COMENIUS UNIVERSITY IN BRATISLAVA
FACULTY OF MATHEMATICS, PHYSICS AND INFORMATICS

INTERACTION OF EMOTIONS PROCESSING AND OLFACTORY PERCEPTION

MASTER THESIS

BRATISLAVA 2012 **Bc. Peter Pružinský**

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FACULTY OF MATHEMATICS, PHYSICS AND INFORMATICS
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I declare this thesis was written on my own, with the only help provided by my supervisor and the referred-to literature and sources.

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Abstrakt

Valencia, hlavná dimenzia multidimenzionálnej čuchovej skúsenosti, pravdepodobne spôsobuje že vône dokážu ovplyvňovať náladu. Príjemné vône majú tendenciu navodiť pozitívnu náladu, zatiaľ čo nepríjemné vône majú tendenciu navodiť náladu negatívnu. Vplyv vôní na kogníciu a správanie je podobný ako vplyv emócií. Vône dokážu vyvolať zmeny fyziologických parametrov, ako sú napríklad tepová frekvencia alebo elektrická vodivosť kože, ktoré sú súčasťou emočných reakcií. Tieto efekty sa zvyčajne interpretujú ako vzájomná závislosť olfaktorickej percepcie a spracovania emócií, spôsobená spoločným neurálnym substrátom. Vplyv spracovania implicitných emócií na intenzitu olfaktorickej percepcie, ďalšej dimenzie vône, bol potvrdený aj prezentovanou behaviorálnou štúdiou. Výsledky tejto štúdie preukázali signifikantný vplyv spracovania emócií na vnímanie intenzity vôní, predpokladajúc že aktivácia amygdaly koreluje so zmenou vnímania intenzity vôní. Neurálna reprezentácia emočného sveta rozdelená na nízkoúrovňovú zložku – intenzitu – a vyššieúrovňovú zložku – valenciu – je v súlade s názorom, že amygdala zodpovedá za nízkoúrovňové spracovanie emočných stimulov. Tieto zistenia sú v súlade s teóriou kognitívneho hodnotenia emócií, ktorá predpokladá, ze emócie nie sú len jednoduchou kladnou alebo zápornou reakciou na stimul, ale vyplývajú skôr z interakcií medzi egom osoby, situačným kontextom a stimulom. Ako teoretickú ukážku podobnosti navrhovaného konceptu vône a teóriou kognitívneho hodnotenia emócií som použil idealizovaný komponentový výpočtový model tejto teórie.

Abstract

The main dimension of a multidimensional odor experience is valence and, thus, it is likely to influence mood, so that pleasant odors tend to induce positive moods, whereas unpleasant odors tend to induce negative moods. Odors produce effects on cognition and behavior that are similar to those produced by emotional stimuli. Odors can provoke changes in physiological parameters, such as heart rate or skin conductance, which are directly involved in the emotional response. These effects are usually interpreted as an interdependence of olfaction and emotion on overlapping neural systems. The influence of implicit emotions processing on the odor intensity, the next dimension of an odor, was also confirmed with the results of the presented behavioral study. The results showed a significant evidence of emotions processing influence on subjectively perceived intensity of an odor, suggesting that activation of amygdala correlates with increasing perception of intensity of an odor. The neural representation of affective space into more primary intensity and higher-order valence components is compatible with the notion that the amygdala supports low-level (intensity) stimulus-driven processing. These findings dovetail nicely with appraisal theories of human emotions, which emphasize that affective responses are not a simple reflection of the intrinsic quality (positive or negative) of a stimulus, but rather result from interactions among the person, the situational context and the stimulus. An idealized computational component model of appraisal theory of emotions, which formalizes this theory, was used to show how an odor theoretically fits into this concept.

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List of abbreviations and signs

aPXDd - dorsal anterior piriform cortex

aPCXv - ventral anterior piriform cortex

ant Ins - anterior insula

ACC - anterior cingulate cortex

Am (BL) - basolateral amygdala

Am (CM) - corticomedial amygdala (including the central nucleus)

ANN - artificial neural network

AOC - anterior olfactory cortex

AON - anterior olfactory nucleus

bOFC - orbitofrontal cortex

CoA - cortical nucleus of the amygdala

DMN - dorsomedial nucleus of the thalamus

EC - entorhinal cortex

ET - external tufted cell

fMRI - functional magnetic resonance imaging

HIP - hippocampus

GC – granule cells

GCL - GC layer

GEOS - Geneva emotion an olfaction scale

GL - glomerular layer

JG - juxtaglomerular neurons

LOT - lateral olfactory tract

MC - mitral cells

MOB - main olfactory bulb

MT - middle tufted cell

NAc - nucleus accumbens

NCCR - The National Centre of Competence in Research

OB - olfactory bulb

OE - olfactory epithelium

OFC - orbitofrontal cortex

ONL - olfactory nerve layer

OR's - olfactory receptors

ORNs - olfactory receptor neurons

pPCX - posterior piriform cortex

PC - Piriform cortex

PG - periglomerular

PH - parahippocampal gyrus

SA - short axon cells

ST - Superficial tufted

Temp P - temporal pole

UPSIT - University of Pennsylvania Smell Identification Test

VG - Van Gehuchten

1 Introduction

Chemotaxis, a primitive way of olfaction, is the evolutionary oldest (3,5 milliard) way to perceiving the world, and it can be found already by prokaryotes, which use it successfully to survive till nowadays. Evolution, evaluated olfaction as so important, that it can be found across of all invertebrates and vertebrates including humans. Evolutionary higher species developed a way, how to use olfaction not just to perceiving the world, but also to communicate with each other. For a long time, the scientific community looked at human's olfaction as a rudimentary sense, which has no significant influence on everyday living and decision making. At least since Linda Buck and Richard Axel identified first 18 members of the olfactory receptor gene family (the biggest one in human genome) using a degenerate polymerase chain reaction strategy (Buck & Axel 1991), is the importance of olfaction for humans no more deniable.

1.1 Motivation

More than any other sensory modality, olfaction is like emotion in attributing positive (appetitive) or negative (aversive) valence to the environment. Certain odors reproducibly induce emotional states (Seubert et al. 2009; Weber et al. 2008), and emotional induction modifies odor perception (Pollatos et al. 2007). Certain cerebral substrates are in fact common to emotional and olfactory processing, and this may account for the olfactory disorders encountered in psychiatric disorders such as depression or schizophrenia (Pause et al. 2008; Schneider et al. 2007). Functionally, odor intensity is associated with amygdala activation (Anderson et al. 2003). Phylogenetically, the medial amygdala is the older one and evolved from the olfactory system to extend its threat-detection capability to other sensory modalities (LeDoux 2007).

In the last few years there is a growing interest in the field of interaction between olfaction and emotions processing, mostly in affective science e.g. The National Centre

of Competence in Research (NCCR) "Affective Sciences", the first Swiss national research centre, dedicated to the interdisciplinary study of emotions and their effects on human behavior and society, hosted by the University of Geneva, is one of the leaders in that field. A researchers team works there on „EmOdor project", to develop a new measurement methodology to study the emotional effects of odors. Concretely, it is suggested that emotions produced by odors should be studied as (more or less conscious) feelings that integrate cognitive, physiological, motivational and expressive effects, which may be accounted for by widely varying production rules. This multicomponential approach includes a major focus on individual and cultural differences, as these seem to play an important role in the relation between olfaction and emotion. To address systematically the complexity of labeling olfactory elicited emotions, they propose to investigate which labels people use in everyday life to describe the feelings and autobiographical memories associated with odors. In a first step, they asked participants to evaluate which terms are best suited to describe the feelings elicited by particular odors. This enabled them to explore the structure of the emotional space related to odor experience. They tested then the fit between a scale for odor-elicited emotions and a new set of judgments using a large set of odorant samples. Finally, they compared this new model with traditional emotion models - such as discrete-emotion or dimensional models - in order to confirm the validity of a specific model for olfactory emotion elicitation. This research concluded in a six dimensional emotion-odor model, called GEOS (Geneva emotion an olfaction scale).This model was used to find cultural influences on emotional verbalization during odor perception.

If all of mentioned above is correct, so we could probably use an emotion theory to create a concept of an odor. This concept will be useful for a cognitive system (cognitive agent) with implemented E-nose (artificial neural network coupled with artificial chemosensors). There are a number of computational implementations of emotion theories, so modifications of these implementations could be probably used as a concept of an odor.

1.2 Objectives

The objective of my research is to find out how processing of implicit emotions modulate the perception of intensity of an odor. I propose that activations of amygdala via audiovisual stimuli should correlate with subjective growing of perceived intensity of an odor probe, which will be still of the same concentration. Theoretical research and behavioral study should support his hypothesis. The results of the study, should show, that there is a significant modulation of emotions processing on olfactory perception. At last I will try to find a relevant psychological emotion theory that will fit the concept of an odor as well.

1.3 Interdisciplinarity

Because of the multidimensionality (valence, intensity, familiarity) and endless number of odors perceived by humans is the definition of an odor still unclear. I am using psychological experimental methods (behavioral study) based on neuroscientific findings of functional physiology of the brain to show why an odor can be seen as an emotion. Based on an idealized computational model of an emotion theory used in AI, I try to show, how this formalized psychological theory fits the concept of an odor.

2 Physiology of olfactory system

The gene family coding mammals olfactory receptors (OR's) is the biggest one in humans genome (cca. 1000 OR's) and they can be found over all but two chromosomes (Glusman et al. 2001). Also if most of these genes are pseudo genes, there are probably fewer than 400 in humans (Gilad et al. 2005) intact genes, expressed in odorant binding proteins placed on the cilia of olfactory receptor neuron in the neuroepitelum. In mammals, each receptor cell expresses only one type of olfactory receptor. Interestingly, recent data suggest that pseudo genes may play an important role in gene regulation, such as governing mRNA stability of homologous coding genes, making the situation more complex than originally envisioned (Hirotsune et al. 2003; Yano et al. 2004).

In the human nose, there are an estimated six million specialized olfactory receptor cells per nostril (Moran et al. 1982). The bipolar olfactory receptor cells serve as the first-order neurons of the system, and their central limbs project directly from the nasal cavity to the olfactory bulb without synapse. When the olfactory epithelium is damaged, the basal cell gives rise to both neural and non-neural cells, allowing for the replacement of damaged receptors (Huard et al. 1998), in a process known as adult neurogenesis.

2.1 Olfactory bulb

The cells expressing the same olfactory receptor project to the same glomeruli, globe-like structures within the olfactory bulb where the first synapses occur (Mombaerts et al. 1996; Serizawa et al. 2003). Thus, the molecular features to which a given receptor type is sensitive (e.g., chain length, functional group configurations) are in effect mapped to circumscribed regions of the olfactory bulb. A‘‘functional topography’’ exists in this system from the epithelium to the olfactory bulb. The paired ovoid-shaped olfactory bulbs, each of which measures approximately 50 mm^3 in a healthy adult, are

laminate-like structures located under the ventral surface of the frontal lobes immediately above the cribriform plate. Contrary to some textbook descriptions, the olfactory bulb is not a simple relay station within the olfactory pathway, but a complex center where sensory input is filtered and modified by neural elements intrinsic and extrinsic to the bulb (Kratskin & Belluzzi 2003). A convergence rate of around 1000 receptor cell axons for every second-order neuron occurs in this structure, at least in the rabbit. The combinations of spatiotemporal activation patterns produce an endless account of odors perceivable by humans. The most superficial layer of the bulb, termed the olfactory nerve layer, is made up of bundles of unmyelinated olfactory receptor cell axons that interweave across its surface.

