International Journal of Psychophysiology 71 (2009) 57–63

Contents lists available at ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

Negative brain: An integrative review on the neural processes activated by unpleasant stimuli

Luis Carretié *, Jacobo Albert, Sara López-Martín, Manuel Tapia

Facultad de Psicología, Universidad Autónoma de Madrid, 28049 Madrid, Spain

ARTICLE INFO

Keywords:
Emotion
Danger
Pain
Repugnance/disgust
Amygdala
Mediodorsal and pulvinar thalamic nuclei
Anterior insula
Ventromedial prefrontal cortex
Anterior cingulate cortex
Visual cortex
Motor cortex
Striatum
Hippocampus

ABSTRACT

Evolutionary pressure has led the nervous system to guarantee rapid and intense responses to negative events (dangerous, harmful or repugnant). Thus, the 'negative brain' (the set of neural mechanisms triggered by unpleasant or negative stimuli) is equipped with several specific characteristics. This review organizes the current data on the human negative brain in three blocks. Firstly, the "Input mechanisms" block describes those structures responsible for the rapid distribution of all sensory information. Secondly, the "Evaluation systems" block refers to the key pieces: those responsible for evaluating negative consequences of stimulation and deciding which response is the most appropriate for coping with them. Thirdly, the "Associated and output processes" block describes how evaluative elements may interact with other brain structures to modulate attention, store and recover situational information, activate defense/withdrawal motor programs (or plan new actions) and develop autonomic/motor actions to cope with the unpleasant event. Finally, an integrative summary that serves as a tentative model of the negative brain is provided.

1. Introduction

Life, in the course of its evolution, has had to deal with a considerable number and variety of hazards that put at risk the physical integrity and even the survival of organisms. The response to this permanent pressure has been the development of a wide variety of sophisticated and effective defensive and withdrawal strategies, ranging from claws or shells to camouflage or speed. In the case of humans, the main defensive tool is the brain. In fact, the human brain circuitry devoted to responding to and coping with dangerous, harmful or repugnant situations (which will all be referred to as 'unpleasant' or 'negative' throughout this review) is probably richer than that of any other life form.

Negative events require processing and response resources to be more intensely and urgently mobilized. This urgency would have obvious adaptive and evolutionary advantages: the consequences of a negative event are often much more dramatic than the consequences of ignoring or reacting slowly to neutral or even appetitive stimuli (Ekman, 1992; Ohman et al., 2000). Indeed, several studies indicate that negative events elicit more rapid and more prominent responses than neutral or positive events. Psychological research has shown that this 'negativity bias' is manifested through diverse response systems, including those related to cognitive, emotional, and social behavior (Cacioppo and Gardner, 1999; Taylor, 1991). Since non-negative events with an *arousal* value similar to that of negative events (the arousal dimension ranges from calming to arousing) do not trigger this bias, it is assumed that it is particularly explained by their *valence* (which ranges from negative or unpleasant to positive or pleasant). Valence and arousal are two affective dimensions widely considered to explain the principal variance of the emotional meaning (Lang et al., 1993; Russell, 1979; Smith and Ellsworth, 1985).

With respect to brain research, the existence of the negativity bias has received recent experimental support, since stronger or faster neural responses to unpleasant than to neutral and pleasant events have been reported (Carretié et al., 2001, 2003; D'Esposito et al., 2000; Ito et al., 1998; Kawasaki et al., 2005; Mourão-Miranda et al., 2003; Northoff et al., 2000; Pourtois et al., 2004, 2005; Smith et al., 2003; Williams et al., 2004). Interestingly, since evolutionary success requires the nervous system to guarantee a rapid and intense reaction even when recognition of danger clues is difficult and does not reach awareness (e.g., they are brief, occluded, or with poor contrast), the brain bias towards negative stimuli is manifested even when they are unconsciously perceived. Thus, in conditions of restricted awareness, the neural response to negative stimuli is higher than to non-negative ones (Carretié et al., 2005; Liddell et al., 2005; Whalen et al., 1998; Williams et al., 2004). Studies on blindsight (i.e., a lesion that prevents conscious perception of visual stimuli) could provide convergent findings (e.g., de Gelder et al., 1999).

---

* Corresponding author. Tel./fax: +34 91 497 5224.
E-mail address: carretie@uam.es (L. Carretié).

0167-8760/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.ijpsycho.2008.07.006

It is important to indicate at this point that circuitry that computes urgent utility (e.g., avoidance of a dangerous event) often diverges from the circuitry subserving deep identification and discrimination (LeDoux, 2000; Shizgal, 1999). Hence, the negativity bias would be in part supported by specific neural mechanisms that are less involved in non-negative situations. In the 'urgency circuits', rapidity is the key issue, at the cost of some precision. The opposite trend would apply to the 'deep processing circuits', where precision and accuracy are the main concerns, at the cost of speed. This dual strategy can be illustrated by considering the two different neural systems for processing visual information. One of them carries low-quality information (i.e., without high spatial frequencies and with poor color information) but rapidly provides, as explained later, visual information to areas important in the response to negative stimuli such as the ventromedial prefrontal cortex (VMPFC: Bar et al., 2006) or the amygdala (Vuilleumier et al., 2003). This system starts out in the magnocellular cells of the lateral geniculate nucleus (LGN) of the thalamus, and is often referred to as the 'magnocellular pathway'. The other system is more accurate, but directs information exclusively to the visual cortex (Merigan and Maunsell, 1993), and allows a deep exploration of the stimulation. It is usually called the 'parvocellular pathway', in reference to the LGN cells in which it originates (e.g., Livingstone and Hubel, 1987). In fact, negative stimuli appear to preferentially make use of the magnocellular pathway to rapidly reach subcortical (Vuilleumier et al., 2003) and cortical processing areas (Carretié et al., 2007; Pourtois et al., 2005).

