. In this kind of dilemmas (e.g., Crying baby dilemma) emotional and cognitive factors are in more balanced tension and the answer is more difficult, like in the example below:

"Enemy soldiers have taken over your village. They have orders to kill all remaining civilians. You and some of your townspeople have sought refuge in the cellar of a large house. Outside, you hear the voices of soldiers who have come to search the house for valuables. Your baby begins to cry loudly. You cover his mouth to block the sound. If you remove your hand from his mouth, his crying will summon the attention of the soldiers who will kill you, your child, and the others hiding out in the cellar. To save yourself and the others, you must smother your child to death.
Is it appropriate for you to smother your child in order to save yourself and the other people?"

Providing more direct evidence for the emotion-cognition competition, results showed that difficult dilemmas elicit activity in both emotional and cognitive brain areas. Moreover, the contemplation of difficult compared to easy moral dilemma exhibited greater activation of anterior cingulate cortex (ACC), previously associated with detection of cognitive conflict (Botvinick et al., 2001; Carter et al., 1998) as well as greater activation of anterior DLPFC, confirming that processes that compete with social-emotional responses rely on abstract reasoning and cognitive control. These findings are consistent with a model in which a combination of intuitive/affective and conscious/rational mechanisms operates to produce moral judgment.
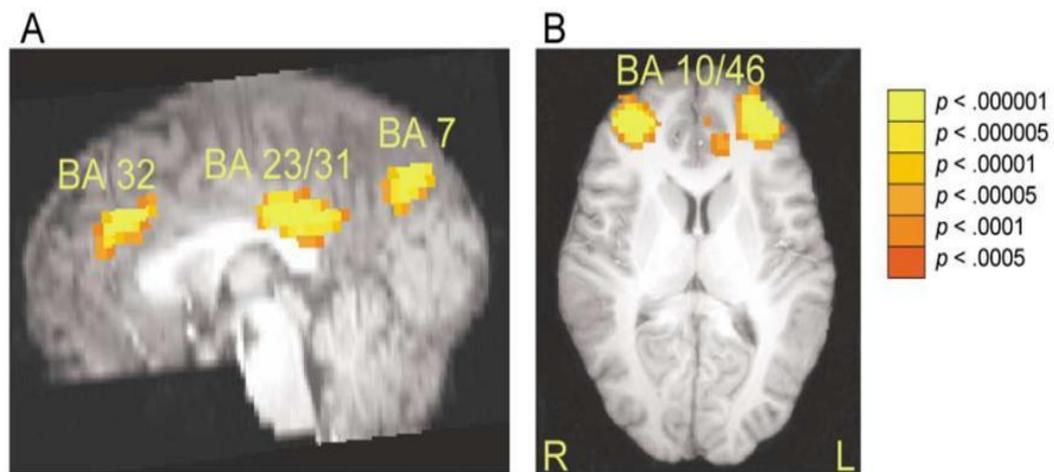
**Figure 6.5:** Difficult vs. easy personal moral judgments. Here are indicated the selected brain regions exhibiting significantly greater activation for difficult as compared to easy moral-personal dilemmas: Anterior and posterior ACC (BA 32, BA 23/31), precuneus (BA 7), right and left middle frontal gyrus (BA 10/46). (Adapted from Greene et al., 2004)

In addition, it has been proposed that within the context of moral reasoning task, cognitive processes are associated with a certain kind of behavioral outcomes that favor utilitarian decisions in order to achieve the greater goods, in terms of costs-benefits analysis. Accordingly, authors provided further evidence that different type of moral judgment engage functionally distinct brain systems. Activity in brain regions associated to cognitive control, particularly DLPFC was found to precede and to be directly related to utilitarian judgments compared to non-utilitarian, even when this competes with a strong negative response to the prospect of harming another individual. These data reveal that neural activity in classically cognitive brain regions predicts a particular type of moral judgment behavior, thus providing strong support for the view that both cognitive and emotional processes play crucial and sometimes mutually competitive roles in moral decision-making.

Rather than a totally rationalist (Kohlberg, 1969) or a totally emotive (Haidt, 2001) view, these findings support the conclusion that moral judgment come from the interaction of both emotion and cognition (Greene & Haidt, 2002) and is the by-product of the resolution of the conflict between these two crucial processes. This model has been extended also to other field of decision-making in which emotion and cognition are important aspects. Works from neuro-economics and inter-temporal choices provided parallel findings, supporting the idea of a dual-process model of decision-making. Indeed, competition between emotional and cognitive processes has also been proposed to explain behavior deviating from the usual idea of economic rationality. There is evidence that, also in an ultimatum game (Thaler, 1988) context, behavior is guided by emotional as well as cognitive processes that come into conflict. In this kind of task people are provided of an amount of money. The proposer must make an offer and the responder may either accept or reject. If the offer is accepted the two players split the money, if the offer is rejected nobody take the money. According to economic rationality accepting any offer and earning money should be always the best option. Nevertheless people not always do so and when the offer is unfair they tend to reject it (Güth et al., 1982, Thaler, 1988). Results from fMRI investigations (Sanfey et al., 2003) showed that unfair offers evoke activity in the insula, a limbic brain region associated to negative emotions (Calder et al., 2001). Moreover, similar to the work of Greene in moral judgment, unfair offers were also tied to activity in prefrontal regions such as ACC and DLPFC and, when activity in emotional regions was greater, responders tended to reject unfair offers significantly more than when activity was greater in DLPFC. Other example of the same mechanisms is provided by fMRI studies in inter-temporal choices (McClure et al., 2004), where people choose between different

rewards delivered at different time delays. In this kind of task impulsive processes and cognitive appraisal processes go into competition with each other. According to the dual-process theory, it has been shown that cognitive regions such as lateral prefrontal cortex are implicated in deciding in any inter-temporal choices, whereas the emotional system and regions such as ventromedial prefrontal cortex and posterior cingulate cortex are preferentially implicated by the immediately available rewards. Moreover, relative activity in the emotional and cognitive system correlated with participants behaviors.

In summary, parallel findings from different instances of decision-making are consistent with the view that a variety of human behaviors and decisions are determined by the interaction and sometimes the competition between emotional and cognitive systems. Neuroimaging techniques have been demonstrated to be very useful in tracking the neural activity of specific brain area in normal human subject while they are performing cognitive tasks. fMRI for instance provides crucial information on the location and the timing of brain activity, nevertheless it has also important limitations. The most important of these limitations is that it is only correlative and does not allow establishing the causality of the relationship between a pattern of brain activity and a particular psychological function of behavior. Even though the neuroimaging findings reported above shed light on and support the engagement of emotional and cognitive processes in decision-making, many questions remain unanswered. It is still not clear for example how the competition is regulated and evidence of a causal relationship between dorsolateral prefrontal cortex and exertion, regulative control is still lacking.

### 6.3.2 Cognitive control and rationalization in change of preferences

It has been previously shown that emotion and cognition interact in shaping our decisions and behaviors. On the contrary, it is also possible that sometimes behavior can create and not only reflect people's attitudes and emotional and cognitive aspects interact at later stages. Indeed, several studies highlight how decisions can alter, not only follow, individuals' preferences (Izuma et al., 2010). Changing preferences and opinions is characteristic of human behavior. In everyday life people often do or say things that contradict their prior belief (Aronson et al., 1995). How and why this happen has fascinated psychologists for years. Typically individuals change their attitude a posteriori to conform to contradicting behavior they were engaged in. Adjusting preferences to support prior decisions is a phenomenon that has been deeply explained by the Cognitive Dissonance theory (Festinger, 1957). Following this theory, cognitive dissonance is a psychological discomfort caused by holding simultaneously conflicting cognitions, such as ideas, beliefs, values or emotional reactions. Accordingly, experimental evidence showed that cognitive dissonance is associated to negative affect and autonomic arousal (Critchley, 2005). It is noteworthy that coherence is an important aspect of human well-being and it may constitute for people a motivational drive to reduce dissonance. Thus, change of preferences serves to specifically reduce a negative affect generated by the inconsistency between what we think and what we do and is crucial to restore consonance (Elliot & Devine, 1983; Losch & Cacioppo, 1990). Furthermore, this intriguing effect has been demonstrated not only in adults but also in children and monkey (Egan et al., 2007), suggesting that cognitive dissonance and reduction processes find their bases in developmentally and evolutionary constrained systems.

A typical example of dissonance is the conflict felt by a smoker person that keeps on smoking although he/she knows that is unhealthy. Engaging in dissonance reduction processes, this person may change his/her feelings about cigarettes to justify behavior. In this perspective, cognitive dissonance is an important concept that can be applied in a wide range of circumstances, such as decision-making, prejudice, deception and politics to explain and predict human behavior.

Consequences of such a behavior have been examined in the past by means of different paradigm like the induce-compliance paradigm (Festinger & Carlsmith, 1959) or the free-choice paradigm (Brehm, 1956) and their variants. In the induced-compliance paradigm used in experimental setting usually participants are required to write counter-attitudinal essay and they are paid varying amounts of money for writing essay expressing opinions contrary to their own. People paid only a small amount of money have less external justification for their inconsistency and must produce internal justification in order to reduce the high degree of dissonance that they are experiencing.

In the free-choice paradigm individuals rate the attractiveness of a variety of items. They are given a choice between two items that they have rated as equally attractive. Thus, both options have positive and negative aspects. This choice is thought to induce a negative affect because decision to avoid the rejected alternative conflicts with the many positive aspects the alternative has. After making the choice subjects are asked to re rank all items. Typically, items that they have chosen are judged as more attractive and items they have rejected as less attractive: subjects have changed their attitudes to fit with their choice. Consistently, Sharot and colleagues (2009) used a free-choice paradigm in an fMRI study demonstrating that after making a choice, activity in caudate nucleus, brain regions associated to reward processing, expectation and learning

(Delgado, 2007), changes to reflect the new evaluation of the alternatives, by increasing for the chosen alternative and decreasing for the rejected one. Similarly, another experiment by Izuma and colleagues (2010) found that the mere act of making a choice can modulate self report preferences as well as its neural representation in striatum activity. Thus, recently interest in the neural substrates of cognitive dissonance has been increasing. Neuroimaging and neurophysiologic techniques have been used to investigate the neural processes implicated in attitude changes, confirming the original idea of Festinger (1957) according to which attitude change is driven by the conflict. Accordingly, the action − based model (Harmon-Jones et al., 1996) of cognitive dissonance posits that conflict between cognitions evokes an aversive state because it potentially interferes with unconflicted, effective, goal-driven action and explicitly predicts involvement of dACC in cognitive dissonance. Following this model, dissonance should evoke activity in ACC as it is a structure strongly associated to detection of a variety of cognitive conflicts. Indeed ACC has been found to be involved in conflict between active but incompatible streams of information processing (VanVeen & Carter, 2006), in monitoring the occurrence of errors or the presence of response conflict (Carter et al., 1998), conflict in moral decision making (Greene et al., 2001, 2004) and when behavior conflicts with self-concept (Amodio & Frith , 2006). fMRI studies support the link between ACC and cognitive dissonance. For instance, Van Veen and colleagues (2009) scanned participants in fMRI while they argued that the uncomfortable scanner environment was nevertheless a pleasant experience. Results showed that cognitive dissonance engaged the dorsal ACC and anterior insula, previously associated with negative affect and autonomic arousal (Critchley 2005; Eisenberger et al., 2003), suggesting these regions to be responsible for representing or