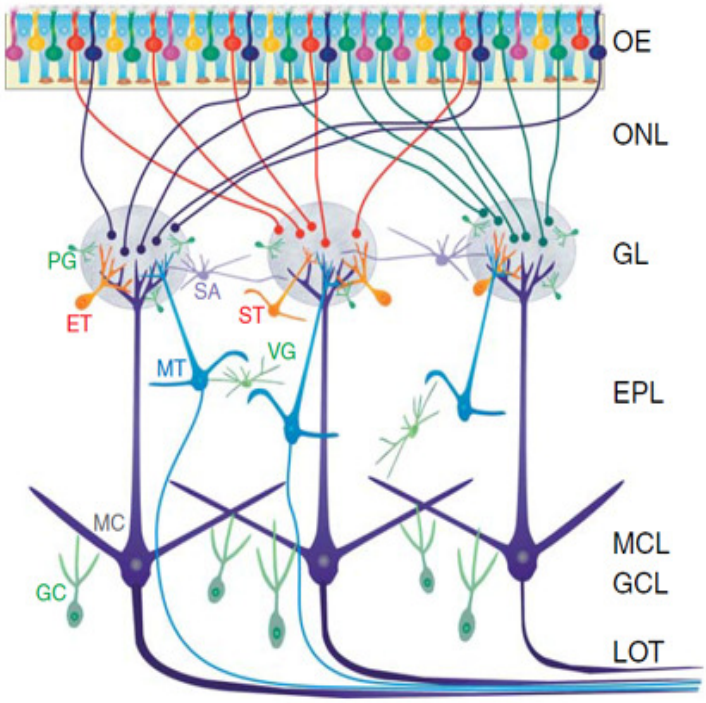


Fig1. Schematic illustration of the basic circuitry of the main olfactory bulb (MOB) - including the projections of olfactory receptor neurons (ORNs) from the olfactory epithelium (OE) to the glomerular layer (GL). ORNs expressing different odorant receptor genes (shown as blue, red, or green cells) are interspersed and widely distributed, yet the axons of ORNs expressing the same odorant receptor gene converge onto the same glomerulus (or pairs of medial and lateral glomeruli) in the GL. Axons of ORNs travel in the olfactory nerve layer (ONL) and synapse in the GL on the dendrites of mitral cells (MC), tufted cells (external tufted cell, ET; middle tufted cell, MT), and generic juxtaglomerular (JG) neurons, which include periglomerular (PG) cells, ET cells, and short axon (SA) cells. SA cells interconnect different glomeruli. There are serial and reciprocal synapses between the apical dendrites of mitral/tufted cells and the processes of

JGneurons. Superficial tufted (ST) cells are located in the superficial EPL or at the GL–EPL border. The lateral dendrites of mitral/tufted cells form serial and reciprocal synapses with the apical dendrites of granule cells (GC) in the EPL. The majority of GCs are concentrated in the GC layer (GCL) but many lie within the MCL. The axons of mitral/tufted cells project locally to GCs (not shown) and also to primary olfactory cortex via the lateral olfactory tract (LOT). The bulb also contains other populations of interneurons neurons, including the Van Gehuchten (VG) cells within the EPL.

Source: Kinnamon SC and Margolskee RF. 2007. in The Senses: A Comprehensive Reference, Volume 4 OLFACTION AND TASTE. San Diego, CA: Academic Press.

The next layer, the glomerular layer, contains the olfactory glomeruli. Although younger people have thousands of these structures arranged in single or double layers, these decrease in number with age and are nearly absent in people over the age of 80 years (Smith 1942). Deep to the bulb's glomerular layer is the external plexiform layer. This layer, which contains very few cell bodies, is formed largely by dendrites of granule cells and numerous secondary dendrites of mitral or tufted cells. Granule cells, the most numerous cells within the olfactory bulb, are relatively small axonless cells whose somata are located in the middle-most layer of the bulb (the granule cell layer). The cell bodies of the mitral cells (so-called because of their resemblance to a bishop's headdress) are found within the mitral cell layer, which is adjacent and medial to the external plexiform layer.

2.2 The olfactory cortex

The olfactory system is unique among sensory systems in communicating directly with the cerebral cortex without first relaying in the thalamus, although reciprocal relays do exist via the dorsomedial nucleus of the thalamus between primary and secondary olfactory cortical structures.

Those areas receiving fibers directly from the olfactory bulb (OB) are known as the ‘‘primary olfactory cortex’’ ,which consists of the following six structures: (1) anterior olfactory nucleus (AON) located in the posterior parts of the OB and olfactory tract near

the trigone; (2) olfactory tubercle (poorly developed in humans); (3) piriform cortex – the major recipient of OB output; (4) anterior cortical nucleus of the amygdala; (5) periamygdaloid complex; and (6) the rostral entorhinal cortex (Dotty & Bromley 2000). All structures of the primary olfactory cortex have rich and reciprocal relations with one another and with other central brain structures, including the hippocampus. Indeed, the olfactory system is unique in that it has the most direct access to the hippocampus of all other sensory systems in terms of synaptic connections.

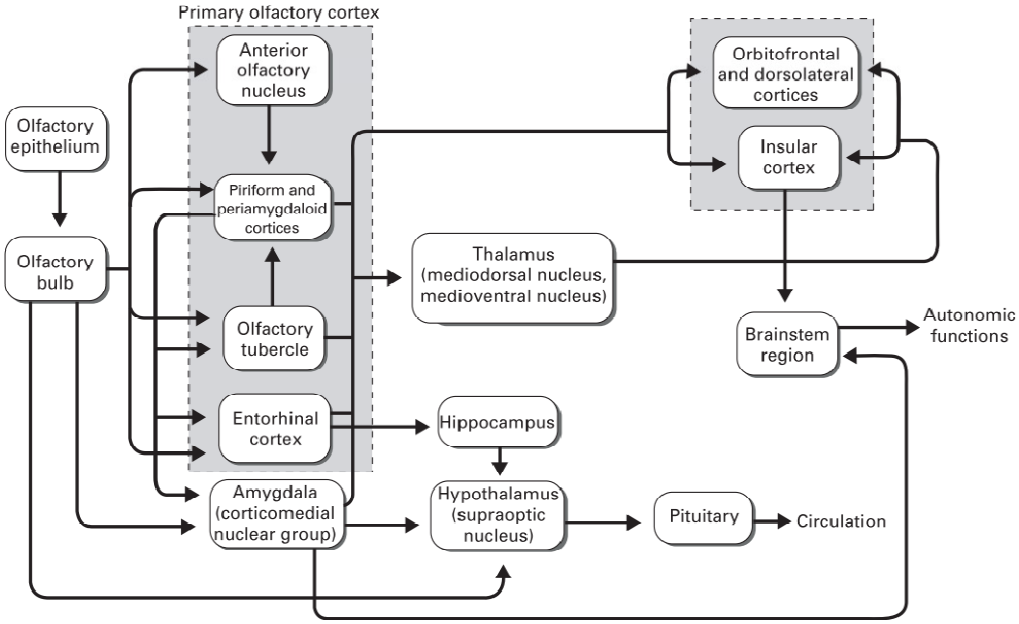


Fig. 2 Olfactory pathways

Source: Doty RL and Bromley SM. Olfaction and taste. 2000. In: A Crockard, R Hayward and JT Hoff, eds. Neurosurgery: The Scientific Basis of Clinical Practice. London: Blackwell Science, pp. 347–65.

2.3 Piriform cortex

Initial studies on the piriform cortex (PC) suggested that it was simply a relay station for olfactory information, but it is now known to have a far more complex function. The PC responds to sniffing odorless air (Sobel et al. 1998), implying that sniffing primes it for optimal reception of an odor – a concept proposed over 60 years ago by Adrian (1942).

It rapidly habituates in the continuous presence of odor (Poellinger et al. 2001; Sobel et al. 1999). It is responsive to odor pleasantness (‘‘valence’’ Gottfried et al. 2002), odor reward value (Gottfried & Dolan 2003), and attention to odor (Zelano et al. 2005). It is involved in odor recognition memory and familiarity judgment (Dade et al. 2002; Plailly et al. 2005), and probably stores olfactory traces of multisensory episodic memories (Gottfried et al. 2004). Recent data suggest that the PC supports olfactory perceptual learning (Li et al. 2006), functional magnetic resonance imaging (fMRI) experiments demonstrate that the PC becomes conditioned to the sight of food and that satiety results in reduced activity. The PC is concerned also with high-order representation of odor quality or identity. According to (Gottfried et al. 2006), there is a ‘‘double dissociation’’ in PC whereby posterior piriform regions encode quality but not odor structure (chemical class), and anterior regions encode structure but not the identity of smell. The presence of structure-based codes suggests that fidelity of sensory information arises from the olfactory bulb and that quality-based codes are independent of any simple structural configuration, implying that synthetic mechanisms underlie our experience of smell. In other words, we perceive most odors (which usually consist of multiple odorous molecules) as a single unified percept. This synthesis underlies our perception of a smell and probably how the brain interprets smell information.

2.4 Orbitofrontal cortex

The orbitofrontal cortex serves as the first neocortical receiving areas for the olfactory pathway. The cortical olfactory areas in turn have multiple complex relations with other chemosensory areas, and with limbic areas involved in learning, memory, motivation, and emotion. This is interestingly, because of conscious perception. In the framework of conscious perception, proposed by Crick and Koch (Crick & Koch 2003). They outline a framework in which primary sensory cortex at the “back” of the brain contains cells and microcircuits that act as “feature detectors” of the information relayed from the thalamus. Feature detection is believed to be largely “unconscious.” No indication is given of how olfactory “conscious” perception would fit into this framework. Toward that end the following considerations may be relevant. In olfactory perception there is

no “back” of the brain; the primary neocortical receptive area is in the orbifrontal cortex, which is at the core of the prefrontal area. Thus, in olfaction, all of the sequences of processing necessary to get from the back to the front of the brain are compressed within the front of the brain itself. This reflects the evolutionary position of smell, with its privileged input to the highest centers of the frontal lobe throughout the evolution of the vertebrate brain. From this perspective, the basic architecture of the neural basis of consciousness in mammals, including primates, should be sought in the olfactory system, with adaptations for the other sensory pathways reflecting their relative importance in the different species.

The odor image, reformatted by the circuits of the olfactory bulb and olfactory cortex, is the input that is processed by the olfactory area of the orbitofrontal cortex. In orbitofrontal cortex, we have detailed analyses of connectivity (Price 2007) and detailed recordings of unit responses to smell stimuli (Rolls et al. 2006). In addition to its specific olfactory sensory role, a special feature of orbitofrontal cortex is that, during feeding behavior, the information contained in the odor images is immediately combined with inputs from taste, somatosensation, audition, and vision into the multimodal perception of flavor. From these sensory areas in lateral orbitofrontal cortex, the integrated information is transferred to medial visceral orbitofrontal output areas that are interconnected with basolateral amygdala and related areas to provide the motivational and emotional dimensions of the feeding experience, with hypothalamic areas involved in control of feeding behavior (Price et al. 2007) in humans, with language areas involved in smell and flavor identification and verbal characterization of these perceptions. Together these form a brain–flavor system that is unique to humans (Rolls et al. 2006). It has been hypothesized that flavor is one of the most important sensory experiences in the evolution of human behavior.

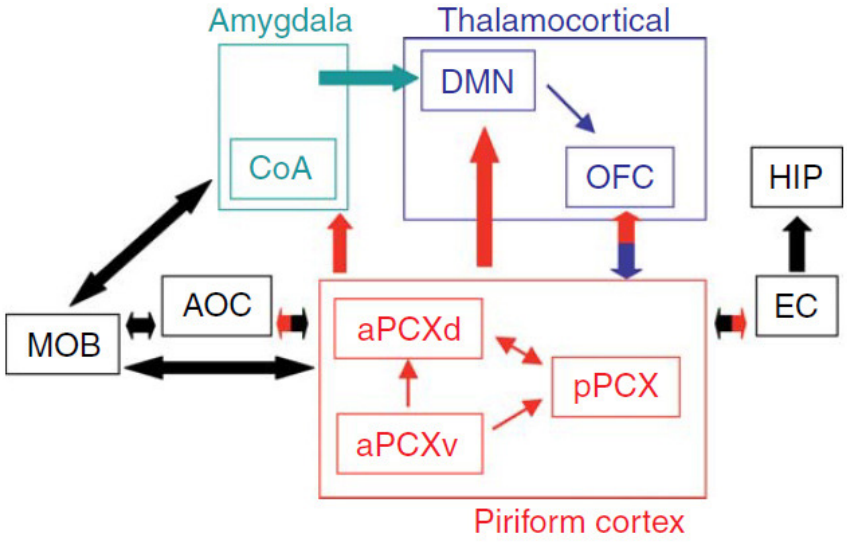


Fig.3 A schematic representation of the major olfactory cortical areas and their interrelationships.

This figure focuses on the piriform and orbitofrontal cortices. Almost nothing is known regarding the sensory physiology of the anterior olfactory cortex (AOC). MOB, main olfactory bulb; AOC, anterior olfactory cortex; aPXDd, dorsal anterior piriform cortex; aPCXv, ventral anterior piriform cortex; pPCX, posterior piriform cortex; CoA, cortical nucleus of the amygdala; DMN, dorsomedial nucleus of the thalamus; bOFC, orbitofrontal cortex; EC, entorhinal cortex; HIP,hippocampus.

Source: Kinnamon SC and Margolskee RF. 2007. in The Senses: A Comprehensive Reference, Volume 4 OLFACTION AND TASTE. San Diego, CA: Academic Press.

3 Amygdala and emotions processing

Human evoked-potential recordings demonstrate that the amygdala is unequivocally concerned with olfactory processing, although the precise nature of this has yet to be elucidated (Hudry et al. 2001). This anteriorly located temporal lobe structure is usually divided into four anatomical regions: (1) corticomedial nuclei that receive most of the output from the OB, which includes the periamygdaloid area, anterior, and posterior cortical nuclei, nucleus of the lateral olfactory tract, and medial nucleus; (2) lateral nucleus; (3) basolateral nuclei; and (4) central nuclei. Apart from strong two-way connections to and from the olfactory bulb, the amygdala has connections from the corticomedial nuclei to its lateral, basolateral, and central nuclei, as well as to the basal ganglia, thalamus, hypothalamus, and orbitofrontal cortex.