2. A definition of 'negative brain'

We shall refer to the neural circuitry involved in the reaction to unpleasant events as the 'negative brain'. This term pretends to illustrate that structures activated by negative events deeply interact, as we are about to see, in order to achieve a unique objective (i.e., efficiently coping with unpleasant situations), so they may be considered a coherent goal-directed neural entity. But it is important to indicate here that the structures constituting the negative brain may participate in other affective (and non-affective) processes, so they are not *exclusively* activated by negative events; rather, they are *preferentially* activated by them.

In this regard, a relevant question is whether a 'positive brain' also exists (i.e., a set of neural structures that are preferentially activated by emotionally positive situations). Indeed, a set of neural circuits responding to positive events has been recently described (Burgdorf and Panksepp, 2006), and strong theoretical and experimental support has been provided for a segregation (at least partial) of neural circuits in charge of coping with negative situations and those activated in positive situations (see reviews in Cacioppo and Gardner, 1999; Davidson and Irwin, 1999; Lang et al., 1997). The 'positive brain' would even be dominant in certain situations, namely in those in which stimuli count with mild arousing content. Thus, an advantage in the processing of positive stimuli ("positivity offset": Cacioppo and Gardner, 1999) is observed in response to soft emotional items such as positive, negative and neutral words or facial expressions (e.g., Carretié et al., 2008; Herbert et al., 2006; Kanske and Kotz, 2007; Kissler et al., 2006), which are less arousing than other stimuli such as affective pictures (Lang et al., 1998). However, when emotional stimuli are markedly arousing, and those with negative content clearly signal threat or pain, the 'negative brain' would dominate and the negativity bias would become evident (Cacioppo and Gardner, 1999).

The negative brain can be divided into three blocks of neural mechanisms (Rolls, 2000). First, one block ("Input mechanisms") would be responsible for the initial distribution of sensory information to further levels of processing. A second block ("Evaluation systems") includes those structures that would be in charge of assessing the risks or negative consequences derived from the situation and deciding on the most appropriate response for minimizing them. And third, a group of processes or tools by which evaluative systems can modulate attention, memory, action planning, and autonomic/motor execution to better cope with the negative event ("Associated and output processes" block). The present review is organized in accordance with this three-block structure taking into account that, in this field, research in humans has focused almost exclusively on the visual modality.

3. Input mechanisms

Sensory information is initially distributed by the thalamus. The best-established line of distribution of visual information runs from the LGN of the thalamus to the visual cortex. The visual cortex then sends the processed information to the amygdala (e.g., Emery and Amaral, 2000), ventromedial prefrontal cortex or VMPFC (e.g., Bar et al., 2006) and insula (e.g., Gallese et al., 2004), the three evaluative structures of the negative brain, as we shall see later. In a parallel way, the thalamus sends direct projections to these evaluative structures. These direct connections from thalamus have not yet been well characterized, particularly with respect to latency-related issues (i.e., the moment in which they enter in action). Current data suggest that at least two thalamic nuclei, the pulvinar and the mediodorsal (MD), play a particularly important role in these connections. The pulvinar nucleus is clearly involved in visual processing, and several studies report on its connections with the amygdala (Romanski et al., 1997), insular cortex (Clascá et al., 1997; Romanski et al., 1997), and VMPFC (Cavada et al., 2000; Morecraft et al., 1992; Romanski et al., 1997). In humans, pulvinar lesions indicate that this nucleus plays a significant role in generating response to visual threat (Ward et al., 2005).

Meanwhile, the MD nucleus, which is located at the hub of multiple transmission lines, probably also plays an important role in transmitting key signals necessary for an efficient defense response. In fact, it is also connected to the amygdala (Li et al., 2004), insula (Clascá et al., 1997), and VMPFC (Kuroda et al., 1998). In line with this proposal, studies in other species suggest that the MD intervenes in fear conditioning (Li et al., 2004), since its lesion impairs this type of learning. According to these data, the MD would participate in the encoding of stimuli, and provide this information to the structures with which it is connected. As a consequence, MD lesions produce emotional dysfunctions (see a review in Oyoshi et al., 1996). Other thalamic nuclei could also connect to evaluative systems, but data on thalamic behavior in response to emotional stimuli are still conspicuously scarce.

A key issue concerns whether thalamic nuclei mentioned above send the information to key elements of the negative brain in parallel to the information transmitted from the LGN to the visual cortex (i.e., whether visual information that reaches evaluative structures necessarily proceeds from the visual cortex or not). The important role of direct thalamo-amygdalar circuits in the response to negative stimuli is well-established in studies in animals (see a review in LeDoux, 2000), but data in humans are still scarce and inconclusive. There are data to suggest that, in fact, the pulvinar nucleus provides direct visual information to the amygdala that has not been processed previously by the visual cortex (de Gelder et al., 1999; Morris et al., 1999), but the interpretation of these scarce data could admit alternative explanations (see Vuilleumier, 2005). In any case, if the pulvinar (and/or MD and/or other thalamic nuclei) is finally found to send information not processed by the visual cortex to the amygdala, there is no reason to discard the possibility that, since it is also connected to other evaluative elements of the negative brain (such as the insular cortex or VMPFC), these cortical areas also receive this crude (magnocellular), but rapid, visual information. In fact, as explained below, VMPFC response latencies to negative events would be in line with this possibility.

4. Evaluation systems

According to current data, the elements making up the evaluative block of the negative brain (those in charge of evaluating the risks of the situation and deciding a response) are the amygdala, the anterior