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triggering the negative affect and related autonomic arousal associated with the dissonance. Interestingly, their results also showed that magnitude of conflict was related to dACC activity and that this was predictive of subsequent attitude change. Activation of dACC was also found in another similar experiment by Izuma and colleagues (2010), while participants were engaged in an induce-compliance paradigm. These results confirm the importance of this region in cognitive dissonance and expand on those findings concerning ACC as candidate region in conflict monitoring.
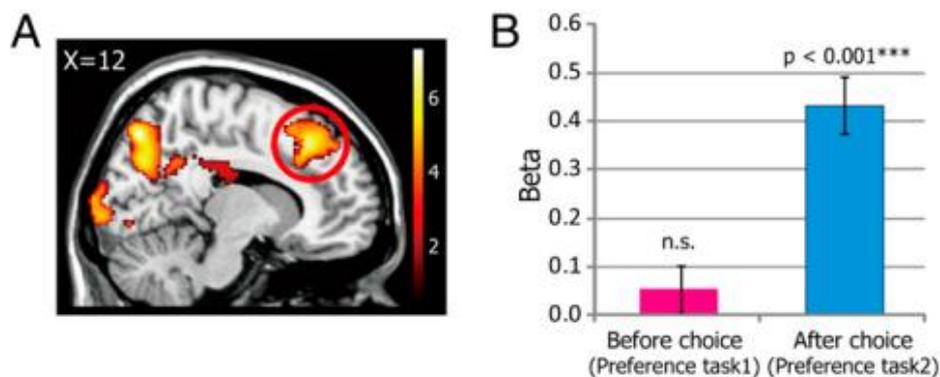


**Figure 6.6:** This figure shows the significant correlation between activity in ACC and the degree of cognitive dissonance, during preference task. (Adapted from Izuma et al., 2010)

One dissonance is aroused and conflict is detected inconsistency reduction processes should occur in order to restore consonance and regulate negative affective state. Consistently, lateral prefrontal cortex activity has been reported to contribute to changes in preferences. In addition to ACC, the work of Izuma and colleagues reported increased activity of DLPFC, regions previously associated to implementation of cognitive control (MacDonald et al 2000) and conflict resolution (Van Veen & Carter, 2006), especially in reduction of dissonance. Interestingly, in another study (Harmon-Jones et al., 2008) EEG biofeedback training was used to manipulate lateral prefrontal

activity after subjects made difficult decisions. Afterwards change of attitudes was measured. Results indicated that lateral prefrontal cortex was causally involved in change of preferences and that the activation of this region affected the extent of this change. Taken together all these data suggest that cognitive dissonance and subsequent reduction recruit the same neural network underlying conflict monitoring and implementation of control, already shown in difficult decisions such as moral judgment. Moreover they provide further evidence of the existence of top-down cognitive mechanisms that modulate regulate emotional aspects and values in our choices.

**Introduction to experiments Four and Five**

In this chapter we reported evidence of that cognitive and emotional processes work in interactive relationship. Taken together previous studies suggest that cognition is necessary to regulate affective processes. Indeed, if the ability to automatically respond to emotional relevant stimuli is evolutionary crucial, equally important is the ability to control these emotional responses, thereby moderating their influence on behavior. Cooperation between reason and emotion contributes to form behavior and brings our actions into line with enduring concerns, motivating and sustaining actions in order to achieve long terms goals. Instances of these mechanisms derive from emotion regulation as well as decision-making studies. Of particular interest is the parallel between forms of "cold" cognitive control and cognitive control of emotion that emerged from previous literature. Evidence of an overlap of neural networks underlying both these mechanisms has been reported. Studies on emotion regulation showed that regulative strategies such as cognitive change involve increased activation in the regions of lateral PFC and medial PFC, essential for working memory and cognitive control and, decreased activation in medial OFC and amygdala, two critical regions for emotion processing. Similar examples are provided by works on decision-making suggesting that both affective and cognitive processes are implicated in forming decisions and preferences. Accordingly, studies on moral judgments reported that more emotionally engaging moral dilemmas (Personal dilemmas) evoke greater activity of VMPFC whereas response to moral dilemmas that engage emotion to a lower extent (Impersonal dilemmas) fail to activate this region. Moreover, fMRI studies supported the notion of emotion-cognition competition by indicating that difficult dilemmas elicit activity in ACC and DLPFC, regions related to cognitive conflict and executive control. In

addition, greater activation of DLPFC was necessary to accept moral violations, confirming a critical role of the cognitive region in regulating affective processing. Similar competitive mechanisms are reported also in forming preferences post decisions. There is evidence that change of preferences after difficult decisions is driven by the conflict between attitudes and behavior, as reflected by activation of ACC and DLPFC in cognitive dissonance paradigms.

In the previous chapter examples have been provided for the interactive and sometimes competitive relationship between emotion and cognition, as critical in shaping human behavior. Nevertheless, although correlative evidence of lateral prefrontal cortex activity and regulative processes is well documented, causal evidence is still lacking. In the next two chapter of this thesis two experimental works aimed at filling this lack will be reported. In particular the issue of the role of DLPFC in resolution of conflict will be addressed.

# CHAPTER 7 - EXPERIMENT FOUR

## Disrupting dorsolateral prefrontal cortex influences moral decisions

## 7.1 Introduction

The relationship between emotion and moral judgment has inspired philosophical disputes for decades, arriving to draw attention of researchers in others fields like cognitive psychology and neurosciences. Rationalist model has long been dominating in moral psychology sustaining the role of reasoning as the main source of moral judgment (Kohlberg, 1969). The intuitionist model, on the contrary, emphasizes the role of emotion, underlying the automatic, fast and effortless aspects of moral judgment (Harrison, 1967). According to this model, the moral intuition would come first in time and therefore it would constitute the key source behind morality. The first displays of the implication of emotion in moral judgment come from behavioral studies. Schnall and colleagues (2008), for instance, showed that moral opinions can be modulated by emotion like disgust. The findings from four experiments demonstrated that disgust effects increase severity of judgments and make moral violation less acceptable, even if the action did not raise disgust per se. These studies demonstrated the affective context to be important. Results from another work showed that participants reported more positive mood and more utilitarian responses to moral dilemmas after watching a funny video clip compared to a neutral one (Valdesolo & DeSteno, 2006). All these studies proved that not only emotional response evoked by the moral stimuli but also the affective mood and context could be critical in guiding the judgment, nevertheless they fail in clarifying at which precise point emotion has a role in moral psychology (Haidt,

2001). Neuropsychology helped to unveil connections between (impaired) emotional processing and moral behavior, emphasizing the crucial role of neural regions implicated in affective and emotional processing, such as ventromedial prefrontal cortex (VMPFC), in moral decision-making. It has been reported that lesions of this area during childhood impair the correct development of moral sense and ethical judgment (Anderson et al., 1999). Moreover, patients with damage on the VMPFC usually exhibit abnormal moral conduct and lack of concern for moral and social rules (Bechara et al., 2005; Moll et al., 2005). Ciaramelli and colleagues (2007) presented patients with focal lesions in VMPFC and healthy controls with different types of moral dilemmas and with non moral dilemmas. In spite of a preserved general moral knowledge and ability to reason, patients revealed a selective deficit only for dilemmas that required high emotional engagement (e.g., personal moral dilemmas). Similarly, Koenigs and co-workers (2007) found that VMPFC patients show an abnormally high rate of utilitarian judgment in moral dilemmas associated with high emotional conflict. These findings are in accordance with a model in which a combination of intuitive/affective and conscious/rational mechanisms operates to produce moral judgment.

The first attempt to combine the involvement of both emotion and cognition in moral judgment is represented by the social intuitionist model (Haidt, 2001),which proposes that moral judgment is mainly driven by automatic quick intuition, then followed by reasoning processes necessary to construct justifications and affect other's opinions. This model is also in accordance with studies on attitude change which indicated that brain regions implicated in cognitive control are necessary to question our own attitudes and believes (Harmon-Jones et al., 2008; Izuma et al., 2010).

Accordingly, recent neuroimaging findings provide critical clarification of the neural substrates underlying moral decision-making and converge toward the idea that both emotion and cognition are crucially relevant for moral decision-making. Affective regions, such as medial prefrontal cortex, have been proposed to be responsible for mediating strong negative emotional responses to moral violations, which prevent individuals from implementing such morally impermissible actions (Greene & Haidt, 2002). Greene and co-workers (2001) tested participants in fMRI scanner, comparing responses of two types of moral dilemmas varying in emotional engagement (footbridge vs. trolley dilemma) so that, personal dilemmas, requiring the infliction of direct and serious body harm on another individual to achieve some good were compared to impersonal dilemmas, also including the infliction of harm but in a less direct fashion. Consistently, data showed strong activation of areas of VMPFC, previously associated with social and emotional processes (Damasio, 1994; Moll, 2002) during contemplation of personal but not impersonal moral violations. Of interest were also behavioral results, showing that the condemnation of moral violations occurred relatively fast, while acceptance of them required longer time. Moreover, participants were significantly slower in trials in which the response was incongruent with emotional responses (e.g., saying "appropriate" to a dilemma such as the footbridge dilemma) relative to trials in which the two were congruent. This pattern was present only within personal moral dilemmas, whereas there was no such difference in response time during impersonal moral dilemmas. These behavioral patterns have been paralleled to patterns of behavioral interference observed in cognitive tasks in which automatic processes can influence responses, such as the Stroop task (Stroop, 1935). This interference effect in the behavioral data strongly suggests that the increased emotional response generated by

the moral-personal dilemmas has an effective influence on and is not merely incidental to moral judgment. Authors assumed that certain kind of moral dilemmas, in which emotional and cognitional factors are into balanced contrast, are more difficult to answer compared to others. This is because they generate a conflict between two competitive processes that needs to be resolved in order to achieve a response. In particular, in order to accept a moral personal violation, individuals need to override an automatic and strong emotional response, which requires a cognitive control process, meant as the ability to guide attention, thoughts and actions along with our aims and intentions (Cohen et al., 1990). A number of studies on regulation of emotion showed that prefrontal regions such as lateral prefrontal cortex (LPFC) and anterior cingulate cortex (ACC) are implicated in cognitive control but that they are dissociable at the level of their function. ACC has been shown to be implicated in detection and monitoring of conflict while DLPFC in top-down control necessary for the resolution of the conflict (McDonald et al., 2000; Botvinick et al., 2001; Yeung et al., 2006). Additional studies on emotion-cognition competition in decision-making (McClure et al., 2004; Sanfey et al., 2003) and emotion regulation (Ochsner et al., 2002, 2004) reported activation of ACC to correlate with degree of conflict between emotional and cognitive responses and to predict subsequent activation of DLPFC. With the hypothesis that moral judgment as well as other kinds of decision-making derives from competitive relationship between affective and cognitive processes, Greene and colleagues (2004) tested participants in the scanner (fMRI) while responding to a class of high conflict moral dilemmas like the Crying baby dilemma (High conflict, Koenigs et al., 2007).

This kind of dilemmas has a particular structure in which one must incur in a personal moral violation (smother the baby) in order to maximize aggregate welfare (save the most lives) (Greene et al., 2004). Responding to this type of dilemmas is difficult and requires longer time because of the competition between the negative emotional states automatically rose by the harmful action and the abstract and cognitive reasoning on the number of saved lives. Consistent with the hypothesis, the results showed increased activity in ACC, DLPFC (BA 10/46) and inferior parietal lobes (BA 40/39), previously associated with detection and resolution of cognitive conflict. In addition, a strong relationship between utilitarian behavior and cognitive processes was found. Specifically, data showed greater activity in DLPFC (BA 10) in accepting violation (utilitarian responses) compared to condemning it (non utilitarian responses). An account for this pattern of activity may be that two cognitive processes occur during utilitarian judgments: abstract reasoning on the computation of costs and benefits of an action and cognitive control process aimed at overcoming the imminent emotional response. Nevertheless, since these results are only correlative they are tenuous and cannot account for a causative relationship between utilitarian behavior and cognitive processes. In this direction, Pizzarro and colleagues (2003) altered judgments on moral responsibility instructing participants to give "intuitive" or "rational" responses, while Valdesolo and DeSteno (2007) used a cognitive load paradigm to demonstrate that control processes are involved in rationalization of unfair behavior. More recently, behavioral data showed that cognitive manipulations during a moral task can selectively interfere with utilitarian behavior (Greene et al., 2008). These authors compared performance of moral judgment of participants in load and control conditions. The "Load" condition required to answer moral dilemmas while a stream of numbers

scrolled across the screen and to hit a button each time the number 5 was detected. Longer Reaction Times for utilitarian answers were shown only in participants in the load condition, but not in controls. As behavioral, these results cannot state an effective causative relationship between utilitarian moral decisions and cognitive processes. We suggest that interfering with cognitive processes during moral decision would provide an effective evidence of the causative link between activity in cognitive regions, such as DLPFC, and utilitarian behavior.