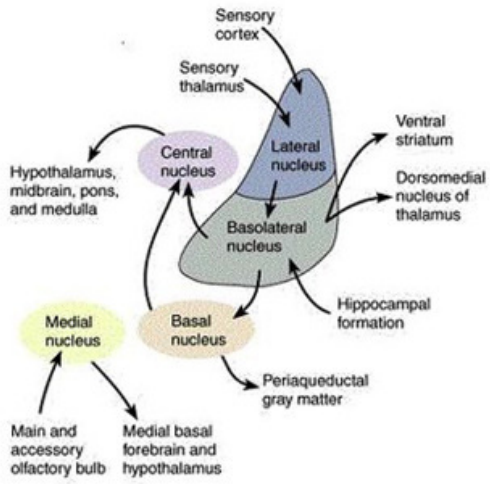


Fig.4 Diagram of the major amygdala cortical areas and their interrelationships.

Source: http://www.unifr.ch/biochem/assets/images/dreyer/research/amygdala_connections.jpg

It has been suggested that the amygdala is activated chiefly in accord with the pleasantness (‘‘valence’’) element of an odor (Zald & Pardo 1997), but the situation is not clear: some experiments suggest a prime role in intensity and not valence. For

example, in an fMRI study (Anderson et al. 2003) intensity and valence were dissociated by presenting one pleasant odor (citral; lemon), and one unpleasant odor (valeric acid; sweaty socks), each at low and high intensity. Citral smells lemony, fruity, and fragrant, and is perceived by most as pleasant (Dravnieks 1985).

It was found that amygdala activation was related only to intensity and not valence. This concept was addressed in further experiments using neutral odors of varying intensity, in addition to pleasant and unpleasant odors (Winston et al. 2005). Contrary to earlier work, neutral odors did not result in amygdala activation, only high-intensity pleasant or unpleasant odors did so, suggesting that the amygdala is concerned with an integrated combination of intensity and valence that reflects the overall behavioral salience of an odor. The contribution of the amygdala to odor memory has received scant attention until recently. A study (Buchanan et al. 2003) assessed olfactory memory in 20 patients with unilateral amygdala damage related to temporal lobe resection and one patient with selective bilateral amygdala lesions.

Fifteen odors from the University of Pennsylvania Smell Identification Test (UPSIT) were presented without response alternatives, followed one hour later by an odor–name matching test and an odor–odor recognition test. Both unilateral groups were impaired in their memory for matching odors with names, but not for odor–odor recognition. The patient with bilateral amygdala damage displayed severe impairment in both odor–name matching, as well as in odor–odor recognition memory. Importantly, none of the patients were impaired on an auditory verbal learning task, suggesting a specific impairment in olfactory memory, not merely a more general memory deficit. In common with the PC, the amygdala is probably concerned with associative learning between olfactory and visual signals. It has been proposed that the amygdala is involved with new associations but not their longterm storage (Buchel et al. 1998; Gottfried et al. 2004), a function more likely reserved for the orbitofrontal cortex as described below. The amygdala is probably concerned with emotional aspects of odor memory and these aspects may be more important than non-olfactory signals, reflecting the strong connections between the amygdala and other elements of the limbic system (Herz 2004). In summary, the corticomedial nucleus of the amygdala and PC have major input from the olfactory bulb and then connect to multiple regions, in particular the basal

ganglia, thalamus, hypothalamus, and orbitofrontal cortex. Functional imaging studies have made it clear that the earlier concept of the PC as a simple relay within the olfactory pathway is incorrect. Both the amygdala and PC respond to intensity, valence, and memory components of smell to produce an olfactory percept for analysis by tertiary centers, most notably the orbitofrontal cortex (OFC), which in turn governs behavioral responses to a given odor.

3.1 Brain systems and emotions

The neural basis of emotion has been studied for over a century. Early explorations suggested that specific brain regions are involved in the expression of emotional behavior. Studies in the '30s and '40s showed that electrodes placed in the hypothalamus elicited widespread activation of the sympathetic nervous system as well as coordinated expression of defensive reactions or presumed feelings of pleasure.

Limbic system was originally proposed to consist of interconnected subcortical structures with pathways to the hypothalamus. The limbic system was proposed to modulate the emotional quality of stimuli and support autonomic effector mechanisms associated with emotional states. A key limbic structure that has a critical role in emotional expression is the amygdala. The amygdala has an important role in evaluating the emotional valence of stimuli. Support for this view arises from extensive work done with lesions of the amygdala. For example, animals with amygdala lesions have difficulty learning associations between environmental stimuli and emotional states. They may fail to learn that a stimulus predicts reward or danger; they may fall in social rank, or show decreased affiliative behavior. Damage to other limbic structures can also produce changes in emotional behavior. An interaction exists between cortical brain regions and the limbic system. There are massive connections between cortical regions, particularly from the frontal and temporal lobes, to subcortical limbic structures. The implication of these connections is that complex sensory information processing occurring in the cortex can directly influence the limbic system. Conversely, limbic processing can strongly influence higher-level cognitive integration occurring in the

cortex. Disconnection in the transmission of information between the cortical and subcortical limbic structures can have dire consequences. For example, patients with frontal lobe lesions show inappropriate emotional and social behavior in the absence of intellectual deficits. These patients might cry or laugh inappropriately or urinate in public.

The work on Kluver–Bucy syndrome involved surgical removal of almost the entire temporal lobes in monkeys (Kluver & Bucy 1937). However, Weiskrantz & Saunders (1984) showed that bilateral lesions of the amygdala was sufficient to induce the orality, passivity, strange dietary behavior and increased exploratory tendencies of the syndrome. Removal of the amygdala also permanently disrupted the social behavior of monkeys, usually resulting in a fall in social standing. The aspiration lesions used in these early studies were anatomically inexact. However, more recent studies involving ibotenic acid lesions have provided similar results, albeit with less severe Kluver–Bucy behaviors. This line of research established the amygdala as one of the most important brain regions for emotion, with a key role in processing social signals of emotion (particularly involving fear), in emotional conditioning and in the consolidation of emotional memories. A Kluver–Bucy-like syndrome becomes apparent in humans only after more extensive bilateral damage, including the rostral temporal neocortex. One of the first studies of human amygdala lesions showed that amygdala damage can lead to impairments in the processing of faces and other social signals. This finding builds on single-unit recording studies in animals that have shown that amygdala neurons can respond differently to different faces and can respond selectively to dynamic social stimuli such as approach behavior. Later studies indicated that the processing of emotional facial expressions, especially fear, was particularly impaired in humans with amygdala lesions. This involvement of the amygdala in the processing of facial expression has been supported by functional neuroimaging studies. Morris and colleagues, using positron emission tomography (Morris et al. 1996) and Breiter and colleagues, using functional magnetic resonance imaging (Breiter et al. 1996), showed selective brain activation in the amygdala in response to the presentation of fearful faces.

The amygdala is also selective for certain emotions, especially fear, in vocal expressions. Such activation of the amygdala by fearful faces occurs even when the faces are presented so quickly that the subject is unaware of them, or are presented in the blind hemifield of patients with blindsight. Nevertheless, there is evidence that amygdala activation can be modulated by attention. Another study (Pesoa et al. 2002) showed that the amygdala did not respond differentially to emotional faces when attentional resources were recruited elsewhere, indicating that emotional processing in the amygdala is susceptible to top–down control.

3.2 Amygdala and fear conditioning

Fear conditioning in humans has been less extensively studied. However, there have been a number of important findings. One study (Angrilli et al. 1996) described a man with extensive right amygdala damage who showed a reduced startle response to a sudden burst of white noise. The patient also seemed relatively immune to fear conditioning, as this startle response was not potentiated by the presence of aversive slides to provide an emotional backdrop - a technique that reliably potentiates startle in healthy subjects. Another study (Bechara et al. 2000) described a patient with bilateral amygdala damage who again failed to fear-condition to aversive stimuli, but who could nevertheless report the facts about the conditioning experience. By contrast, another patient with hippocampal damage successfully acquired a conditioned fear response but had no explicit memory of the conditioning procedure - indicating that fear conditioning depends on the amygdala. Morris and colleagues showed that the amygdala was activated differentially in response to fear-conditioned angry faces that had been previously paired with an aversive noise, compared with angry faces that had not been paired with noise. In line with LeDoux‘s ideas, there is also evidence from functional neuroimaging that such conditioning to faces operates by a subcortical thalamo–amygdala route. Finally, as well as its role in fear conditioning, the amygdala has also been implicated in appetitive conditioning.

3.3 Amygdala and memory consolidation.

In a seminal study (Cahill et al. 1995), reported on a patient with amygdala damage who did not show the usual enhanced memory for emotional aspects of stories (compared with non-emotional aspects).This was confirmed in another patient with nearly selective amygdala damage. Subsequent PET studies showed that levels of glucose metabolism in the right amygdala during encoding could predict the recall of complex negative or positive emotional stimuli up to several weeks later. These studies indicate that the amygdala is involved in the consolidation of long-term emotional memories. As well as its role in memory, the amygdala has been associated with the modulation of other cognitive processes, such as visual perception.

3.4 Amygdala and audio stimuli

The amygdala is involved in the emotional processing of stimuli from multiple sensory modalities (Davis and Whalen 2001; Zald 2003). In the auditory modality, the amygdala has been shown to be involved in the processing of affective nonverbal vocal expressions: Involvement of the amygdala in the recognition of emotion has been suggested by functional imaging techniques using PET (Morris et al. 1999) and fMRI (Phillips et al. 1998), and case studies on patients with damage to the amygdala suggest that the amygdala supports the appraisal of auditory signals of danger (Anderson and Phelps 1998).

Following study (Koelsch et al. 2006) was using pleasant and unpleasant musical stimuli to investigate emotion. The pleasant musical excerpts were not computerized sounds but natural musical stimuli (joyful, instrumental dance-tunes recorded from commercially available CDs): eight excerpts of joyful instrumental dance-tunes from the last four centuries. Unpleasant stimuli were electronically manipulated counterparts of the original tunes (stimuli were processed using CoolEdit Pro software): for each pleasant stimulus, a new sound file was created in which the original (pleasant) excerpt was recorded simultaneously with two pitch-shifted versions of the same excerpt, the

pitch-shifted versions being one tone above and a tritone below the original pitch. One of these excerpts and his counterpart, J.S. Bach, Badinerie (Overture No. 2, BWV 1067), was used in my behavioral experiment. Unpleasant stimuli were permanently dissonant counterparts of the original musical excerpts. Permanently dissonant signals are usually perceived as more unpleasant compared to mainly consonant signals (Blood et al. 1999). Because the amygdala has been implicated in the processing of aversive stimuli, they expected that unpleasant music elicits activity changes in the amygdala.

Subjects from the study rated the original (mainly consonant) stimuli as pleasant, and the manipulated (permanently dissonant) stimuli as unpleasant. The results of this study were that by listening of consonant (pleasure) music correlated only with marginally activated amygdala, but by listening to dissonant (unpleasant) music correlated with significantly stronger activations of amygdala.

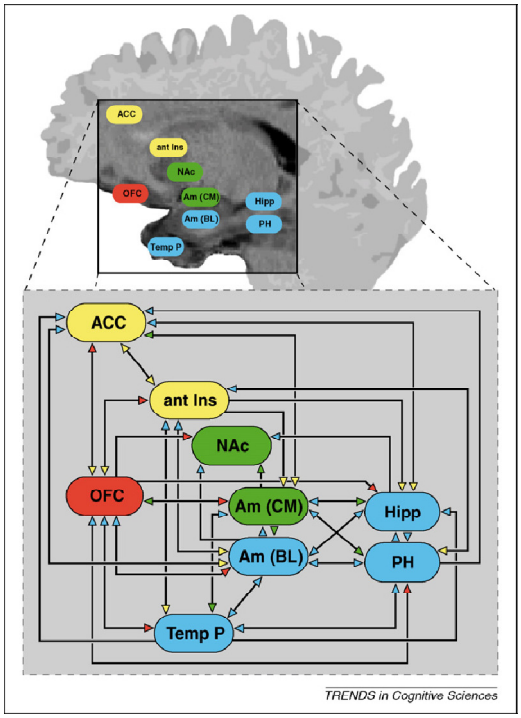


Fig. 5 Schematic representation of anatomical connections of some limbic and paralimbic structures involved in the emotional processing of music . ACC: anterior cingulate cortex; ant Ins: anterior insula; Am (BL): basolateral amygdala; Am (CM) corticomedial amygdala (including the central nucleus), Hipp: hippocampal formation; NAc: nucleus accumbens; OFC: orbitofrontal cortex; PH: parahippocampal gyrus; Temp P: temporal pole.

Source: Koelsch S. 2010. Towards a neural basis of music-evoked emotions. Trends in Cognitive Sciences, 14, 131-137.

4 Functional physiology of olfaction and emotion processing

More than any other sensory modality, olfaction is like emotion in attributing positive (appetitive) or negative (aversive) valence to the environment. Certain odors reproducibly induce emotional states (Seubert et al. 2009; Weber et al. 2008), and emotional induction modifies odor perception (Pollatos et al. 2007). Certain cerebral substrates are in fact common to emotional and olfactory processing, and this may account for the olfactory disorders encountered in psychiatric disorders such as depression or schizophrenia (Pause et al. 2008; Schneider et al. 2007). The piriform cortex projects onto the orbitofrontal cortex indirectly, via the amygdala. Functionally, odor intensity is associated with amygdala activation (Anderson et al. 2003), as is response to aversive stimuli. The amygdala is also a strategic bridge integrating olfactory and neuroendocrine stimuli to modulate feeding behavior.

One essential function of the amygdala is rapid, sometimes non-conscious, detection of emotional signals, especially of threat. Closely connected to the hippocampus, the amygdala plays a key role in emotional memory: i.e., enhanced memory performance for events associated with emotion (Hamann 2001), including emotions elicited by odor (Pouliot & Jones-Gotman 2008).

The amygdala complex is located anteriorly, superiorly and medially to the head of the hippocampus and comprises several graymatter nuclei composing two main structures: the medial and the basolateral amygdala. Phylogenetically, the medial amygdala is the older and evolved from the olfactory system to extend its threat-detection capability to other sensory modalities (LeDoux 2007), it is essential in the perception and expression of fear (Whalen et al. 2004). Activation recruits brain centers involved in anxiety symptoms: hypervigilance and vegetative symptoms. The basolateral amygdala receives multiple sensory afferents, which take on a negative valence as they are processed; its activity can be regulated by the prefrontal cortex during subjective awareness of emotion. The secondary olfactory cortex is located mainly in the insula and entorhinal cortex, the hippocampus input area. Olfactory stimulation was reported to lead to activation of the entorhinal cortex, but independently of valence (Anderson et al. 2003).

On the medial face of the temporal lobe, the fifth temporal circumvolution is part of the limbic system. It comprises the hippocampus above and the parahippocampal gyrus below, separated by a transitional area called the subiculum. The hippocampus is composed of two mainly parallel open tubes: Ammon's horn and the enclosed dentate gyrus; it shows great neuroplasticity, and is phylogenetically older (archeocortex) than it adjacent parahippocampal neocortex. It plays a fundamental role in long-term memory, response to stress and contextualization of emotional experience. The entorhinal cortex is part of the parahippocampal gyrus, but is the main hippocampal input structure, a pathway along which information converges to be memorized. The hippocampus is one of the most widely studied brain structures in the physiopathology of depression. Two independent MRI meta-analyses found it to be smaller in depressed patients (Videbech & Ravnkilde 2004). It also plays a critical role in autobiographical memory, which is impaired in depressed subjects, even in remission (Lemogne 2006).

The secondary olfactory cortex receives fibers from the primary olfactory areas, and is mainly located in the insula and entorhinal cortex. Exploration of brain activation to pleasant and unpleasant odor stimuli finds activation of the insula (Rolls et al. 2010). Apart from its role in olfaction, the insula is involved in processing aversive emotion and in integrating bodily sensation in the assessment of emotional status. It is invisible from outside the brain, on the floor of the fissure of Sylvius. Covered by the frontal, parietal and temporal opercula, which form its edges, it constitutes the fifth lobe of the brain and also includes the primary taste area. In network with the neocortex, limbic system and central gray nuclei, it plays an important role in the perception of intrusion signals such as disgust and pain, contributing to unifying their sensory and emotional dimensions (Paulus & Stein 2006). It also plays a role in social cognition: relating observation of the reactions of others (mimicry, movement) to associated emotional experience, it underlies the affective resonance component of empathy.

The anterior cingulate cortex, also known as the limbic lobe, is activated by olfactory stimulation; according to some reports, this activation is independent of valence, while according to others the anterior cingulate cortex is activated only in response to pleasant odors (Fulbright et al. 1998). The anterior cingulate cortex is involved in detecting conflicts of attention; it underlies the emotional dimension of physical pain and moral

pain and social distress in situations of separation or exclusion (Eisenberger et al. 2003). The piriform cortex projects onto the orbitofrontal cortex directly or indirectly via the amygdala. The olfactory contingent of the amygdala projects onto the orbitofrontal cortex. Functionally, the orbitofrontal cortex is involved in odor identification and olfactory memorization (Zald & Pardo 1997; Zald et al. 2002). According to certain authors, aversive stimuli are associated with left and more pleasant stimuli with right orbitofrontal cortex activation; according to others, olfactory stimulation elicits orbitofrontal cortex activation, but independently of valence (Grabenhorst et al. 2007).

Anteriorly to the central sulcus (fissure of Rolando), the frontal lobe is in close relation with the thalamus and central gray nuclei via five frontal-subcortical-frontal loops, which regulate the frontal lobe's motor, oculomotor, cognitive, emotional and motivational functions. Posteriorly to anteriorly, the frontal lobe comprises the motor cortex, controlling movement, the premotor cortex, which prepares movement, and the prefrontal cortex.

The prefrontal cortex is the most anterior art of the brain, constituting one-third of the human cortex. It has no sensory afferents or motor efferents, but integrates information preprocessed by the associative sensory areas and the limbic system. Schematically, the prefrontal cortex can be divided in three: dorsolateral, orbitoventral and medial.

The dorsolateral prefrontal cortex underlies short-term memory and executive functions (planning, mental flexibility, inhibition). It takes the subject beyond immediate perception, enabling projection in time (Wheeler et al. 1997) and, in network with the hippocampus (involved in longterm memory), suppression of undesirable memories (Anderson 2004). In network with the central gray nuclei, the medial prefrontal cortex supports motivation; it enables anticipation of reward and self-initiation of action. Medial prefrontal cortex lesions induce apathy and even akinetic mutism. In network with the posterior cingulate cortex, it also plays an important role in social cognition: it underlies self-representation, attribution of emotional valence to odors (Rolls et al. 2010) and personalization of emotion.

The prefrontal orbitoventral cortex, or orbitofrontal cortex, comprises the inferior side of the superior, medial and inferior frontal convolutions and the gyrus ectus (the most medial) and secondary olfactory cortex (the most posterior). Connected to the limbic system by the cingulate cortex, it processes the somatic markers of the autonomic nervous system associated with emotional context (Bechara et al 2000; Koch 2007) and integrates emotion into cognition in decision-making (Bechara et al 2000). It subordinates reptilian system fixed action patterns to rules established by the dorsolateral prefrontal cortex. Orbitofrontal cortex lesions induce errors of judgment and personality disorders such as acquired sociopathy (Bechara et al. 2000).

5 Study

5.1 Introduction to study

The processing of happy faces compared with baseline is associated with an increased activation in the right middle occipital gyrus, left precuneus, **left amygdala**, left insula, left medial frontal gyrus, left putamen, left cerebellum, bilateral supramarginal gyrus and left middle temporal gyrus (Fusar-Poli 2009).

During the processing of fearful faces compared with baseline, there is a significant increase of neural activation in the **bilateral amygdala** and fusiform gyrus, right cerebellum, left inferior parietal lobule, left inferior frontal and right medial frontal gyrus. In other words, it is possible to conclude that amygdala engagement during processing of fearful faces is a strong and consistent finding in the available fMRI literature (Fusar-Poli 2009). Such a result is in line with evidence suggesting that the amygdala is specifically sensitive to fearful emotional processing (Adolphs 2008).

As mentioned above, amygdala can be activated also by listening to music. The findings indicate that activations of amygdala, parahippocampal gyrus, and temporal poles are significantly stronger during the listening to dissonant music like to consonant music (Koelsch 2006).

Findings and results from fMRI study by Anderson et al. (2003) showed that amygdala activation was related only to intensity and not valence, what could result in **influencing of processing of implicit emotions on intensity of olfactory perception.**

Amygdala is not a homogeneous one-function structure, but a network of high interconnected nuclei (about 20). Its olfactory input area (medial cortical nucleus) is different that hipocampampal (visual and audio) input (basolateral complex), but there is a bidirectional connection between this two nuclei, what could cause the proposed influences of this two cognitive phenomena.

5.2 Methods

Behavioral study.

5.3 Participants

189 students of medicine (133 females age range 19–29 years, mean 22.6 years, 56 males age range 19–26 years, mean 22.3 years) participated in the study after giving written informed consent. 189 students participated in the first and second block and 102 of them participated also in third block. None of the subjects had any acute respiratory diseases or were a strong smoker.

5.4 Stimuli

As visual stimuli were used pictures from The Ekman 60 Faces Test, which uses a range of photographs from the Ekman and Friesen series of Pictures of Facial Affect (Ekman & Friesen 1976), which has been the most widely used and validated series of photographs in facial expression research. From this series, two faces were chosen, each displaying one of basic emotions (happiness or fear).

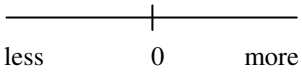
As audio stimuli were used one consonant musical excerpt and his dissonant counterpart, J.S. Bach, Badinerie (Overture No. 2, BWV 1067), used and tested in above mentioned qualitative study (Koelsch et al. 2006).

5.5 Procedure

To comply the exact same audiovisual stimuli in every block software application based on JAVA Swing framework was developed and used.

5.5.1 First block

In the first block participants (133 females, 56 males) got a short introduction about the study and they were asked to sniff on an odor probe (jasmine) for a second or two, long enough to realize the intensity of the odor probe. Immediately after the sniff they were exposed to audiovisual stimuli (**happy face expression, showed on a black screen and consonant musical excerpt**). After 15 seconds of their concentration on audiovisual stimuli they were asked to sniff again (on the same way, just as long and powerful as at the first sniff) the next odor probe, which was the same quality and concentration like the first one, what was not conveyed information to participants. The audiovisual stimuli were present also next 15 second, in the time where the next decision tasks were made. After the second sniff (to the same odor probe) they have to evaluate, if the second odor probe was the same, lower or higher concentration. This they have to mark on a scale:



After that they had to recognize the emotion of showed face expression, choosing one of following emotions: happiness, disgust, fear and neutral. Next task was to decide if the music excerpt was perceived as pleasurable or unpleasurable music.

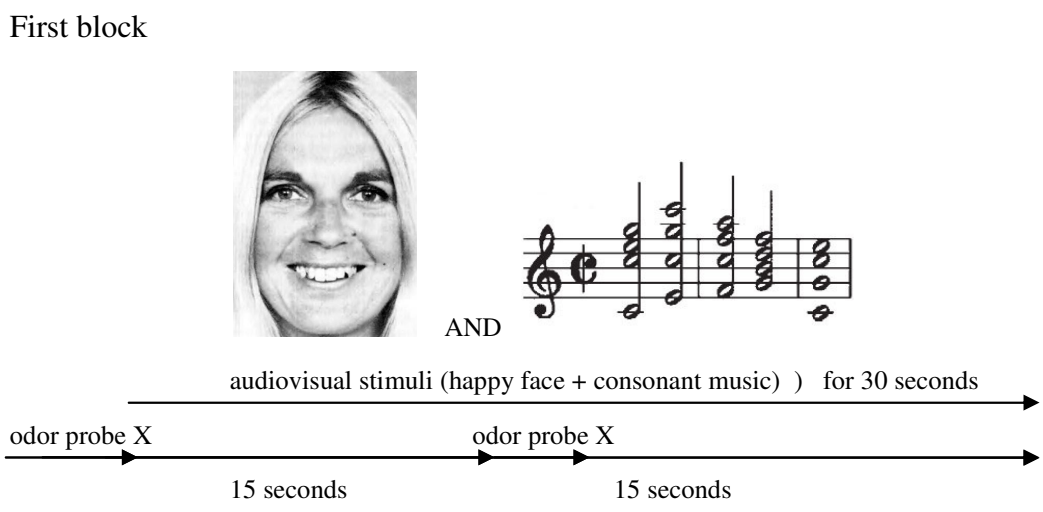
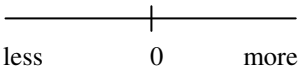


Fig. 6 Setup of the first block

5.5.2 Second block

In the second block participants (133 females, 56 males) were asked to sniff to odor probe (citral; lemon) for a second or two, long enough to realize the intensity of the odor probe. Immediately after the sniff they were exposed to audiovisual stimuli (**fear face expression, showed on a black screen and dissonant musical excerpt**). After 15 seconds of their concentration on audiovisual stimuli they were asked to sniff again (on the same way, just as long and powerful as at the first sniff) on the next odor probe, which was the same quality and concentration like the first one, what was not conveyed information to participants. The audiovisual stimuli were present also next 15 second, in the time where the next decision tasks were made. After the second sniff (to the same odor probe) they have to evaluate, if the second odor probe was the same, lower or higher concentration. This they have to mark on a scale:



After that they had to recognize the emotion of showed face expression, choosing one of following emotions: happiness, disgust, fear and neutral. Next task was to decide if the music excerpt was perceived as pleasurable or unpleasurable music.