In the current study we used Transcranial Magnetic Stimulation (TMS) to disrupt activity in right DLPFC while participants responded to high conflict moral personal dilemmas and impersonal dilemmas. Previous studies showed low-frequency repetitive TMS on this region to be effective in modulating behavioral responses (Knoch et al., 2006, 2009). We hypothesized that DLPFC is crucial to override emotional automatic response raised by personal moral dilemmas and that its activity is causally related to utilitarian behavior. Thus, by disrupting activity of this regions by means of TMS during contemplation of moral dilemmas we expected: 1) a general decrease of the percentage of utilitarian responses (approval of moral violations) only in personal dilemmas that engage emotion-cognition conflict in greater extent compared to impersonal ones and, 2) an increase of response times in accepting personal violations compared to impersonal. We suggest this increase in RT to be a further display of conflict between emotional and cognitive processes.

Such an effect could be considered as a direct evidence of causality between activity of cognitive brain regions and utilitarian behavior. Moreover, it would allow ruling out the hypothesis of a mere interference of cognitive process in moral judgment and assigning them a specific role in forming moral behavior.

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## 7.2 Methods and Materials

**Participants**

18 healthy volunteers (13 females; mean age = 25.7, range: 20-34; mean years of education = 15.2, range: 8-18), recruited through posted advertisements, participated in the experiment. Participants were not taking psychoactive medication, and they were free of current or past psychiatric or neurological illness as determined by history. None of the participants had contraindications to brain stimulation. All were *naïves* to TMS effects and the nature of the experiment, and they were not explicitly informed of the experimental variable tested. All participants gave informed written consent before entering the study and they were refunded of 50 euro for their participation before leaving the lab. The experiment was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki, and was approved by the Ethical Committee of the Department of Psychology, University of Bologna.

**Transcranial Magnetic Stimulation (TMS)**

The TMS is a neurophysiologic technique that allows stimulating the nervous system in a non-invasive way. The generation of transient magnetic fields at a stimulator coil to induce electric fields produces behavioral and/or physiological reversible effects upon neural tissue (Pascual-Leone et al., 1999, 2000; Walsh & Cowey, 2000).

Participants received both sham and real cTB stimulation over the right dorsolateral prefrontal cortex (Talairach coordinates x = +28, y = +49, z = +6, corresponding Brodmann's Area 10). The cTBS was performed following the standard procedures:

burst of three TMS pulses delivered at 50 Hz, with each train repeated every 200 ms (5Hz) were administered. The application of trains was continuous and it lasted 40 seconds (600 pulses total). The intensity of stimulation was at 80% of active motor threshold (aMT) defined as the minimum single pulse intensity required to produce a MEP of greater than 200 µV on more than five out of ten trials from the contralateral FDI muscle while the subject was maintaining a voluntary contraction of about 20% of maximum using visual feedback (Huang et al., 2005).

The cTBS was administered positioning the coil tangentially to the stimulated area (Real-cTBS) or at 90° with no current in the brain (Sham-cTBS). After the stimulations, the participant remained relaxed for 6 minutes before beginning the experimental task.

The region of stimulation was identified on each participant's scalp with the SoftTaxic Navigator system (Electro Medical Systems, Bologna, Italy). Skull landmarks (nasion, inion and two preauricular points) and about 100 points providing a uniform representation of the scalp were digitized by means of a Polaris Vicra digitizer (Northern Digital Inc, Ontario, Canada). Talairach coordinates were automatically estimated by the SofTaxic Navigator from an MRI-constructed stereotaxic template.

**Procedure**

Once arrived at the lab, the participant was given few minutes to sit, read and sign the informed consent and the TMS exclusion/contraindication questionnaire. After receiving information about the stimulation and the task, the subject was trained on a practice session with an example of a moral dilemma.

Once the active motor threshold (aMT) was defined and the region of stimulation was identified, the subject was ready to go through the experimental session. The

experiment was divided in two identical sessions, which were two hours delayed from each other. They consisted of receiving Real-cTBS or Sham-cTBS and performing the task. Before stimulations the participant relaxed about 10-15 minutes. Both sessions lasted approximately one hour. The order in which stimulation was delivered was counterbalanced across participants. The participants performed the same task twice, once in the first session and once in the second session, after both stimulations.

In both sessions, the task consisted of expressing approval or disapproval for moral dilemmas presented on a computer screen, moving through two screens describing the scenarios and a third screen presenting the following question: "Is it morally acceptable for Person X to perform Action Y in order to achieve goal Z? Participants indicated their choice by pushing one of two buttons (Yes/No) and had one minute time limit to read the scenario and answer the question. We used two sets of dilemmas in the experiment: set A and set B. In each experimental session, subjects responded to one set (either A or B) composed of 12 dilemmas, which included 6 personal dilemmas, designed as "high conflict dilemmas" by Koenigs and colleagues (2007) and 6 impersonal dilemmas, all randomly presented. The order in which the sets were presented was counterbalanced across sessions. In all high-conflict dilemmas the agent must decide whether to actively harm one person in order to save the lives of several people. Within this constraint, the structure of these dilemmas varied. Thus, only the high conflict dilemmas are eligible for studying the difference between utilitarian and non-utilitarian responses and only in this kind of dilemma the affirmative answer "Yes" corresponds to a utilitarian response.

An example of high-conflict dilemmas is the *Crying baby dilemma:*

Enemy soldiers have taken over your village. They have orders to kill all remaining civilians. You and some of your townspeople have sought refuge in the cellar of a large house. Outside you hear the voices of soldiers who have come to search the house for valuables.
Your baby begins to cry loudly. You cover his mouth to block the sound. If you remove your hand from his mouth his crying will summon the attention of the soldiers who will kill you, your child, and the others hiding out in the cellar. To save yourself and the others you must smother your child to death.
Is it morally acceptable for you to smother your child in order to save yourself and the other townspeople?

An example of impersonal dilemmas is the *Trolley dilemma* (Thompson, 1986), in which there is only a deflection of an existing threat and the agent cannot actively harm anyone:

You are at the wheel of a runaway trolley quickly approaching a fork in the tracks. On the tracks extending to the left is a group of five railway workmen. On the tracks extending to the right is a single railway workman.
If you to do nothing the trolley will proceed to the left, causing the deaths of the five workmen. The only way to avoid the deaths of these workmen is to hit a switch on your dashboard that will cause the trolley to proceed to the right, causing the death of the single workman.
Is it morally acceptable for you to hit the switch in order to avoid the deaths of the five workmen?

During the task we recorded reaction times (ms) of approval and disapproval of moral violations, in both high conflict personal dilemmas and impersonal dilemmas, and the number of times the subjects accepted moral violations. This latter measure was expressed by percentage (%). To ensure that the stimulation did not interfere with the understanding of the task, all subjects read the instructions before that any stimulation occurred. The order of conditions was counterbalanced across participants, such that

subjects were randomly assigned to one of four treatments: 1) Sham with Set A, two hour wait, then cTBS with set B; 2) cTBS with set A, two hour wait, then Sham with Set B or Sham with Set B, two hour wait, then cTBS with Set A or cTBS with Set B, two hour wait, then Sham with Set A.

At the end of the second session of the experiment, the participant was required to fill out some questionnaires and an exit form, giving his/her opinion about the task and rank the discomfort due to the stimulation. Subjects were then debriefed, paid and thanked.

**Questionnaires**

Participants were required to complete the Cognitive Reflection Test (CRT; Frederick, 2005) which was designed to assess the specific cognitive ability to suppress an intuitive and spontaneous wrong answer in favor of a reflective and deliberative right answer. Namely, this questionnaire gives a measure of a person's tendency to effectively use his cognitive reasoning ability to override, when necessary, his brain's reflexive (and usually impulsive) decision making center. Moreover, we asked the participant to fill out the Need for Cognition scale (NfCs, Cacioppo & Petty, 1982) which was designed to assess the tendency to engage in and enjoy effortful cognitive endeavors. This questionnaire has also been shown to predict deontological/utilitarian moral judgments (Bartels, 2008). Lastly, we gathered some further information about social and economic attitudes of the participants, his/her momentary mood and his/her religious belief.

**7.3 Results**

We performed analysis on two variables: 1- Reaction time (RT) of approval (Yes) and disapproval (No) responses to high conflict personal moral dilemma and impersonal moral dilemmas and 2- Percentage of approval of moral violations in both type of dilemmas.

Following our hypothesis of a causal role of DLPFC in utilitarian moral judgment, we expected an increase of reaction time and a decrease in the percentage of utilitarian responses (yes) to high conflict personal dilemmas after cTBS compared to Sham stimulation. Notably, only the approval (namely a "Yes" response) of violation to high conflict personal but not impersonal dilemmas corresponds to utilitarian judgments, thus only the modulation of responses to this kind of dilemmas is able to show a difference between utilitarian and non utilitarian responses. Analyses for high conflict personal and impersonal dilemmas were then conducted separately. Moreover, data were trimmed based on RT to within two SDs of the group mean. Analysis included all 18 participating subjects.

*Response Time (RT)* - A 2 (Stimulation: Sham vs. cTBS) x 2 (Response: Yes vs. No) repeated measure ANOVA conducted on RTs for approval (Yes), and disapproval (No) of high conflict personal moral dilemmas yielded only a marginally significant interaction between Stimulation and Response [$F(1, 17) = 3, 62$; $p = 0.06$], revealing that participants were slower in approving personal moral violations (Yes) after cTBS compared to Sham stimulation (6989 ms vs. 5898 ms, $p < .05$). This pattern was not present for disapproval (No responses) of personal moral violations, so that response time for "No" did not vary significantly across cTBS and Sham stimulation (5999 ms

vs. 6396 ms, p = .68). No other significant main effects of stimulation and response emerged.

For completeness, even though we predicted no variation of response pattern on impersonal moral dilemmas, we conducted the same analysis on RTs for approval and disapproval of impersonal moral violations. The same ANOVA as before yielded only a significant main effect of response [F (1, 17) = 9.43; p < .01], showing significantly faster response time for approval of impersonal moral violations, compared to disapproval (5376 ms vs. 6482 ms, p <.01). Crucially for our purpose, analysis on impersonal moral dilemmas showed no significant or close to significance interaction Stimulation x Response [F (1, 17) = 2. 85; p = .60].

These results are consistent with the hypothesis and replicate findings reported by Greene and colleagues (2008), which showed that utilitarian responses under cognitive load were slower compared to non utilitarian responses in the same condition.
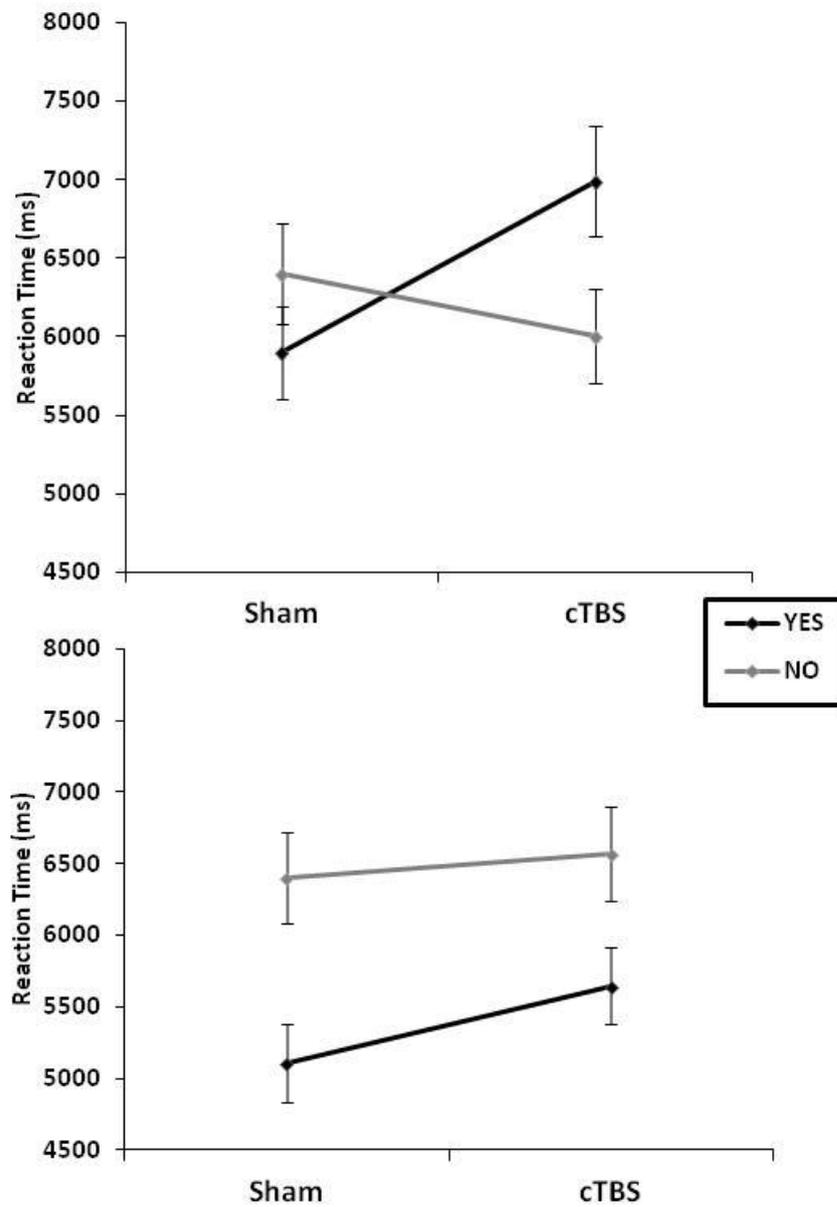
**Figure 7.1** Upper panel: Reaction time (ms) for approval (YES) and disapproval (NO) of Personal moral violations after Sham and cTBS stimulation. Lower panel: Reaction time (ms) for approval (YES) and disapproval (NO) of Impersonal moral violations after Sham and cTBS stimulation.

We conducted a further analysis only on high conflict personal dilemmas to explore the possibility that pattern of RT varies systematically among participants based on their tendency to be utilitarian. We calculated the median of percentage of utilitarian responses to high conflict personal dilemmas in Sham condition, so that we obtained two equal groups of participants considered as Low- and High- utilitarian. The Low-utilitarian participants averaged 33% of utilitarian responses and High-utilitarian 73%. Both groups showed the same pattern on RT of Yes responses. Namely, both low- and high-utilitarian participants were slower in approving personal moral violations after cTBS than after Sham stimulation (Low-utilitarian: 7335 vs. 6220 ms; High-utilitarian: 6642 vs. 5576 ms, respectively), whereas they remained relatively stable in the No responses (Low-utilitarian: 5756 vs. 5752 ms; High-utilitarian: 6242 vs. 7041 ms). Nevertheless, due to the small number of subjects in each group, the interaction Stimulation x Response in both groups did not reach significance (p=.22). Moreover, data showed that low-utilitarian group had a general tendency to be slower in approval of the high conflict personal violations and faster in disapproval of them, compared to participants in the high-utilitarian group, although this difference did not reach significance (Yes: 6778 ms vs. 6109 ms; No: 5754 ms vs. 6642 ms; both p=.15).

*Percentage of approval responses (Yes)* - As before, analyses on percentage of approval responses (Yes) for personal and impersonal dilemma were conducted separately. No significant difference was shown for both type of dilemmas, even if there was a tendency to decrease the percentage of approvals (Yes) after cTBS stimulation, compared to Sham, in high conflict personal dilemmas but not in impersonal ones (Personal: 45% vs. 53%; p=.09, one-tailed; Impersonal: 54% vs. 57%; p=.16, one-

tailed).Therefore, we considered the possibility that participants could be differently affected by the stimulation based on their tendency to give utilitarian judgments to high conflict personal moral dilemmas. Thus, we conducted a 2 (Stimulation: Sham vs. cTBS) x 2 (Group: Low- vs. High-utilitarian) ANOVA on the percentage of approval (Yes) of violation only in high conflict personal dilemmas. Interestingly, the analysis yielded a significant Stimulation x Group interaction [$F (1, 17) = 5. 77$; $p= .02$]. Post hoc tests showed a significant decrease of Yes responses (utilitarian) in cTBS condition compared to Sham only in high utilitarian participants (72% vs. 53%, p=.01), whereas Low-utilitarian participants remained stable across conditions (37% vs. 32%, p= .58). However, we are cautious in interpreting this latter result, as it may simply reflect a "regression toward the mean" effect, due to the fact that high utilitarian participants show higher percentage of yes responses in the sham condition. Nevertheless, it should be considered that Low utilitarian participants did not show any increase of yes responses, as one may expect for a regression toward the mean effect.

In sum, these results are consistent with our initial hypothesis. As expected, disrupting activity in DLPFC by means of cTBS produced longer responses time of utilitarian but not non utilitarian judgments only in high conflict personal dilemmas. Moreover, a tendency to decrease percentage of utilitarian responses after cTBS but not after Sham stimulation was present. Taken together these results may be considered as a valid evidence of a crucial role of DLPFC in utilitarian moral judgment.

## 7.4 Discussion

In this study we investigated the role of areas associated with cognitive control and reasoning in moral decision-making. We used repetitive transcranial magnetic stimulation (TMS) to transiently disrupt neural activity in right DLPFC immediately before participants responded to personal and impersonal moral dilemmas (off-line stimulation). As for personal dilemmas, we used "high conflict" dilemmas (Koenigs et al., 2007) in which the conflict between emotional engagement and total amount of welfare were balanced. These dilemmas are difficult to respond, because no widely accepted formal moral principle exists that establishes a priori what behavior is appropriate in these circumstances.

We hypothesized DLPFC to be crucial in resolution of emotion-cognition conflict and to be causally associated with utilitarian moral judgment. Thus, we expected a decrease of percentage of utilitarian responses after cTBS stimulation over DLPFC compared to sham stimulation. Moreover, as a display of the greater cognitive effort required to achieve utilitarian responses, we expected increase of time responses after cTBS compared to sham stimulation when participants approved high conflict moral violations. According to our initial hypothesis, we found that after cTBS on DLPFC participants were slower to accept high conflict moral violation compared to sham stimulation. No similar pattern was found for impersonal moral dilemmas which are not associated with competition between emotion and cognition. We consider these results as a further evidence of an interaction of emotion and cognitive processes in moral psychology.

The debate on the role of emotion and cognitive processes in moral psychology is still a very heated debate. While proponents of the rationalist view indicate the source of

moral judgment in cognition, the supporters of the intuition model defend the automatic and effortless aspects of a moral decision. Results from different disciplines have begun to converge on the idea that both emotions and cognition vested with an important role. As noted by Heubner and colleagues (2009), we cannot deny that moral judgment has predominant emotional aspects: violating a moral norm, for instance, is emotionally taxing per se. Emotions, such as guilt or embarrassment, are often evoked by moral violations (Rozin et al., 1999). Behavioral studies on disgust showed that emotional contexts are able to modulate our judgment about moral issues. Neuropsychological studies showed that psychopaths who lack feelings of guilt or embarrassment fail to refrain from violent actions (Nichols, 2002); patients with lesions in brain areas involved in emotion (vmPFC) show behavior not conformed to social norms (Bechara et al., 2005, Moll et al., 2005) and appear more inclined to accept moral violations in a task of moral judgment (Ciaramelli et al., 2007; Koenigs et al., 2007). Furthermore, neuroimaging studies demonstrated that the Amygdala is important for the affective response to the moral transgressions (Berthoz et al., 2006). Consistently, activation of the Orbitofrontal cortex and the ventromedial prefrontal cortex, involved in emotion, were found in healthy subjects in studies concerning moral judgment (Moll et al., 2002), moral reasoning (Greene et al., 2001, 2004) and social emotions like guilt and embarrassment, which still have a close affinity with the moral violation (Takahashi, 2004).

In this emotional and affective context what is the role of cognition?

Some studies emphasize that a multidimensional model of moral judgment is needed that takes into account the various aspects of moral psychology. Cushman (2008) for example emphasizes the interaction of intuition and conscious reasoning, highlighting

the fact that the principles guiding moral judgments of people are distinct from those used to justify their answers, and that only some of them are available to consciousness. In support of this, studies from cognitive neuroscience showed that morality is not represented in just one place in the brain but instead is mediated by multiple networks. Indeed, not only emotional neural regions but also activation of the prefrontal areas with executive functions has been found in moral decision-making studies (Greene et al., 2001; 2004; Heekeren & Wartenburger, 2003; Moll et al., 2001). Moll and colleagues argued that the moral processes are the product of the integration of contextual social knowledge, represented as event knowledge in the PFC, social semantic knowledge in the anterior and posterior temporal cortex and motivational and basic emotional states relying on cortical-limbic system (Moll et al., 2005, 2007). Borg and colleagues (2006) have shown that different patterns of brain activity were associated with different types of moral scenario: cognitive areas were more active in the calculation and evaluation of the consequences of an action and activity of areas associated with emotion was elicited by moral scenarios involving intentional harm. Greene and colleagues proposed a dual process theory according to which cognitive processes in DLPFC and ACC are necessary to override emotional automatic responses in order to produce utilitarian moral responses (Greene et al., 2004, 2008). This theory posits a mutual competitive interaction between emotion and cognition in moral judgment. Our results are in line with this account and with subsequent neuroimaging findings indicating stronger activation of cognitive areas (right DLPFC) to respond to high conflict moral dilemma and greater cognitive effort to engage in utilitarian behavior (Greene et al., 2001, 2004).The utilitarian responses require greater cognitive effort in order to compete with the overwhelming emotional response that would drive moral condemnation of the

violation without considering the gain of the action. Our results can be considered as effective display of a causative relationship between DLPFC activity and in utilitarian moral reasoning. In addition, the evidence reported here confirms that moral behavior depends on the mutual interaction of affective and cognitive processes and expands on the role of lateral prefrontal cortex in cognitive control and emotion regulation. According to this conclusion previous studies showed DLPFC to be fundamental in goal-directed behavior (McDonalds et al. 2000) and to be implicated in detection and correction of behaviors that cause different consequences from those expected (for review see Forbes & Grafman, 2010). In addition, many studies argued that DLPFC plays a key role in self-regulation (Hare et al., 2009), affective modulation (Boggio et al., 2008) and emotion regulation (Oschner & Gross, 2005) as well as exercising control in mitigating negative emotional responses to aversive situation such as risk choices (Rao et al., 2008).

Some limitations of the current study should be accounted for. Indeed, in line with our initial hypothesis we succeed in finding longer response time to personal moral dilemmas after stimulation but we failed in proving significant decrease in percentage of utilitarian responses. This may be due to several reasons: first and foremost the lack of variability. Many participants have expressed little utilitarian judgments in general, preventing the modulation of utilitarian behavior after stimulation. Moreover, we suggest that a too small number of dilemmas was used (6 Personal and 6 impersonal). However, the choice of the number of dilemmas was forced by the risk of losing the effect of stimulation after a certain period of time. To overcome this problem in future experiments, an on-line stimulation could be used.

In conclusion, despite the limitations described above, these results shed light on the neural basis of moral judgment and extend on the functional role of specific brain regions.