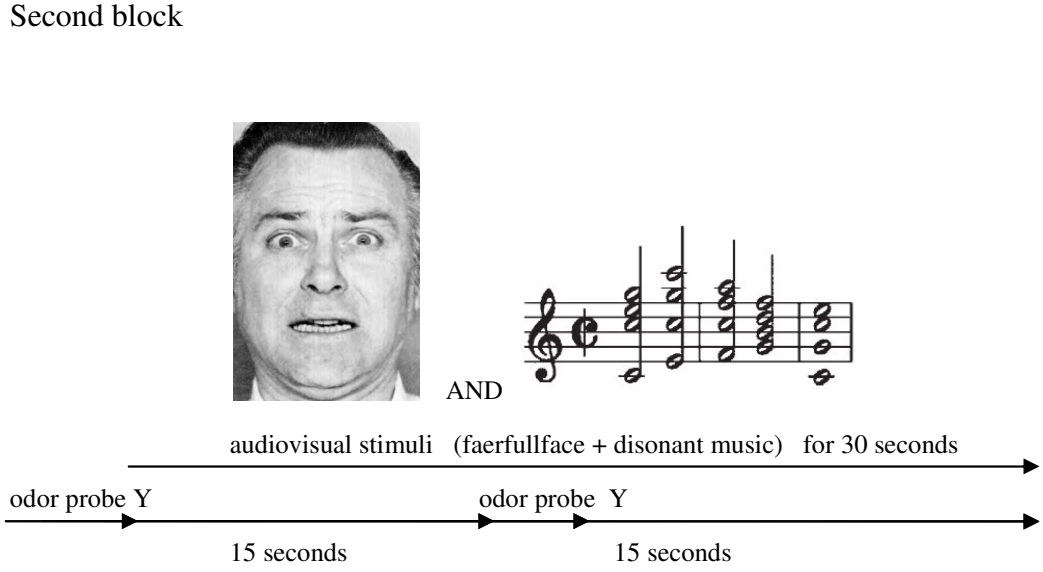


Fig. 7 Setup of the second block

5.5.3 Third block (Control group)

In the third block participants (73 females, 29 males) were asked to sniff to odor probe (citral; lemon or jasmine) for a second or two, long enough to realize the intensity of the odor probe. Immediately after the first sniff they were asked to close their eyes, so they weren't exposed to any audiovisual stimuli. After 15 seconds they were asked to sniff again (on the same way, just as long and powerful as at the first sniff) on the next odor probe, which was the same quality and concentration as the first one, what was not conveyed information to participants. After the second sniff (to the same odor probe) they have to evaluate, if the second odor probe was the same, lower or higher concentration, what they had to report just verbally.

5.6 Results

5.6.1 Statistics

All of in the next section presented results were tested using chi-square test of independence in contingency table with significance level of 5%. In every case the null hypothesis, about absence of no influence of emotions processing on perception of intensity of an odor was denied, so the presented results are statistically relevant.

	less	neutral	more
First block	59	31	99
Second block	42	48	99
Third block	25	59	18

Tab. 1 Contingency table

5.6.2 First block

In the first block evaluated 52% of all paricipants (99) the second odor probe as more intensive as the first odor probe. 31% of participants (59) evaluated the second odor probe as less intensive as the first odor probe and 17% of paricipants (31) evaluated the second odor probe as equal intensive as the first odor probe.

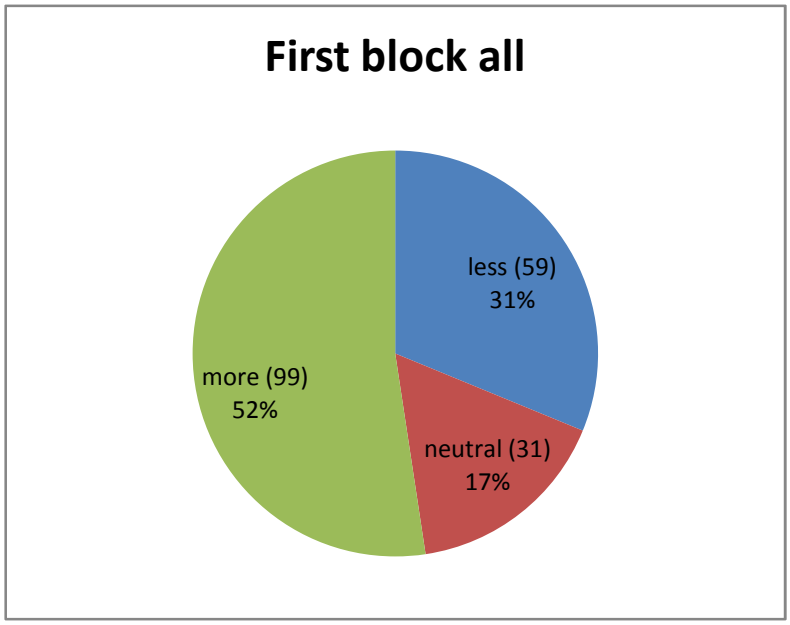


Fig. 8 Percentage and numbers of all participants in the first block

92 % of the participants (173) evaluated the musical excerpt as pleasure and every particiant, who evaluated the face expresion wrong (not a happy face), were excluded from the resuting.

In the first block evaluated 51% of females (68) and 55% of males (31) the second odor probe as **more intensive** as the first odor probe. 30% of females (40) and 34% of males (19) evaluated the second odor probe as less intensive as the first odor probe and 19% of females (25) and 11% of males (6) evaluated the second odor probe as equal intensive as the first odor probe.

	Less	neutral	more	∑
females	40	25	68	133
males	19	6	31	56
all	59	31	99	189

Tab. 2 Numbers of participants and their results in the first block

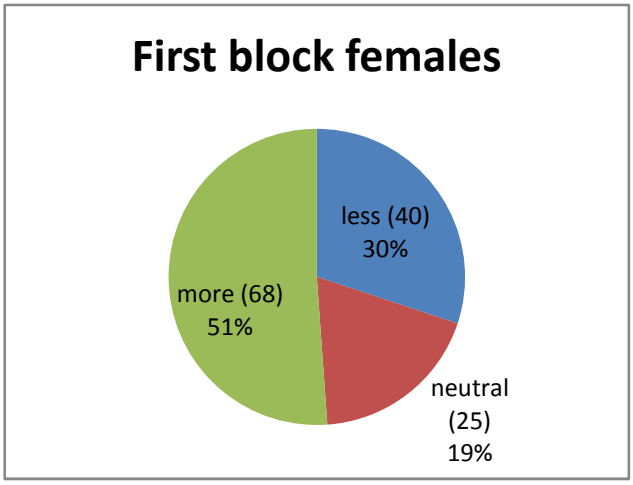


Fig.9 Percetage and numbers of females in the first block

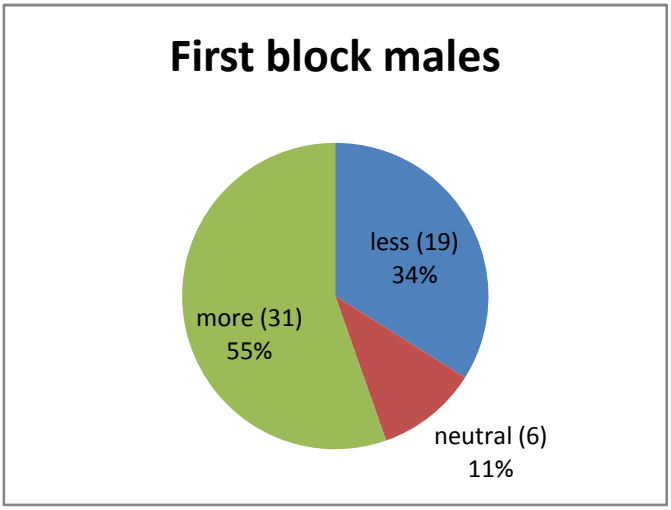


Fig.10 Percentage and numbers of males in the first block

5.6.3 Second block

In the second block evaluated 52% of participants (99) the second odor probe as more intensive as the first odor probe. 22% of paricipants (42) evaluated the second odor probe as less intensive as the first odor probe and 26% of participants (48) evaluated the second odor probe as equal intensive as the first odor probe.

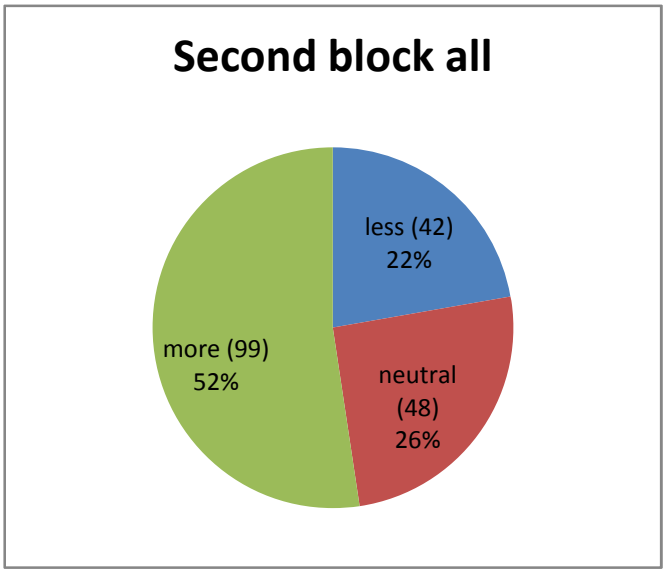


Fig.11 Percentage and numbers of all participants in the second block

91 % of the participants (172) evaluated the musical excerpt as pleasure and every particiant, who evaluated the face expresion wrong (not a fearful face), were excluded from the resuting.

In the second block evaluated 51% of females (68) and 55% of males (31) the second odor probe as more intensive as the first odor probe. 20% of females (27) and 27% of males (15) evaluated the second odor probe as less intensive as the first odor probe and 29% of females (38) and 18% of males (10) evaluated the second odor probe as equal intensive as the first odor probe.

	Less	neutral	more	∑
females	27	38	68	133
males	15	10	31	56
all	42	48	99	189

Tab. 3 Numbers of participants and their results in the second block

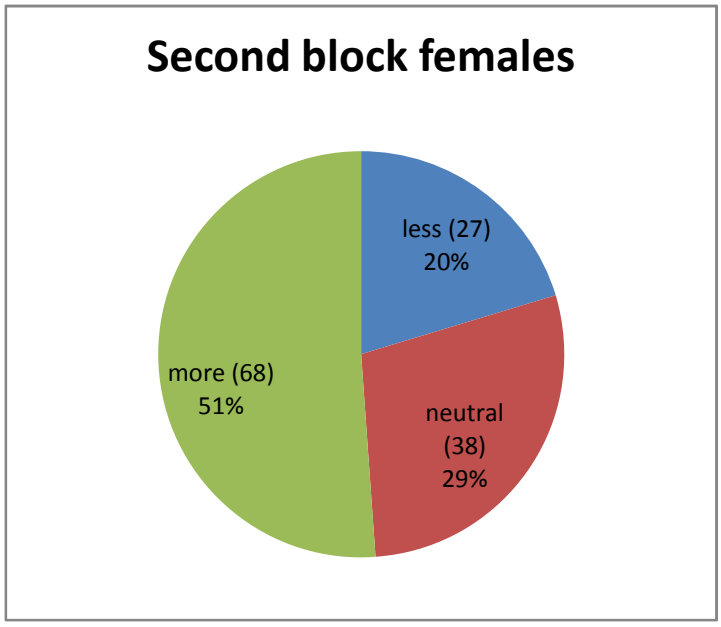


Fig.12 Percetage and numbers of females in the second block

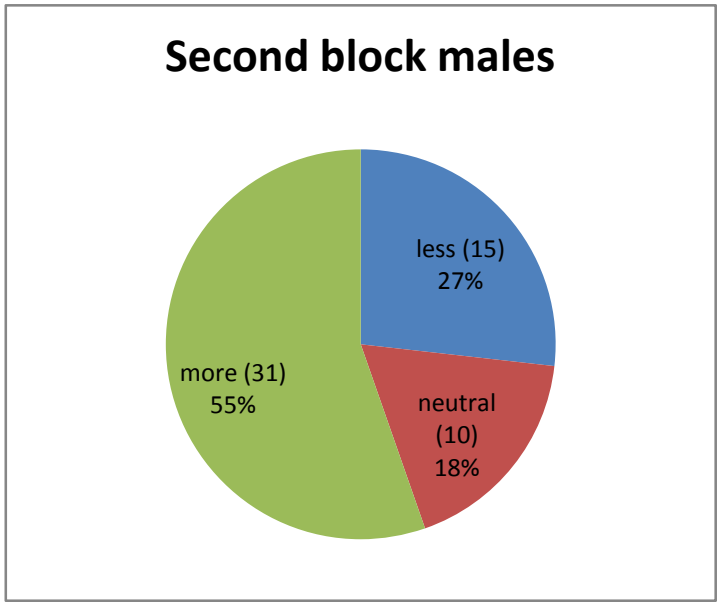


Fig.13 Percetage and numbers of males in the second block

5.6.4 Third block (Control group)

From 102 participants, who participated in the third block, 18% of them (18) evaluated the second odor probe more intensive as the first odor probe. 24% of participants (25) evaluated the second odor probe as less intensive as the first odor probe and 58% of participants (59) evaluated the second odor probe as equal intensive as the first odor probe.