# CHAPTER 8 – EXPERIMENT FIVE

## Disrupting the prefrontal cortex reduces choice-induced preference change

## 8.1 Introduction

Behaviours can create, not only reflect, people's attitudes. Several studies highlight how decisions can alter, not just follow, individuals' preferences (Izuma et al., 2010). Making difficult choices between options that are equally attractive to us is an ever-present part of our everyday life, like deciding between jobs offered by two different companies or selecting a new car among the different alternatives. Notably, after such a choice between equally preferred options is made, people no longer find the alternatives similarly desirable (Brehm, 1956; Harmon-Jones & Harmon-Jones, 2002), and they like the selected option more and the rejected option less than they initially did. The preference change serves to settle the psychological conflict due to the cognitions in contradiction with the choice executed: the positive attributes of the rejected alternative are dissonant with not having chosen it, and the negative attributes of the preferred alternative are dissonant with having chosen it (Aronson, 2011). Adjusting preferences to support prior decisions is a phenomenon that has been deeply explained by the theory of cognitive dissonance (Festinger, 1957), according to which inconsistent (dissonant) behaviours and attitudes result in a psychologically uncomfortable state (arousal) that motivates people to reduce the dissonance by changing their original attitudes to be more consonant with the displayed behaviour.

The effect of difficult decisions on preference change has been studied in several experiments in social psychology, nevertheless which are the neural substrates of

cognitive dissonance and dissonance reduction is still unclear. Recent functional magnetic resonance imaging (fMRI) studies have provided some insight and have shown that the detection of the cognitive conflict generated by the inconsistency between attitudes and actions could be associated with activity in the dorsal anterior cingulate cortex (dACC) (Van Veen et al., 2009; Izuma et al., 2010), and the triggering of the aversive autonomic arousal by anterior insula (Van Veen et al., 2009; Qin et al., 2010).

Once conflict is detected by the dACC and dissonance is aroused, decision-related attitude change may occur rapidly (Harmon-Jones et al., 2008). Several evidences support the involvement of dorsolateral prefrontal cortex (DLPFC), a region known to be involved in implementation of control and conflict resolution (Botvinick et al., 2001; Botvinick et al., 2004), in this process. Previous research has shown that activity in left, right or bilateral DLPFC may be associated with decision-induced preference change, but none of these studies can allow causal inferences. Harmon-Jones and colleagues (2008) measured choice-induced preference change after left DLPFC activity was manipulated by EEG biofeedback training. They found that participants who received neurofeedback training to decrease left frontal cortical activity showed a significant reduction in changing their preferences following difficult decisions. Consistently with these results, Qin and colleagues (2010) used fMRI to monitor neural activity as subjects rated musical CDs both before and after making difficult choices and they observed that individual difference in preference change (increase of preference for the chosen items minus decrease of preference for the rejected items) was predicted by post-choice neural activity in left DLPFC, dorsal medial prefrontal cortex (DMPFC) and right precentral cortex. Although the above-mentioned literature focused on the role

of left DLPFC in cognitive dissonance reduction processes, there are studies that reported a crucial role of DLPFC especially in the right side. For example, Jarcho and colleagues (2010) examined brain activity while participants were taking difficult decisions in fMRI and they noticed that greater post-decisional preference change was associated with increased activity of right inferior frontal gyrus (IFG) and with decreased activity in anterior insula. Finally, Izuma and colleagues (2010) tested brain activity as independent measure of preference in a neuroimaging study and they found bilateral DLPFC activity, during the post-choice re-rating of the items, to be positively associated with the degree of cognitive dissonance, computed as the discrepancy between subjects' past decisions and their reported preferences for each item.

These studies suggest that DLPFC may be involved in resolving the conflict between actions and attitudes by bringing our attitudes into line with behavioural commitment. Although DLPFC activity is strongly associated with attitude change, this does not necessarily mean that DLPFC is causally engaged in this process. In order to explore whether DLPFC activity is crucial in choice-induced preference change we need to recur to the lesion method. To this end, we applied inhibitory transcranial Direct Current Stimulation (tDCS) to the right or to the left DLPFC during a revised version of Brehm's free-choice paradigm (1956). In addition, we included a control condition where we applied sham stimulation to the right or left DLPFC. Each subject participated in only one of the three conditions (*Right* DLlPFC, *Left* DLPFC, *Sham*). In this procedure, participants were first required to rank two sets of art prints, from most liked to least liked. Then, they were asked to choose between pairs of prints, among which those images they had seen before were included and ranked as equally pleasing. Finally, after tDCS stimulation, they ranked the two sets of prints again. We

hypothesized that subjects who received tDCS stimulation on DLPFC would not show any preference change after difficult decisions compared to controls, and that their ratings would remain relatively stable in time. Moreover, because Harmon-Jones and colleagues (2008) found that a manipulated decrease in left frontal cortical activity led to a corresponding decrease in post-decisional preference change, we conjectured that disruption of the left DLPFC, and not of the right DLPFC, might be associated with this effect.

## 8.2 Methods and Materials

### Participants

48 healthy volunteers (28 women; mean age = 24, 7; range: 20-38; mean years of education = 16, 9; range: 13-21), recruited through posted advertisements, participated in the experiment. Participants were not taking psychoactive medication, and they were free of current or past psychiatric or neurological illness as determined by history. None of the participants had contraindications to brain stimulation. All were *naïves* to tDCS effects and to the nature of the experiment and they were not explicitly informed of the experimental variable tested. All participants gave informed written consent before entering the study. The experiment was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki, and was approved by the Ethical Committee of the Department of Psychology, University of Bologna.

### Direct Current Stimulation (tDCS)

Participants were randomly assigned to receive either unilateral active stimulation with the cathode electrode over the right dorsolateral prefrontal cortex (referred to as *right DLPFC* group) (F4, international EEG 10/20 system), unilateral active stimulation with the cathode electrode over the left dorsolateral prefrontal cortex, referred to as *left DLPFC* group (F3, international EEG 10/20 system), or placebo stimulation over the same cortical areas (*sham* or *control* group). In all three conditions the anode electrode (which was the reference electrode) was placed over the controlateral supraorbital area. This electrode arrangement has been shown effective to induce unilateral modulation of

one DLPFC in various studies (Kincses et al., 2004; Fregni et al., 2005). Each condition consisted of 16 participants and they were matched for sex ($X^2$ (2) = 1. 75, $p$ = 0. 41), age ($F$ (2, 45) = 1. 82, $p$ = 0. 17) and years of education ($F$ (2, 45) = 0. 87, $p$ = 0. 42).

Referring to previous literature (Herwig et al., 2003), coordinates in Talairach space (Talairach & Tournoux, 1988) corresponding to F3 were x = -37 y = 27 z = 44 (BA 8/9) and those corresponding to F4 were x = 39 y = 26 z = 43 (BA 8/9). Electrodes position was identified on each participant's scalp with the SoftTaxic Navigator system (Electro Medical Systems, Bologna, Italy). Skull landmarks (nasion, inion and two preauricular points) and ~100 points providing a uniform representation of the scalp were digitized by means of a Polaris Vicra digitizer (Northern Digital Inc, Ontario, Canada). Talairach coordinates were automatically estimated by the SofTaxic Navigator from an MRI-constructed stereotaxic template.

For active stimulation, cathodal direct current, generated by a battery-driven electrical stimulator, was constantly delivered for 15 minutes at 1 mA intensity (current density: *0,028 mA/cm²*) through two saline-soaked surface sponge electrodes (35 cm²). We ramped current up over the first 40 *s* of the stimulation and down over the last 40 *s*. Cathodal tDCS decreases cortical excitability in the targeted brain region (Nitsche & Paulus, 2001). For sham stimulation, instead, the stimulator was turned on only for 15 seconds. Thus, participants felt the initial itching sensation associated with tDCS, but received no active current for the rest of the stimulation period. This method of sham stimulation has been shown to be reliable (Gandiga et al., 2006).

**Procedure**

We reworked the Lieberman and colleagues (2001) modified version of Brehm's free-choice paradigm (1956). As cover story, on entering the testing room participants were informed that they would be performing some tasks aimed to assess the influence of classical music on their aesthetic preferences. All tasks were completed in a single session divided in four phases.

In phase 1, participants were given two sets of 15 art prints measuring 9x9 cm and were asked to rank them in order of preference (from 1 = the most liked to 15= the least liked). A sorting board measuring 57x40 cm was placed on the table to help the participant in sorting the cards while making the rankings. Participants sorted a set of 15 cards that reproduced seascape paintings from French impressionism, and a second set of 15 cards that reproduced paintings from Aboriginal art. The order in which these two sets were sorted was counterbalanced across participants, and the second set was always referred to as the *critical set.* As soon as the rankings were completed*,* participants were asked to wear headphones and sit quietly for 15 minutes, listening to classical music. In the meantime, the experimenter removed two pairs of prints from the critical set. These were designated as the *critical pairs*. One pair consisted of the 4th- and 10th- ranked prints (referred to as the 4-10 pair), and the other pair consisted of the 6th- and 12th-ranked prints (referred to as the 6-12 pair). Thus, each critical pair was composed of a relatively liked and a relatively disliked print.

Once the 15 minutes were finished, the phase 2 of the study began. In this phase, participants were informed that they were now going to complete another aesthetic task. More specifically, they were asked to choose which of two pairs of art prints they would prefer if they could have full-size reproductions of that pair to take home with them.

Participants made six such choices for each set. For the critical set, five choices involved novel pairs of prints (but always of the same art category) and one involved the critical pairs. For the noncritical set, everything was identical to the critical one but all the choices included novel pairs of prints, never seen by the participant during the session. For each choice, two pairs of prints were placed on the table in front of the participant, with one pair on the left and one pair on the right. The participant indicated the pair that he or she preferred and this pair was designated as the *selected pair*. The other pair was designated as the *rejected pair*. As soon as the participant chose, the next pairs of prints were placed before him/her. The pairs of prints used for the participant's fourth choice in the critical set were the two critical pairs drawn from the first ranking. The left and right sides of the table on which the 4-10 pair and 6-12 pair were placed, as well as the order of presentation of the two (critical and noncritical) sets were counterbalanced across participants. Once the last choice was made, the tDCS was applied, and the participant was required to remain seated and relaxed for 15 minutes. In the sham condition the stimulation period was the same because participants were not aware of the absence of active stimulation.

Phase 3 followed the end of the stimulation period and it was similar to phase 1. Once again, the participants were asked to rank each set of prints in order of their preference. It was specified that this was not a memory test and that they had to classify the pictures according to their preferences in that particular moment. The order of presentation of the two sets followed that one of phase 2, so it was counterbalanced across participants as well.

In the last phase, phase 4, participants were shown the 15 prints from the critical set (either the seascape set or the Aboriginal set) and asked to identify the 4 prints that had

appeared in phase 2 (memory of the critical pairs). As a test of memory for their previous choice, participants were also asked to remind which pair they had selected and which pair they had rejected during phase 2.

Finally, participants had to complete the Cognitive Reflection Test (CRT, Frederick, 2005), which assess the cognitive ability to suppress an intuitive and spontaneous wrong answer in favor of a reflective and deliberative right answer (that can be considered a measure of intelligence). Participants indicated also their level of discomfort during the tDCS in a Likert scale (from 1 = not at all annoyed to 7 = extremely annoyed).