	Less	neutral	more	∑
females	15	45	13	73
males	10	14	5	29
all	25	59	18	102

Tab. 4 Numbers of participants and their results in the third block

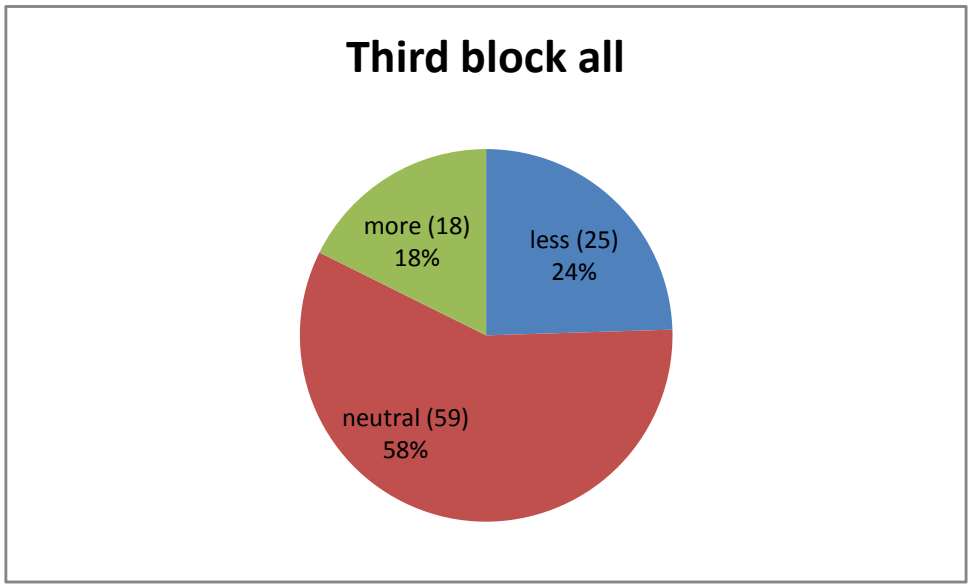


Fig.14 Percentage and numbers of all participants in the third block

5.6.5 All blocks comparison

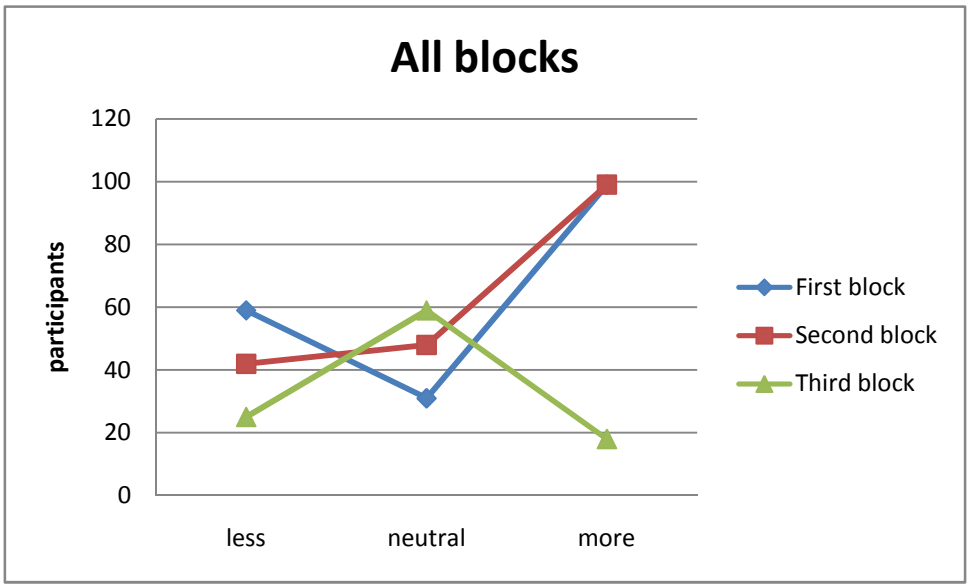


Fig.15 Numbers of all participants and their results in all three blocks

Although in the third block participated just 102 participants, the percentage value can be compared with percentage of first and second block (189 participants), because of the statistical relevance confirmed with chi-square test.

	less	neutral	more
First block	31%	17%	52%
Second block	22%	26%	52%
Third block	24%	58%	18%

Tab. 5 Percentage of all three blocks

As we can see in the graph the results of the third block are in contrast with the results of the first and second block results. In the first block just 17% and 26% in the second block of the participants evaluated the second odor probe as the same intensity as the first one. Compared to the results of the third block, where 58% of participants

evaluated the second odor probe as the same intensity as the first one, what is a significant disproportion.

In the first and second block evaluated 52% of participants the second odor probe as more intensive as the first one, what is in contrast with results of the third block, where just 18% of participants evaluated the second odor probe as more intensive as the first one, what is the next significant disproportion.

In the first block evaluated 31% of participants the second odor probe as less intensive as the first one and in the second block evaluated 22% of participants the second odor probe as less intensive as the first one, what is in harmony with results of the third block, where 24% of participants evaluated the second odor probe as less intensive as the first one.

These disproportions of decisions distribution of participants will be discussed in the next section.

5.7 Discussion

Studies in human and nonhuman animals suggest that the amygdala may be responsive to the valence properties of both unpleasant and pleasant events. Electrophysiological studies have shown that the rat amygdala is important for acquiring both unpleasant and pleasant associations with once neutral stimulus events (LeDoux 1995; Davis 1992; Gallagher 2000). Neuroimaging studies show the human amygdala is responsive to both positive sexually provocative and negative scenes (Hamann 2002). These bivalent responses could reflect that the amygdala codes both pleasant and unpleasant valence (Hamann 2002), or rather that it codes the intensity of experience regardless of valence.

As mentioned above processing happy faces and listening to consonant music correlate with activations of the left amygdala, processing fearful faces and listening to dissonant music correlate with a significant activation of bilateral amygdala.

Another function of amygdala is to give an intensity vector of appraisal stimuli. **Based on these findings we can assume that, activations of amygdala have to correlate with increasing subjective perceiving intensity of an odor. This is in harmony with the results of this study.** This trend can be found across all participated subjects.

All this findings show the very strong interaction of emotions processing and olfactory perception. Olfaction can reproduce emotions and moods, but there is also an evidence of influence of emotions processing on intensity but also valence of olfactory perception.

No statistically significant gender differences in influencing of implicit emotions processing on intensity perceiving of an odor could be found in this study.

6 Concept of an odor based on emotion theory

This intensity-driven response of the amygdala is thought to extend to how emotion influences memory formation (Hamann 1999; Cahill, 1998). The presented study focused on olfaction and its implication for other sensory modalities and cognitive processes.

The anatomy of the olfactory system (Price 1999) suggests that initial intensity coding may occur in primary olfactory regions, which include the amygdala and piriform cortex. Higher-order hedonic encoding may occur in secondary olfactory regions, which includes the orbitofrontal cortices. **This division of the neural representation of affective space into more primary intensity and higher-order valence components is compatible with the notion that the amygdala supports low-level stimulus-driven processing (Whalen 1999).** Amygdala responsiveness to odor intensity, a correlate of stimulus properties coded at the olfactory epithelium, may be a reflection of its rapid but more basic analysis of potentially important environmental events. In contrast to amygdala responsiveness to intensity independent of valence, orbitofontal responsiveness to valence independent of intensity demonstrates a higher-order differentiation of hedonic dimensions, with separate orbitofrontal areas extracting information about the pleasant and unpleasant properties of stimulus events.

Neutral odors did not result in amygdala activation, only high-intensity pleasant or unpleasant odors did so, suggesting that the amygdala is concerned with an integrated combination of intensity and valence that reflects the overall behavioral salience of an odor.

Thus, the presented results support the suggestion for a major division of the neural representation of affective space into lower-order intensity and higher-order hedonic components. Whereas hedonic responses are relatively preserved in patients with amygdala lesions (Anderson 2002), prefrontal damage often significantly impacts hedonic tone (Davidson 1999; Robinson 1984). Recent studies highlight the critical role of the orbitofrontal regions of the prefrontal cortices in particular (Davidson 1999;

Bechara 1994). **Such critical prefrontal contributions to hedonicity dovetail nicely with appraisal theories of human emotion, which emphasize that affective responses are not a simple reflection of the intrinsic quality (positive or negative) of a stimulus, but rather result from interactions among the person, the situational context and the stimulus (Lazarus 1991).** Such flexibility of hedonic response is a hallmark of orbitofrontal representations, which are modulated by changes in affective relevance, as in the hungry versus sated state of the perceiver (O'Doherty 2000). Thus, unlike the evolutionarily conserved functions of the amygdala, it seems that the malleability of human hedonic experience is characteristic of the more flexible, integrative and evolved functions of the prefrontal cortices.

6.1 Appraisal theory

In appraisal theory, emotion is argued to arise from patterns of individual judgment concerning the relationship between events and an individual's beliefs, desires and intentions, sometimes referred to as the person-environment relationship (Lazarus 1991). These judgments, formalized through reference to devices such as situational meaning structures or appraisal variables (Frijda 1987), characterize aspects of the personal significance of events. Patterns of appraisal are associated with specific physiological and behavioral reactions. In several versions of appraisal theory, appraisals also trigger cognitive responses, often referred to as coping strategies—e.g., planning, procrastination or resignation—feeding back into a continual cycle of appraisal and re-appraisal (Lazarus 1991).

6.2 Computational models of appraisal theory

Appraisal theory is a predominant force among psychological perspectives on emotion and arguably the most fruitful source for the design of symbolic AI systems, as it

emphasizes and explains the connection between emotion and cognition. Indeed, the large majority of computational models of emotion stem from this tradition.

Work in computational models of emotion impacts research in human emotion by transforming how theories are formulated and evaluated. One way this occurs is through a process of concretizing concepts in the theory. Psychological theories of emotion have typically been cast at an abstract level and through informal (natural language) descriptions. **Concepts** in the theory are usually not defined formally, and how processes work may not be laid out in systematic detail. The structures and processes of the theory must be explicitly and formally defined in order to implement them in a computational model, thus making a computer model a particularly concrete realization of the theory (Marsella et al. 2010).

Olfaction can be seen as a part of such model. A cognitive agent with implemented E-nose (artificial neural network (ANN) coupled with artificial chemosensors) can cope with his environment more relevant than without. Because of the multidimensionality (valence, intensity, familiarity - agent's former relation of this odor to his environment) of an odor, gives the agent a new point of view for further reasoning. Olfaction may also provide information about the underlying dimensions along which people appraise the emotional significance of events: valence, intensity, certainty, expectedness etc.

Findings on the functional, often adaptive role that emotions play in human behavior have motivated AI and robotics research to explore whether computer analogues of human emotion can lead to more intelligent, flexible and capable systems. Early work by Simon (Simon 1967) argued that emotions serve the crucial function of interrupting normal cognition when unattended goals require servicing.

Models of emotion and affective expression have been incorporated into virtual humans, software artifacts that look and act like humans, capable of perception and action in a virtual world that they can co-habit with people.

6.2.1 Component Model and an odor

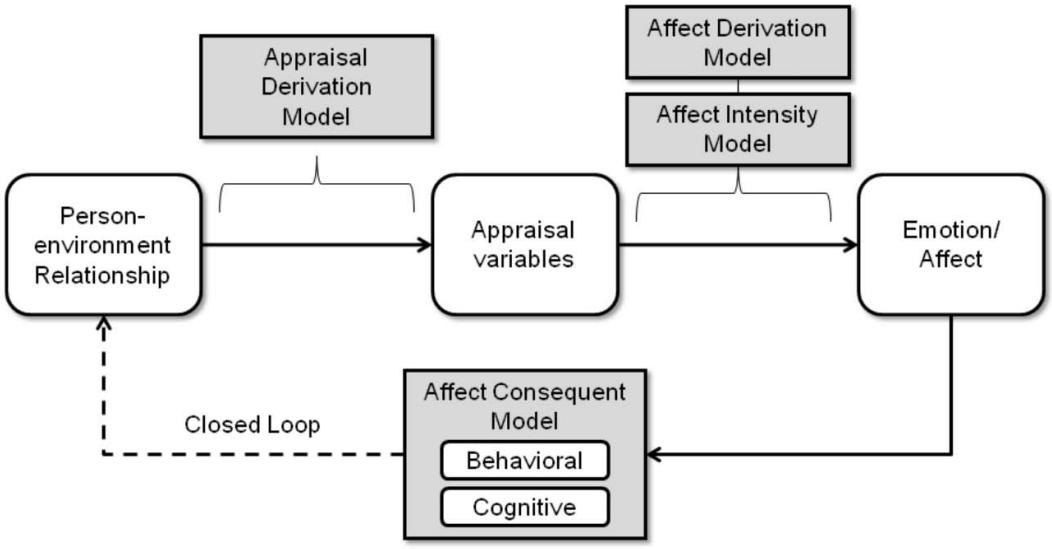


Fig. 16 This scheme presents an idealized computational appraisal architecture consisting of a set of linked component models and what we see as natural joints at which to decompose appraisal systems into coherent and often shared modules, though any given system may fail to implement some of these components or allow different information paths between components. In this architecture, information flows in a cycle as argued by several appraisal theorists (Lazarus 1991; Scherer 2001): some representation of the person-environment relationship is appraised; this leads to an affective response of some intensity; the response triggers behavioral and cognitive consequences; these consequences alter the person-environment; this change is appraised; and so on. Each of these stages can be represented by a model that represents or transforms state information relevant to emotion-processing.