The primary measure of choice-induced preference change was the mean change in ranks of the selected and rejected pairs between Phases 1 and 3.
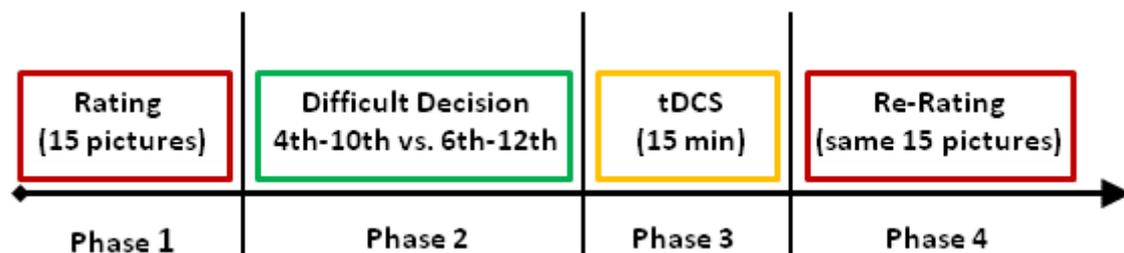


**Figure 8.1** A schematic illustration of the experimental paradigm.

## 8.3 Results

The higher ranked pair 4-10 was chosen 81% of the time by Left DLPFC group, 69% of the time by Right DlPFC group and 75% of the time by Sham group. The three groups did not differ significantly in the percentage of choice of 4-10 pair, $X^2 (2) = 3.12$, $p = .20$. These percentages were also consistent with those existing in previous literature: in Lieberman and colleagues' study (2001) 64% of their participants chose the higher-ranked pair in the first experiment, and 75% in the second one; as well as Gerard and White (1983) reported that 75% of their participants chose the 4-10 pair. Eliminating the data of those participants who selected the lower-ranked pair (6-12 pair) did not change our results, so we chose to include them in our analysis.

*Preference change -* For both the critical and noncritical sets, to assess preference change we measured the mean ranks of the selected and rejected pairs in phase 1 and phase 3, using a 2 (Phase: 1 vs. 3) x 2 (Pair: Selected vs. Rejected) x 3 (Group: *Left* DLPFC vs. *Right* DLPFC vs. *Sham*) repeated measures analysis of variance (ANOVA). An increase in the mean ranks of the selected pair (more liking) and a decrease in the mean ranks of the rejected pair (less liking) in phase 3 compared to phase 1, respectively, would indicate the typical choice-induced attitude change.

For the critical set, the analysis yielded a significant main effect of Pair, $F (1, 45) = 43.11$, $p < .0001$. The mean ranks of the chosen pair ($M = 7.17$) were significantly higher than the mean ranks of the rejected pair ($M = 8.93$). This indicates that participants liked more the chosen pair than the rejected one. Moreover, the typical choice-induced attitude change was shown by a significant two-way Phase x Pair

interaction, $F(1, 45) = 16.90$, $p < .001$: there was a larger difference between the mean ranks of the selected and rejected pairs in phase 3 than in phase 1, given that selected pairs increased in ranking and rejected pairs decreased in ranking between phase 1 and 3 (phase 1: $M$ selected pair = 7.50, $M$ rejected pair = 8.50; phase 3: $M$ selected pair = 6.83, $M$ rejected pair = 9.35).
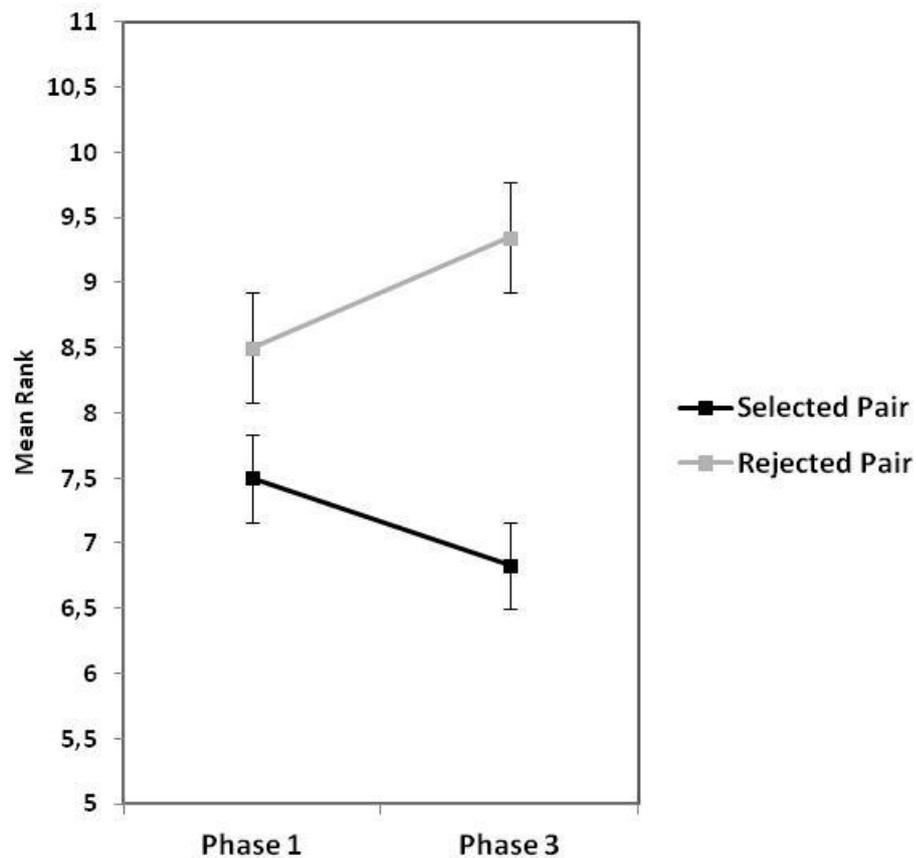


**Figure 8.2** Mean ranks of selected and rejected pairs of the critical set in phase 1(Ranking) and Phase 3 (Re-ranking). To be noticed that higher number in rank indicates less liking, while lower number indicates more liking.

More importantly for the purpose of the present study, a significant three-way Phase X Pair X Group interaction [$F(2, 45) = 3.04$, $p = .05$] revealed that the manipulation of DLPFC disruption was successful and the three groups acted differently relative to attitude change. To further examine this interaction, three two-way 2 (Phase: 1 vs. 3) x 2 (Pair: Selected vs. Rejected) repeated measures ANOVAs were performed separately on the *Sham* group, the *Right* DLPFC group and the *Left* DLPFC group. The analysis on the *Sham* group showed a significant Phase x Pair interaction, $F(1, 15) = 9.42$, $p < .01$. The analysis on *Right* DLPFC group demonstrated similar results, $F(1, 15) = 31.49$, $p < .0001$. Post hoc comparisons (Newman-Keuls test) showed a significant difference between ratings for selected and rejected pairs across phase 1 and 3: the mean rank of the selected pair indicated more liking in phase 3 than in phase 1 ($p = .18$ and $p < .01$, for *Sham* group and *Right* DLPFC group respectively) whereas the mean rank of the rejected pair indicated less liking in phase 3 than in phase 1 ($p < .01$ and $p < .01$, for *Sham* group and *Right* DLPFC group respectively). That is, for participants in both *Sham* and *Right* DLPFC conditions, the chosen pair decreased in ranking (liking), and the rejected pair increased in ranking (disliking), following decision. On the contrary, the same analysis on the *Left DL*PFC group provided no such a significant interaction, $F(1, 15) = 0.09$, $p = .76$: participants who received stimulation on the left DLPFC did not show any changes in their rankings between phase 1 and 3, and consequently showed no attitude change. To sum up, participants who received tDCS on the left DLPFC did not present the typical choice-induced attitude change, as compared to participants who received stimulation on the right DLPFC and sham stimulation.
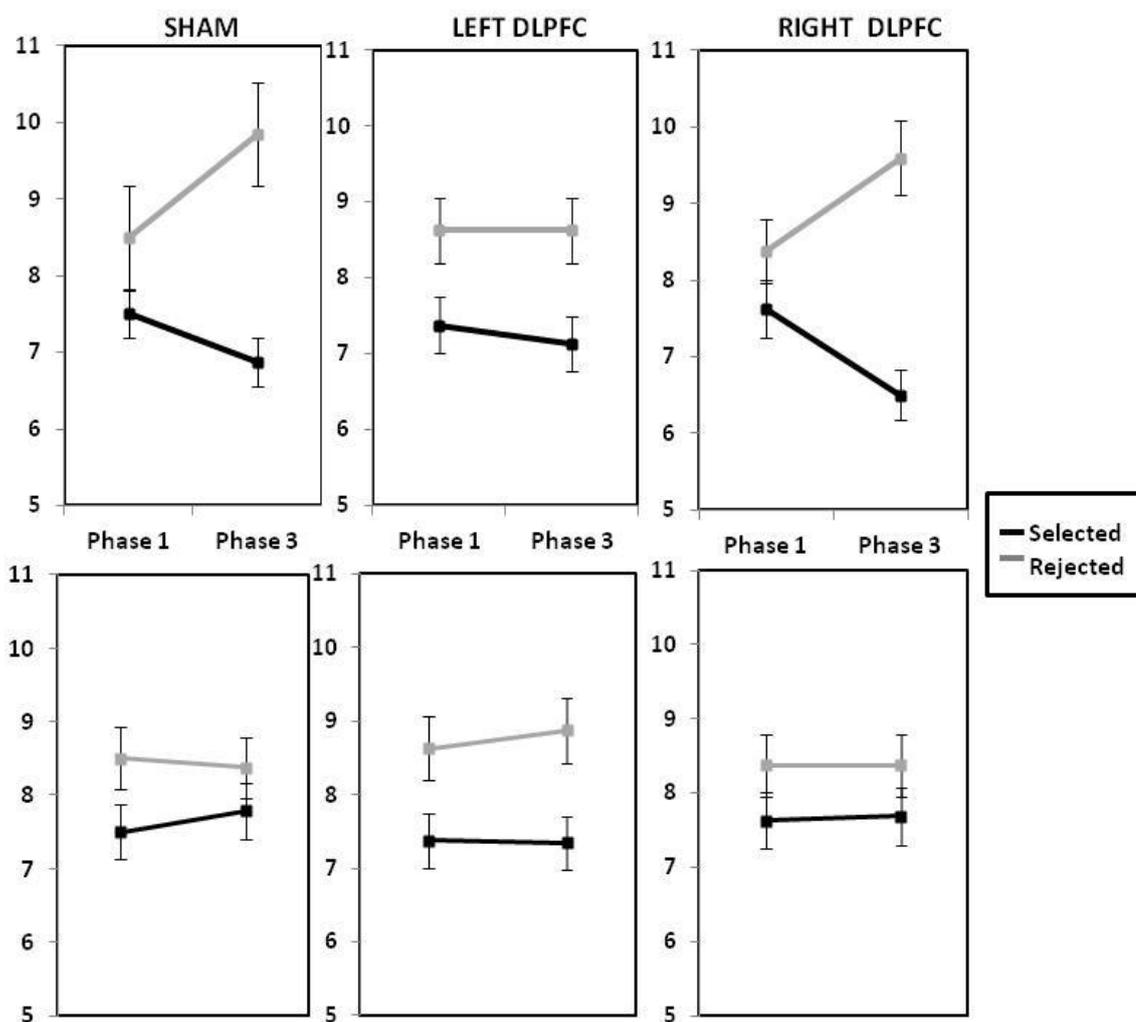
**Figure 8.3** Upper panel: Change of preference for selected and rejected pairs of the critical set in Sham, Left DLPFC and Right DLPFC groups. Lower panel: Change of preference for pairs in non critical set with initial rank equivalent to the ranks of selected and rejected pairs of the critical set in Sham, Left DLPFC and Right DLPFC groups.

We also analysed data from the noncritical set, considering as selected and rejected those pairs of prints with initial ranks equivalent to the ranks of the selected and rejected prints from the critical set (for similar method see Lieberman et al, 2001). Note that prints from the noncritical sets were ranked twice with no intervening choice, so that

they provided baseline levels of attitude change in the absence of choice. As before, a 2 (Phase: 1 vs. 3) x 2 (Pair: "Selected" vs. "Rejected") x 3 (Group: *Left* DLPFC vs. *Right* DLPFC vs. *Sham*) repeated measures statistical analysis was performed on the mean ranks of these pairs in the noncritical set. This ANOVA indicated only a significant main effect of Pair [$F$ (1, 45) = 12.53, $p$ < .001], showing that the mean ranks of the "selected" pair ($M$ = 7.55) were significantly higher than those of the "rejected" pair ($M$ = 8.52). This is because, in the critical set, participants choose more frequently the 4-10 pair than the 6-12 pair, therefore explaining why the "selected" pair in the noncritical set was ranked higher than the "rejected" pair.