Source: Marsella S, Gratch J, Petta P. 2010. Computational Models of Emotion. Blueprint for Affective Computing A Source Book, Volume: 3, Publisher: Oxford University Press, Pages: 1598-1602

Person-environment relationship: Lazarus (1991) introduced this term to refer to some representation of the agent's relationship with its environment. This representation should allow an agent, in principle, to derive the relationship between external events (real or hypothetical) and the beliefs, desires and intentions of the agent or other significant entities in the (real or hypothetical) social environment (Marsella et al. 2010).

Odor processing role in person-environment relationship:

An odor can be seen as emotion, so his multidimensionality (valence, intensity and familiarity - agent's former relation of this odor to his environment) can represent the relationship of the agent's relationship with its environment and gives the agent a new point of view to its beliefs, desires and intention

Appraisal-derivation model: An appraisal-derivation model transforms some representation of the person-environment relationship into a set of appraisal variables. For example, if an agent's goal is potentially thwarted by some external action, an appraisal-derivation model should be able to automatically derive appraisals that this circumstance is undesirable, assess its likelihood, and calculate the agent's ability to cope, i.e., by identifying alternative ways to achieve this goal (Marsella et al. 2010).

Odor processing role in appraisal-derivation model:

The major contribution of odor processing is in appraisal derivation. If the agent finds out, that in his environment is an odor of special valence (pleasant, unpleasant or an odor coupled with a previous emotional event) he can better derivate appraisal variables, used in further reasoning.

Appraisal variables: Appraisal variables correspond to the set of specific judgments that the agent can use to produce different emotional responses and are generated as a result of an appraisal-derivation model (Marsella et al. 2010).

Odor processing role and appraisal variables:

Affective valence, stressfulness, motivational congruence, expectedness, coping potential, uncertainty, causation and norm compatibility may by cross-culturally valid appraisal variables (Frijda 1995; Scherer 1997). Olfaction can take a part to the determination of these variables, because of its dimension of valence, stress-relevance, conduciveness to goals or needs and coping potential.

Affect-derivation Model: An affect-derivation model maps between appraisal variables and an affective state, and specifies how an individual will react emotionally once a pattern of appraisals has been determined (Marsella et al. 2010).

Odor processing role in Affect-derivation Model:

There are different approaches of implementation how models define emotion and the contribution of olfaction depends on this implementation e.g. mapping of appraisal variables into discrete emotion labels.

Affect-Intensity model: An affect-intensity model specifies the strength of the emotional response resulting from a specific appraisal. There is a close association between the affect-derivation model and intensity model (the intensity computation is often implemented as part of the affect-derivation model). Intensity models usually utilize a subset of appraisal variables (e.g., most intensity equations involve some notion of desirability and likelihood) (Marsella et al. 2010).

Odor processing role in Affect-Intensity model:

Olfaction contribution to affect-intensity model depends on the situation to be solved e.g. in the environment is a evidence of some harmful gas, so the intensity of affect have to increase.

Emotion/Affect: Affect is a representation of the agent's current emotional state. This could be a discrete emotion label, a set of discrete emotions, core affect (i.e., a continuous dimensional space), or even some combination of these factors. An important consideration in representing affect, particularly for systems that model the consequences of emotions, is if this data structure preserves the link between appraisal factors and emotional state (Marsella et al. 2010).

Affect-consequent model: An affect-consequent model maps affect (or its antecedents) into some behavioral or cognitive change. Consequent models can be usefully described in terms of two dimensions, one distinguishing if the consequence is inner or outer directed (cognitive vs. behavioral), and the other describing whether or not the consequence feeds into a cycle (i.e., is closed-loop) (Marsella et al. 2010).

7 Conclusion

In the last few decades, a growing scientific literature has documented various emotional effects of odors (Ehrlichman and Bastone 1992; Herz 2002). By using a large variety of approaches, research investigating the relation between odor and affective phenomena (Chrea et al. 2009) showed, for example, that odor experience is inextricably linked to odor hedonic tone and, thus, is likely to influence mood such that pleasant odors tend to induce positive moods, whereas unpleasant odors tend to induce negative moods (Schiffman et al. 1995; Retiveau et al. 2004). Numerous experiments also showed that odors produce effects on cognition and behavior that are similar to those produced by emotional stimuli in other perceptual modalities (Ludvigson and Rottman 1989; Degel and Koster 1999; Millot and Brand 2001; Millot et al. 2002; Chebat and Michon 2003). In addition, odor experience has been shown to provoke changes in physiological parameters, such as heart rate or skin conductance, which are directly involved in the emotional response (Robin et al. 1999; Heuberger et al. 2001; Bensafi et al. 2002a, 2002b, 2002c; Pössel et al. 2005). Finally, odors can evoke autobiographical memories that are emotionally intense and long forgotten (Chu and Downes 2000). These effects are usually interpreted as an interdependence of olfaction and emotion on overlapping neural systems (Phillips and Heining 2002), which has been confirmed with neuroimaging evidence (Royet et al. 2003; Herz, Eliassen, et al. 2004).

The interdependency of implicit emotions processing on an intensity of an odor was also confirmed with the results of above mentioned behavioral Study. These results showed a significant evidence of emotions processing influence on intensity of an odor, suggesting that activation of amygdala correlates with increasing perception of odor intensity. The neural representation of affective space into more primary intensity and higher-order valence components is compatible with the notion that the amygdala supports low-level stimulus-driven processing (Whalen 1999).

These findings dovetail nicely with appraisal theories of human emotion, which emphasize that affective responses are not a simple reflection of the intrinsic quality

(positive or negative) of a stimulus, but rather result from interactions among the person, the situational context and the stimulus (Lazarus 1991).

An idealized computational model of appraisal theory (Marsella et al. 2010), which formalizes this theory was used, to show how theoreticaly an odor fits to this concept.

8 References

Adolphs R. 2008. Fear, faces, and the human amygdala. Curr Opin Neurobiol, 18:166-172.

Adolphs R, Tranel D, Hamann S et al. 1999. Recognition of facial emotion in nine individuals with bilateral amygdala damage. Neuropsychologia 37, 1111–1117.

Anderson AK, Phelps EA. 1998. Intact recognition of vocal expressions of fear following bilateral lesions of the human amygdala. Neuroreport 9, 3607–3613.

Adolphs R, Gosselin F, Buchanan TW et al. 2005. A mechanism for impaired fear recognition after amygdala damage. Nature 433, 68–72.

Adrian ED. 1942. Olfactory reactions in the brain of the hedgehog. Journal of Physiology, 100,459–73.

Poellinger A, Thomas R, Lio P et al. 2001. Activation and habituation in olfaction – an fMRI study.Neuroimage, 13(4), 547–60.

Anderson AK & Phelps EA. 2002. Is the human amygdala critical for the subjective experience of emotion? Evidence of intact dispositional affect in patients with amygdala lesions. J. Cogn. Neurosci. 14, 709–720.

Anderson AK, Christoff K, Stappen I et al. 2003. Dissociated neural representations of intensity and valence in human olfaction. Nat Neuroscience, 6:196—202.

Anderson MC. 2004. Neural systems underlying the suppression of unwanted memories. Science, 303:232—5.

Angrilli A et al. 1996. Startle reflex and emotion modulation impairment after right amygdala lesion. Brain 119, 1991–2000.46.

Bechara A, Damasio AR, Damasio H & Anderson SW. 1994. Insensitivity to future consequences following damage to human prefrontal cortex. Cognition 50, 7–15.

Bechara A, Tranel D, Damasio H & Adolphs R. 1995. Double dissociation of conditioning and declarative knowledge relative to the amygdala and hippocampus in humans. Science 269, 1115–1118.

Bechara A, Damazio H, Damasio AR. 2000. Emotion, decision making and the orbitofrontal cortex. Cereb Cortex;10:295— 307.

Bensafi M, Rouby C, Farget V, Bertrand B, Vigouroux M, Holley A. 2002a. Autonomic nervous system responses to odours: the role of pleasantness and arousal. Chem Senses. 27:703–709.

Bensafi M, Rouby C, Farget V, Bertrand B, Vigouroux M, Holley A. 2002b. Influence of affective and cognitive judgments on autonomic parameters during inhalation of pleasant and unpleasant odors in humans. Neurosci Lett. 319:162–166.

Bensafi M, Rouby C, Farget V, Bertrand B, Vigouroux M, Holley A. 2002c. Psychophysiological correlates of affects in human olfaction. Neurophysiol Clin. 32:326–332.

Breiter HC et al. 1996. Response and habituation of the human amygdala during visual processing of facial emotion. Neuron 17, 875–887.

Buchanan TW, Tranel D and Adolphs R. 2003. A specific role for the human amygdala in olfactory memory. Learning and Memory, 10(5), 319–25.

Buchel C, Morris J, Dolan RJ and Friston KJ. 1991. Brain systems mediating aversive conditioning: an event-related fMRI study. Neuron, 1998, 20(5), 947–57.

Buck L and Axel R. 1991. A novel multigene family may encode odorant receptors: A molecular basis for odor recognition. Cell 65, 175–187.

Cahill L, Babinsky R, Markowitsch HJ & McGaugh, JL. 1995. The amygdala and emotional memory. Nature 377, 295–296.

Cahill L & McGaugh JL. 1998. Mechanisms of emotional arousal and lasting declarative memory. Trends Neurosci., 21, 294-9.

Cleland TA and Linster C. 2003. Central Olfactory Structures. In: Handbook of Olfaction and Gustation, 2nd edn. (ed. R. L. Doty), pp. 165–180. Dekker.

Crick F, Koch C. 2003. A framework for consciousness. Nat. Neurosci. 6: 119–126.

Chebat JC, Michon R.2003. Impact of ambient odors on mall shoppers'emotions, cognition, and spending: a test of competitive causal theories. J Bus Res. 56:529–539.

Davidson RJ & Irwin W. 1999. The functional neuroanatomy of emotion and affective style. Trends Cogn. Sci. 3, 11–21.

Dade LA, Zatorre RJ and Jones-Gotman M. 2002. Olfactory learning: convergent findings from lesion and brain imaging studies in humans. Brain, 125, 86–101.

Davis M. 1992. The role of the amygdala in fear and anxiety. Ann. Rev. of Neurosci., 15, 353-375.

Degel J, Koster EP. 1999. Odors: implicit memory and performance effects. Chem Senses. 24:317–325.

Doty RL and Bromley SM. 2000. Olfaction and taste. In: A Crockard, R Hayward and JT Hoff, eds. Neurosurgery: The Scientific Basis of Clinical Practice. London: Blackwell Science, pp. 347–365.

Dravnieks A. 1985. Atlas of odor character profiles. ASTM Press, PA.

Ehrlichman H, Bastone L. 1992. Olfaction and emotion. In: Serby M.J., Chobor K.L., editors. Science of olfaction. New York: Springer-Verlag.p. 410–438.

Eisenberger NI, Lieberman MD, Williams KD. 2003. Does Rejection Hurt? An fMRI study of social exclusion. Science, 302:290—2.

Ekman P, Friesen W. 1976. Pictures of facial affect, Consulting Psychologists Press, Palo Alto, CA.

Frijda N. 1987. Emotion, cognitive structure, and action tendency. Cognition and Emotion, 1, 115-143.

Frijda N et al. 1995. Emotion and emotion words. In J.A. Russell et al. Everyday conceptions of emotions(pp. 121 - 44) Dordrecht:Kluwer

Fulbright RK, Skudlarski P, Lacadie CM. 1998. Functional MR imaging of regional brain responses to pleasant and unpleasant odors. Am J Neuradiol, 19:1721—6.

Fusar-Poli P, Placentino A, Carletti F et al. 2009. Functional atlas of emotional faces processing: a voxel-based meta-analysis of 105 functional magnetic resonance imaging studies. J Psychiatry Neurosci. Nov, 34(6):418-32.

Gallagher M. 2000. in The amygdala: a functional analysis, J. P. Aggleton Ed. (Oxford Univ. Press, New York). pp. 311-330.

Glusman G, Yanai I, Rubin I and Lancet D. 2001. The complete human olfactory subgenome. Genome Research, 11, 685–702.

Gilad Y, Man O and Glusman G. 2005. A comparison of the human and chimpanzee olfactory receptor gene repertoires. Genome Research, 15, 224–30.

Gottfried JA, Deichmann R, Winston JS and Dolan RJ. 2002. Functional heterogeneity in human olfactory cortex: an event-related functional magnetic resonance imaging study. Journal of Neuroscience, 22(24), 10 819–28.