The analysis did not exhibit any other significant main effect or interaction, indicating that participants' ratings for those images remained stable across the study. Hence, the differences shown by the three groups in the attitude change in the critical set could not be ascribed to chance variations in preferences because there were no changes in the ratings of the corresponding prints in the noncritical set.

*Questionnaires and Control Tests* - We tested for participants' memory of the critical pairs and of their choice. All the three groups had some difficulty identifying the 4 critical prints constituting the 2 critical pairs they evaluated in phase 2, from the set of 15. Indeed, accuracy was 50% in the *Left* DLPFC condition, 55% in the *Right* DLPFC condition and 45% in the *Sham* condition. The three groups did not significantly differ from each other in this percentage, as demonstrated by a one-way (Group: *Left* DLPFC vs. *Right* DLPFC vs. *Sham*) between-participants ANOVA, $F$ (2, 45) = 0.32, $p$ = .72. Similarly, of the pictures correctly identified as critical prints, *Left* DLPFC group categorized 53% of the prints correctly as selected or rejected, *Right* DLPFC group 71%

and *Sham* group 45%. Thus, the three groups did not differ in the ability of correctly remembering which of the critical prints they had previously selected or rejected, as revealed by a one-way (Group: *Left* DLPFC vs. *Right* DLPFC vs. *Sham*) between-participants ANOVA, $F$ (2, 45) = 2.12, $p$ = .13.

This kind of memory specifically refers to the counter-attitudinal behavior. Two analysis of covariance (ANCOVA) Phase (1 vs. 3) x Pair (Selected vs. Rejected) x Memory were then performed so that individual differences in memory of the critical pairs and of their choice or rejection could be statistically controlled: the results showed that the memory of the 4 critical prints and of which they chose or rejected did not explain post-decisional attitude change [$F$ (1, 44) = 0.09, $p$ = .75 and $F$ (1, 44) = 0.33, $p$ = .56, respectively].

Moreover, we controlled for participants' cognitive ability to resist their first instinct in decision making by means of the Cognitive Reflection Test (CRT, Frederick, 2005). Participants had a mean score of 6.38 (out of 9) in the *Left* DLPFC condition, 7.25 in the *Right* DLPFC condition and 6.13 in the *Sham* condition. A one-way (Group: *Left* DLPFC vs. *Right* DLPFC vs. *Sham*) between-participants ANOVA conducted on the mean scores at the CRT revealed no differences in cognitive abilities between the three groups, $F$ (2, 45) = 2.31, $p$ = .11. An ANCOVA Phase (1 vs. 3) x Pair (Selected vs. Rejected) x CRT Scores also showed that individual differences in cognitive abilities as measured by CRT did not account for the attitude change existing between phase 1 and 3: $F$ (1, 44) = 3.28, $p$ = .07.

Finally, participants indicated the level of discomfort they experienced during tDCS in a seven-point Likert Scale ranging from 1 (not at all annoyed) to 7 (extremely annoyed). Data indicated no significant differences in the degree of discomfort between *Left*

DLPFC group (*M* = 2.63), *Right* DLPFC group (M = 2.38) and *Sham* group (M = 2.38), as demonstrated by a one-way (Group: *Left* DLPFC vs. *Right* DLPFC vs. *Sham*) between-participants ANOVA, *F* (2, 45) = 0.22, *p* = .80.

## 8.4 Discussion

After making choice between equally attractive options, people no longer find the alternatives similarly desirable and they often change their existing preferences to align more closely with the choice they have just made. In line with previous literature (Brehm, 1956; Kitayama et al., 2004), our behavioral results showed the typical attitude change that follows a difficult choice between two similarly likable options. After making a choice, participants increased their liking for the chosen paintings and decreased their liking for the rejected ones. This study aimed at investigating the neural correlates of attitude change after a difficult choice is made. Previous functional studies suggested that activity in the dorsolateral prefrontal cortex, either on the left (Harmon-Jones et al., 2008; Izuma et al., 2010; Qin et al., 2010) or the right (Jarcho et al., 2010) hemisphere, is associated with choice-induced preference change. Most of the studies mentioned above are correlational which means that they do not allow establishing the effective function of this region in cognitive dissonance. Observing behavioral modulation after disruption of activity in lateral prefrontal cortex would provide a direct evidence of the effective role of this area in cognitive dissonance. In the current study we meant to investigate this issue in a causal way. We therefore used transcranial direct current stimulation (tDCS) on Left and Right DLPFC as well as Sham stimulation while participants performed a revised version of Brehm's free-choice paradigm. According to

cognitive dissonance theory (Festinger, 1957), inconsistency between behavior and attitudes triggers an unpleasant emotional state which requires that cognitive processes step in for its reduction. In accordance to this theory, Van Veen and colleagues (2009) pointed the dACC as one candidate region for the detection of cognitive dissonance, for one of dACC's functions is monitoring conflicts between incompatible streams of information or processes (Botvinick et al., 2001, 2004). Using the induced compliance procedure in an fMRI design, they found that during the counter-attitudinal argument (to respond to target sentences as though they were enjoying the scanner and the task) magnitude of activity in dACC predicted the final attitude change of participants in the dissonance condition. They were not monetary rewarded for lying, unlike the participants in the control group. Moreover, cognitive dissonance and dACC activation have been related to negative affect and consequent autonomic arousal (Croyle & Cooper, 1983; Losch & Cacioppo, 1990). In line with previous functional studies, suggesting that DLPFC is implicated in post-decisional attitude change (Harmon-Jones et al., 2008; Izuma et al., 2010; Jarcho et al., 2010; Qin et al., 2010), and consistent with theories on engagement of DLPFC in cognitive control (Miller, 2001; Carter & Van Veen, 2007), emotion regulation (Ochsner et al., 2005), as well as Self control (Hare et al., 2009), here we hypothesized a pivotal role of DLPFC in the processes responsible of dissonance reduction.

Our results showed that only cathodal tDCS on the Left DLPFC impaired cognitive dissonance reduction. In sharp contrast, those participants who received Sham stimulation or tDCS on the Right DLPFC kept the typical attitude change after the choice, ruling out the possibility of a widespread effect of the tDCS per se. Two important conclusions can be inferred from these results. Firstly, that DLPFC is

crucially implicated in dissonance reduction processes and, secondly that left, but not right, DLPFC plays a crucial role in change of preference after a difficult decision. The differences shown by the three groups in attitude change in the critical set were not present in the non-critical set, where the mean ranks of the corresponding prints remained stable across the ratings in all the conditions. Only when a forced difficult choice intervenes and generates a mismatch between prior attitudes and present behavior the participant changes his attitudes consistently with his decision. Indeed, the left DLPFC group did not display any differences between the mean ranks of the critical and noncritical set, suggesting that the inhibitory tDCS on this particular cortical region could have prevented the cognitive process of preference change from occurring. This is a further demonstration that interfering with DLPFC activity has not a general and a-specific effect on the stimuli evaluation per se.

In addition, the obtained results could not be attributable to other factors such as memory of the critical pairs and of the choice made in phase 2, cognitive abilities or level of discomfort experienced during tDCS, because we controlled for differences across the three groups. Consistent with our findings, previous studies showed that neither explicit memory nor attentional resources are responsible for behavior-induced preference change and that this process may occur automatically (Lieberman et al 2001a, 2001b).

We found DLPFC to be crucial in change of preferences after a difficult choice, but what are the mechanisms underlying this process? Our findings are consistent with several prior observations. Previous research has associated relative left frontal cortical activity to a reduction in the amount of spreading of alternatives that typically occurs following a difficult decision (Harmon-Jones, 2011). Harmon-Jones and colleagues

(2008) measured attitude change after participants made a difficult choice and their relative left PFC activity was manipulated using EEG biofeedback training. This technique provides the participant real-time feedback on brainwave activity and is able to induce changes in EEG after only 3 days of training (even if previous literature has demonstrated that this brief neurofeedback training was effective at decreasing but not increasing left frontal activity; Allen et al., 2001). Participants who received neurofeedback to decrease, as compared to increase, left frontal activity showed a significant reduction in changing their attitudes after choice. According to Harmon-Jones and colleagues (2008), these results indicate that it is specifically the left PFC that is involved in dissonance reduction. Although in line with our findings, this study lacks a control condition in which other cortical regions (i.e., the right PFC) are likewise manipulated by neurofeedback training of EEG, or the decrease-left and the increase-left frontal groups are compared to a sham condition (that is, a left frontal group with no real manipulation occurring). Since the current study included these critical control conditions it provides stronger evidence of the causality of left DLPFC in attitude change, and compensate for such methodological limitations. Similarly, findings from an fMRI study (Qin et al., 2010) on choice justification showed that post-decisional neural activity in the left DLPFC was positively correlated with overall attitude change scores. These results are consistent with the hypothesis that choice justification requires regulation processes that are mediated by the left DLPFC: it would enhance choice-consistent information while would inhibit choice-inconsistent information (by boosting the preference for chosen items and weakening that for rejected ones). Accordingly, event-related fMRI studies (McDonald et al., 2000) have previously shown that left

DLPFC was involved in processes aimed at resolving cognitive conflict and that more activity in this region is associated with conflict decrease.

Theories that associate DLPFC activity to self-control processes are also consistent with our results. We suggest that cognitive processes mediated by left DLPFC (i.e. rationalization) occur in order to cope with the inconsistency between behavior and attitudes and led to consequential attitude change. Left hemisphere propensity for rationalization is well recognized. Based on studies on split-brain patients, Gazzaniga (1996) postulated that the left brain contains an "interpreter" which helps to grant a sense of order to our lives, allowing us to settle our present attitudes with our past actions and feelings and vice versa. Similarly, Ramachandran (1995, 1996) proposed that, once an anomaly or discrepancy is detected by the Right hemisphere (which generates the appropriate emotion too), the Left hemisphere tries to restore Self consistency by ignoring or suppressing the dissonant evidence. There are displays of an important role of left, but not right, DLPFC also in intention, self-regulation, planning processes (Tomarkenand & Keener, 1998), as well as affective modulation (Boggio et al., 2008). In an fMRI study, Hare and colleagues (2009) examined neural processes responsible for the deployment of self-control in dieters making real decisions about which food to eat. Greater activity in left DLPFC was found during implementation of self-control strategies and in those participants who were more capable to regulate themselves. In addition, testing rTMS on DLPFC in inter-temporal choices, Figner and colleagues (2010) demonstrated that only disruption of the Left, but not Right, DLPFC led to increased impatient choice for immediate but less available rewards. Additional evidence coming from EEG and fMRI indicated high levels of baseline Left prefrontal activation to be associated with increased capacity to voluntarily suppress negative

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emotions (Pena-Gomez et al., 2011). Recent reviews on emotion regulation (Ochsner & Gross, 2008; Berkman & Lieberman, 2009) showed how nearly all the published studies indicate dorsal and ventral portions of the lateral PFC, especially left-lateralized, dorsomedial PFC and dACC as consistently activated by reappraisal strategy. These studies conclude that regulation trials recruit a top-down executive control, possibly mediated by DLPFC. One hypothesis is that this high-level cognitive form of regulation may depend upon systems engaged in working memory, language and goal representation (Left DLPFC) when subjects are asked to reinterpret situational or contextual aspects of stimuli (as the individual creates a new story about its meaning), whereas it may rely more upon medial PFC, implicated in estimating one's own affective states, and right PFC, involved in attentional control, when they have to distance themselves from stimuli. Moreover, reappraisal-related increases in Left ventrolateral PFC are negatively correlated with the activity in the amygdala and medial orbito-frontal cortex (MOFC), regions implicated in detecting affective salience (Ochsner et al., 2002). Our results seem to be in line with these previous evidences and confirm that left DLPFC is a crucial neural substrate for Self control and Self regulation processes.