Gottfried JA and Dolan RJ. 2003. The nose smells what the eye sees: crossmodal visual facilitation of human olfactory perception. Neuron, 39(2), 375–86.

Gottfried JA, Smith AP, Rugg MD and Dolan RJ. 2004. Remembrance of odors past: human olfactory cortex in cross-modal recognition memory. Neuron, 42(4), 687–95.

Gottfried JA, Winston JS and Dolan RJ. 2006. Dissociable codes of odor quality and odorant structure in human piriform cortex. Neuron, 49(3), 467–79.

Grabenhorst F, Rolls ET, Margot C et al. 2007. How pleasant and unpleasant stimuli combine in different brain regions: odor mixtures. J Neurosci, 27:13532—40.

Hamann SB, Ely TD, Grafton ST & Kilts CD. 1999. Amygdala activity related to enhanced memory for pleasant and aversive stimuli. Nat. Neurosci., 2, 289-93.

Hamann S. 2001. Cognitive and neural mechanisms of emotional memory. Trends Cogn Sci, 5:394—400.

Hamann SB, Ely TD, Hoffman JM & Kilts CD. 2002. Ecstasy and agony: activation of the human amygdala in positive and negative emotion. Psychol. Sci., 13, 135-41.

Hirotsune S, Yoshida N, Chen A et al. 2003. An expressed pseudogene regulates the messenger-RNA stability of its homologous coding gene. Nature, 423, 91–6.

Herz RS. 2002. Influences of odors on mood and affective cognition. In: Rouby C, Schaal B, Dubois D, Gervais R, Holley A, editors. Olfaction, taste, and cognition. Cambridge: Cambridge University Press. p. 160–177.

Herz RS. 2004. A naturalistic analysis of autobiographical memories triggered by olfactory visual and auditory stimuli. Chemical Senses, 29(3), 217–24.

Herz RS, Eliassen J, Beland S, Souza T. 2004. Neuroimaging evidence for the emotional potency of odor-evoked memory. Neuropsychologia. 42:371–378.

Heuberger E, Hongratanaworakit T, Bohm C, Weber R, Buchbauer G. 2001. Effects of chiral fragrances on human autonomic nervous system parameters and self-evaluation. Chem Senses. 26:281–292.

Huard JM, Youngentob SL, Goldstein BL et al. 1998. Adult olfactory epithelium contains multipotent progenitors that give rise to neurons and non-neural cells. Journal of Comparative Neurology, 400, 469–86.

Hudry J, Ryvlin P, Royet JP and Mauguiere F. 2001. Odorants elicit evoked potentials in the human amygdala. Cerebral Cortex, 11(7), 619–27.

Chrea CH, Grandjean D, Delplanque S et al. 2009. Mapping the Semantic Space for the Subjective Experience of Emotional Responses to Odors. Chem. Senses 34: 49–62.

Chu S, Downes JJ. 2000. Odour-evoked autobiographical memories: psychological investigations of proustian phenomena. Chem Senses.25:111–116.

Kinnamon SC and Margolskee RF. 2007. in The Senses: A Comprehensive Reference, Volume 4 OLFACTION AND TASTE (Firestein,S., Beauchamp,G.R,Hoy, R.R., Shepherd, G.M., Basbaum, A.I., Kaneko, A. and Westheimer, G., eds), Elsevier, Amsterdam,in the press.

Kluver H & Bucy PC. 1937. ‚Psychic blindness' and other symptoms following bilateral temporal lobectomy. Am. J. Physiol. 119, 254–284.

Koch K, Pauly K, Kellermann T et al. 2007. Gender differences in the cognitive control of emotion: an fMRI study. Neuropsychologia, 45:2744—54.

Koelsch S, Fritz T, Cramon DY et al. 2006. Investigating Emotion With Music: An fMRI Study, Human Brain Mapping 27:239 –250.

Koelsch S. 2010. Towards a neural basis of music-evoked emotions. Trends in Cognitive Sciences, 14, 131-137.

Kratskin IL and Belluzzi O. 2003. Anatomy and neurochemistry of the olfactory bulb. In: RL Doty, ed. Handbook of Olfaction and Gustation. New York, NY: Marcel Dekker, pp. 139–64.

Lazarus RS. (1991). Emotion and adaptation. New York: Oxford University Press. In Pervin, L. A. (Ed.). Handbook of personality: Theory and Research, pp609-637, New York: Guilford.

LeDoux JE. 1986. Sensory systems and emotion: a model of affective processing. Integr. Psychiatry 4, 237–248.

LeDoux J. (1995). Emotion: Clues from the brain. Ann. Rev. of Psych., 46, 209-235.

LeDoux J. 2007. The amygdala. Current Biology, 17:868—74.

Lemogne C, Piolino P, Friszer S et al. 2006. Episodic autobiographical memory in depression: specificity. Autonoetic consciousness and self-perspective. Consciousness and Cogni- tion, 15:258—68.

Li W, Luxenberg E, Parrish T and Gottfried JA. 2006. Learning to smell the roses: experience-dependent neural plasticity in human piriform and orbitofrontal cortices. Neuron, 52(6), 1097–108.

Ludvigson HW, Rottman TR. 1989. Effects of ambient odors of lavender and cloves on cognition,memory, affect andmood.ChemSenses. 14:525–536.

Marsella S, Gratch J, Petta P. 2010. Computational Models of Emotion. Blueprint for Affective Computing A Source Book, Volume: 3, Publisher: Oxford University Press, Pages: 1598-1602.

Millot J, Brand G. 2001. Effects of pleasant and unpleasant ambient odors on human voice pitch. Neurosci Lett. 297:61–63.

Millot JL, Brand G, Morand N. 2002. Effects of ambient odors on reaction time in humans. Neurosci Lett. 322:79–82.

Mombaerts P, Wang F, Dulac C et al. 1996. Visualizing an olfactory sensory map. Cell, 87, 675–86.

Moran DT, Rowley JC III, Jafek BW and Lovell MA. 1982. The fine structure of the olfactory mucosa in man. Journal of Neurocytology, 11, 721–46.

Morris JS et al. 1996. A differential neural response in the human amygdala of fearful and happy facial expressions. Nature 383, 812–815.

Morris JS, Friston KJ ,Buchel C et al. 1998. A neuromodulatory role for the human amygdala in processing emotional facial expressions, Brain 121.

Neville KR and Haberly L. 2004. Olfactory Cortex. In: The Synaptic Organization of the Brain, 5th edn. (ed. G. M. Shepherd), pp. 415–454. Oxford University Press.

O'Doherty J et al. 2000. Sensory-specific satiety-related olfactory activation of the human orbitofrontal cortex. Neuroreport 11, 893–897.

Paulus MP, Stein MB. 2006. An insular view of anxiety. Biol. Psychiatry, 60:383—7.

Pause BM, Hellmann G, Göder R et al. 2008. Increased processing speed for emotionally negative odors in schizophrenia. Int J Psychophysiol, 70:16—22.

Pessoa L, McKenna M, Gutierrez E, and Ungerleider LG. 2002. Neural processing of emotional faces requires attention. Proc. Natl. Acad. Sci. USA 99, 11458–11463.

Phillips ML, Young AW, Scott SK et al. 1998. Neural responses to facial and vocal expressions of fear and disgust. Proc R Soc Lond B, 265:1809 –1817.

Phillips ML, Heining M. 2002. Neural correlates of emotion perception: from faces to taste. In: Rouby C, Schaal B, Dubois D, Gervais R, Holley A, editors. Olfaction, taste, and cognition. Cambridge: Cambridge University Press. p. 196–208.

Pössel P, Ahrens S, Hautzinger M. 2005. Influence of cosmetics on emotional, autonomous, endocrinological, and immune reactions. Int J Cosmet Sci. 27:343–349.

Plailly J, Bensafi M, Pachot-Clouard M et al. 2005. Involvement of right piriform cortex in olfactory familiarity judgments. Neuroimage, 24(4), 1032–41.

Pouliot S, Jones-Gotman M. 2008. Medial temporal-lobe damage and memory for emotionally arousing odors. Neuropsychologia, 46:1124—34.

Pollatos O, Kopietz R, Linn J et al. 2007. Emotional stimulation alters olfactory sensitivity and odor judgment. Chem. Senses, 32:583—9.

Price JL. 1999. Prefrontal cortical networks related to visceral function and mood. Ann. NY Acad. Sci., 877, 383.

Price JL. 2007. Definition of the orbital cortex in relation to specific connections with limbic and visceral structures, and other cortical regions. Ann N Y Acad Sci. Dec;1121:54-71.

Retiveau AN, Chambers IVE, Milliken GA. 2004. Common and specific effects of fine fragrances on the mood of women. J Sens Stud. 19:373–394.

Robin O, Alaoui-Ismaili O, Dittmar A, Vernet-Maury E. 1999. Basic emotions evoked by eugenol odor differ according to the dental experience. A neurovegetative analysis. Chem Senses. 24:327–335.

Robinson RG, Kubos KL, Starr LB, Rao K & Price TR. 1984. Mood disorders in stroke patients. Importance of location of lesion. Brain 107, 81–93.

Rolls ET. 2006. Brain mechanisms underlying flavour and appetite. Philos. Trans. R. Soc. Lond. B Biol Sci. 361: 1123–1136.

Rolls ET, Grabenhorst F, Parris BA. 2010. Neural systems underlying decisions about affective odors. J Cogn Neurosci, 22:1069—82.

Royet JP, Plailly J, Delon-Martin C, Kareken DA, Segebarth C. 2003. fMRI of emotional responses to odors: influence of hedonic valence and judgment, handedness, and gender. Neuroimage. 20:713–728.

Serizawa S, Miyamichi K, Nakatani H et al. 2003. Negative feedback regulation ensures the one receptor–one olfactory neuron rule in mouse. Science, 302, 2088–94.

Seubert J, Rea AF, Loughead J, Habel U. 2009. Mood induction with olfactory stimuli reveals differential affective responses in males and females. Chem. Senses, 34:77—84.

Simon HA. 1967. Motivational and emotional controls of cognition. Psychological Review, 74, 29-39.

Scherer KR. 1997. Profiles of emotion antecedent appraisal: Testing theoretical predications across cultures. Cognition and emotion, 11, 113 -50.

Scherer KR. 2001. Appraisal Considered as a Process of Multilevel Sequential Checking. IN SCHERER, K. R., SCHORR, A. & JOHNSTONE, T. (Eds.) Appraisal Processes in Emotion: Theory, Methods, Research. Oxford University Press.

Schiffman SS., Sattely-Miller EA, Suggs MS, Graham BG. 1995. The effect of pleasant odors and hormone status on mood of women at midlife. Brain Res Bull. 36:19–29.

Schneider F, Habel U, Reske M et al. 2007. Neural substrates of olfactory processing in schizophrenia patients and their healthy relatives. Psychiatry Res, 155:103—12.

Smith CG. 1942. Age incident of atrophy of olfactory nerves in man. Journal of Comparative Neurology, 77, 589–94.

Sobel N. et al. 1998. Sniffing and smelling: separate subsystems in the human olfactory cortex. Nature, 392, 282–6.

Sobel N, Prabhakaran V, Hartley CA et al. 1999. Blind smell: brain activation induced by an undetected air-borne chemical. Brain, 122, 209–17.

Videbech P, Ravnkilde B. 2004. Hippocampal volume and depression: a meta-analysis of MRI studies.Am J Psychiatry, 161:1957—66.

Weber ST, Heuberger E. 2008. The impact of natural odors on affective states in humans. Chem Senses, 33:441—7.

Weiskrantz L & Saunders RC. 1984. Brain 107:1033-1072

Whalen PJ, Rauch SL, Etcoff NL et al. 1998. Masked presentations of emotional facial expressions modulate amygdala activity without explicit knowledge. J. Neurosci., 18, 411-8.

Whalen PJ, Kagan J, Cook RG et al. 2004. Human amygdale responsivity to masked fearful eye whites. Science, 306:2061.

Wheeler MA, Stuss DT, Tulving E. 1997. Toward a theory of episodic memory: the frontal lobes and autonoetic consciousness. Psychol Bull, 121:331—54.

Winston JS, Gottfried JA, Kilner JM and Dolan RJ. 2005. Integrated neural representations of odor intensity and affective valence in human amygdala. Journal of Neuroscience, 25(39), 8903–7.

Yano Y, Saito R, Yoshida N et al. 2004. A new role for expressed pseudogenes as ncRNA: regulation of mRNA stability of its homologous coding gene. Journal of Molecular Medicine, 82, 414–22.

Zelano C, Bensafi M and Porter J et al. 2005. Attentional modulation in human primary olfactory cortex. Nature and Neuroscience, 8, 114–20.

Zald DH, Pardo JV. 1997. Emotion, olfaction, and the human amygdala: amygdala activation during aversive olfactory stimulation. Proc Natl Acad ScUSA,94:4119—24.

Zald DH, Mattson DL, Pardo JV. 2002. Brain activity in ventromedial prefrontal cortex correlates with individual differences in negative affect. Proc Natl Acad ScUSA,99:2450—4.