In contrast with our findings, Jarcho and colleagues (2010) examined brain activity with fMRI during the decision phase of a free-choice paradigm and observed that increased activity in Right inferior frontal gyrus (IFG) was positively correlated with decision-related attitude change. According to Jarcho and colleagues, these results are consistent with studies suggesting that cognitive dissonance can be resolved rapidly, without extended awareness and deliberation, as an automatic byproduct of decision-making itself (Lieberman et al., 2001; Egan et al., 2007). This study, however, scanned the brain

during the choice and did not assess the differences in cortical activity before and after it, so it is not clear whether and how attitude change might occur as a consequence of a choice (Qin et al., 2010). Moreover, Jarcho and colleagues found also left regions being engaged in cognitive dissonance reduction: activity in left anterior insula was in fact negatively correlated with attitude change and with activity in right IFG during trials with large, compared to small, amount of attitude change.

Our findings illustrate the importance of tDCS for progress in understanding the neural substrates of cognitive dissonance reduction and provide a causal evidence for the role of DLPFC in the self regulation process of attitude change. One putative neural network underlying the cognitive strategy of preference change to reestablish self consistency might include the DLPFC, the ventromedial PFC and the striatum. When individuals are confronted with goal-directed decision-making, the deployment of self control is needed and DLPFC activity is required to modulate the value signal of stimuli encoded in the VMPFC, as demonstrated by Hare and colleagues (2009). In their study, in fact, activity in the left DLPFC increased during successful self-control trials and was negatively correlated with activity in the VMPFC, that otherwise makes the choices driven only by the immediate value of the stimuli. This value is actually computed in the VMPFC-striatal network (Kable & Glimcher, 2007). Several fMRI studies on cognitive dissonance showed how post-choice changes in desirability of the chosen and rejected alternatives were reflected in parallel changes in the activation of the dorsal striatum, specifically in the caudate nucleus (Sharot et al., 2009; Izuma et al., 2010). This region is a key target for the dopaminergic system and is commonly related to reward processing (Delgado, 2007). Attitude change resulted in alterations in the physiological representation of the stimuli's expected hedonic value. So, choice can modify

individual's self-report likings as well as their neural representations. Importantly, our data add to these findings that DLPFC, a widely known region for its role in the implementation of cognitive control, conflict resolution and top-down modulation, is responsible for dissonance-induced preference change.

# GENERAL CONCLUSIONS

Over the course of the last decades, cognitive psychology and cognitive neuroscience have dedicated much attention to the relationship between emotion and cognition. Although historically the view of emotion and cognition as two distinct and well separated processes has been dominating, recently the view of a dynamic and interactive relationship of these two processes has become more prevalent. Several studies have provided evidence that complex human behaviors result from a joint contribution of both emotional and cognitive processes and that brain regions previously indicated as exclusively emotional are also involved in cognition as well as cognitive brain regions also being involved in emotion (for review see Pessoa, 2008). Thus, the idea that emotion and cognition not only interact with each other, but they influence each other, is becoming increasingly central to theories in this area of studies.

The present work has focused on two main fields, such as attention and decision-making, which highlight how emotion and cognition mutually affect and sometimes compete with each other. In particular, the first part of this dissertation reported three experimental studies concerning emotional perception and attention and how these processes may be modulated by other factors such as personality, internal states of the individuals and social context.

In experiment one the impact of aggression traits of personality on recognition of emotion has been investigated, showing that individuals that are more aggressive are also less sensitive to facial expressions of emotion and need more time to discriminate them. In accordance with previous literature on clinical and non-clinical populations

(Van Honk et al., 2000, 2001; Matheson et al., 2005) we concluded that traits of aggression are associated with an impairment in recognition of emotion. Even if to date it did not receive much attention compared to other traits of personality (i.e. anxiety), we showed aggression to be a crucial aspect of personality. It is noteworthy indeed that the ability to discriminate emotion is an important prerequisite for recognition of social cues and consequently for a good functioning of social interactions. Previous literature has shown that aggression has several components, such as impaired recognition of social cues and enhanced impulsivity (for review see: Nelson & Trainor, 2007). Much further research is required to expand on these results and test their potential for future research and their implications in other fields. Indeed, behavioral results may represent the basis for further investigation on the role of personality traits in modulating brain activity. A plausible hypothesis concerning emotion recognition is that personality characteristics may contribute to modulate activity in specific brain regions, such as the amygdala, implicated in the discrimination of emotional facial expressions. Furthermore, it could be interesting to expand knowledge on the effects of aggression traits of personality on attentional processes and to investigate whether attention towards certain kind of stimuli is affected by aggression traits. This could have implications in both developmental and clinical fields. In addition, the current results are more generally in line with previous observations that personality is a determinant factor in our relationship with the environment and in how we react to information coming from the environment. The influence of aggression traits in modulating emotion recognition represents a good example. Nevertheless, the ability to detect information in the environment and process it based on its current relevance or salience is attributed to selective attention (Driver, 2001). If in experiment one we showed that personality may

influence how we observe and perceive emotional expressions, experiment two investigated how internal motivational states of the individuals may affect information processing and subsequent allocation of attention. Several recent studies have suggested that the emotional significance of sensory events can determine how visual attention is allocated (Lang et al., 1997; Vuilleumier, 2005). Accordingly, we showed that transitory changes in the pleasantness and the rewarding value of the stimuli play an important role in modulating the functioning of covert mental processes, such as visual selective attention. In particular, we found that a food-specific devaluation treatment induced a considerable decrease in the attentional bias for devalued foods, parallel to the perceived pleasantness of those foods, whereas visual selective attention to valued foods remained stable. These findings are in line with the idea that mechanisms of selective attention are flexibly regulated to optimize interaction of the individual with the environment, depending on his/her current motivational state (Lang et al., 1997). Interestingly this could find clinical applications in treatment of obesity or eating disorders by working on the motivational and affective value patients attribute to food stimuli. In addition, these results expand on the evidence that attentional processes are mediated by the affective and motivational value of the stimuli. The results of experiment three are also in line with this assumption. Indeed, experiment three showed that emotional stimuli, with both positive and negative valence are more likely to draw attention compared to neutral stimuli. Moreover, we explored the possible influence of an external factor such as the presence of another individual on the emotional enhancement of attention. We found that social presence selectively decreases early attentional capture and emotional arousal prompted by pleasant erotic stimuli, while it leaves unaltered behavioral and physiological responses to equally arousing (salient)

unpleasant pictures. This is of particular interest in understanding the strong influence that cultural aspects have in our everyday life and in behavior modulation. The crucial difference between processing pleasant erotic images and negative threat images in a social context is that only the former is culturally considered as highly inappropriate, thus providing the potential for negative social evaluation and rejection (social-evaluative threat). These results suggest that automatic influence of emotion on attentional processes may, in turn, be regulated, providing more evidence of interactive and jointed mechanisms involving emotional and cognitive processes in parallel. Indeed a possible explanation for these results is that in social contexts individuals may automatically regulate their responses to emotionally pleasant but inappropriate stimuli to avoid social negative evaluation. This explanation is in accordance with theories and evidence that concern cognitive control of emotions. Indeed even if we usually refer to emotion regulation as a set of conscious processes (Beauregard et al., 2001) aimed at modulating emotional response in accordance with individuals' current goals and intentions, there is also evidence that regulatory processes may occur without awareness (Fujita & Han, 2009; Mauss et al., 2007). The second part of this thesis has addressed this issue by showing that cognitive brain regions are effectively and unconsciously implicated in regulative processes of emotional responses.

Experiment four showed that in particular types of decision-making such as moral judgments, implicating strong emotional engagement as well as cognitive resources, DLPF, a well-known cognitive brain region, is causally associated with regulation of emotional responses and moreover with utilitarian (cognitive) answers. Indeed, we found that after disruption of activity in this area utilitarian judgment requires longer

time responses, thus suggesting greater cognitive effort in order to compete with the overwhelming emotional response that would lead to moral condemnation.

While experiment four showed that DLPFC is necessary in regulating emotional responses to form decisions, experiment five expanded on this showing that similar control mechanisms are also involved in shaping preferences, once difficult choices between equally attractive options are made. According to cognitive dissonance theory (Festinger, 1957), inconsistency between behavior and attitudes triggers an unpleasant emotional state that requires cognitive processes to be reduced. Our results showed that when we interfered with left DLPFC activity by tDCS stimulation after a difficult choice, participants no longer showed the choice-induces change of preferences that typically occurs after difficult choices implicating conflict between prior attitudes and effective decisions. Therefore, we argued DLPFC to be crucial in reduction of negative affect due to inconsistency, as well as in implementation of regulative strategies such as change of preferences. The use of different stimulation techniques allowed us to illustrate the crucial importance of some brain regions for modulation of behavior. Moreover, we reported a good display that these techniques themselves are effective in establishing causal association between some brain regions' activity and specific functions. It is worthwhile to note the distinction between the roles of left and right DLPFC in cognitive dissonance reduction. Although the study on moral judgment indicated right DLPFC as crucially involved in conflict reduction in moral decision-making, since activity in left DLPFC has not been tested, the possibility that left DLPFC is also implicated in the same mechanisms cannot be excluded. This probably represents a limitation of the study and might be the starting point for further research.

Taken together the results of the experiments reported in this thesis lead to important conclusions. First of all, they confirm the importance of emotion in perceptual and attentional processes, by showing that emotional and motivational value of stimuli is crucial in guiding allocation of attention. Secondly, although historically emotional responses are considered quick and automatic, they demonstrate that emotional responses are in some way modulated and influenced by different factors such as factors inherent to the individuals (e.g. personality traits), temporary factors (e.g. individuals' internal states), and external factors (e.g. social context). This evidence suggests that emotional processes may be rapid but are not entirely automatic. Therefore, definition of emotion as an automatic reflex may require qualification perhaps with reference to specific circumstances, types of stimuli in question or with reference to specific-emotional states of the individuals. Moreover, we reported valid evidence that cognitive resources are required for the modulation and regulation of emotional responses to drive them in accordance with current intentions. In general cognitive processes seem to be crucial in the resolution of conflictual states.

In conclusion all these data converge in affirming that emotion and cognition are not well distinguished processes but rather that they interact and compete to shape human behavior.

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**APPENDIX A**


IAPS (Lang et al., 2005) code for the target and control pictures:

Unpleasant target pictures: 2141, 2683, 2691, 2694, 2703, 3064, 3210, 3500, 3530, 6212, 6312, 6313, 6315, 6540, 6571, 6836, 9400, 9410, 9429, 9433.

Neutral target pictures: 2037, 2038, 2102, 2104, 2221, 2320, 2370, 2372, 2381, 2383, 2393, 2396, 2397, 2480, 2485, 2570, 2593, 2594, 2595, 2605.

Pleasant target pictures: 4001, 4002, 4006, 4180, 4210, 4232, 4250, 4290, 4300, 4311, 4320, 4649, 4652, 4666, 4670, 4676, 4677, 4680, 4681, 4683, 4687.

Control pictures: 5000, 5001, 5010, 5020, 5120, 5130, 5200, 5201, 5220, 5250, 5300, 5390, 5471, 5480, 5500, 5510, 5520, 5530, 5534, 5535, 5593, 5594, 5631, 5660, 5711, 5731, 5740, 5750, 5760, 5779, 5780, 5781, 5800, 5811, 5814, 5870, 5890, 6150, 7000, 7002, 7004, 7006, 7009, 7010, 7020, 7025, 7030, 7031, 7034, 7035, 7036, 7037, 7038, 7039, 7040, 7041, 7042, 7050, 7052, 7053, 7055, 705, 7057, 7058, 7059, 7080, 7090, 7100, 7110, 7130, 7140, 7150, 7161, 7175, 7190, 7205, 7207, 7211, 7217, 7224, 7233, 7234, 7235, 7242, 7490, 7495, 7500, 7501, 7504, 7508, 7545, 7546, 7547, 7560, 7595, 7700, 7705, 7710, 7920, 7950.