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Influence of affective and cognitive judgments on autonomic parameters during inhalation of pleasant and unpleasant odors in humans

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Abstract

Hedonic tone is so salient in odor perception that several authors have used odors to induce affective states. Various studies have shown that the electrophysiological and psychophysiological response patterns induced by olfactory stimuli are different for pleasant and unpleasant odors, and that these types of odor activate brain structures differentially. These results suggest that odors are first categorized according to pleasantness. The objective of the present work was to study the possible existence of an involuntary affective categorization in olfaction. Given that certain variations in the autonomic system, such as skin conductance amplitude and heart rate, are not under the voluntary control of human subjects, we used such psychophysiological methods for this investigation. Our results indicate that unpleasant odors provoke heart-rate acceleration during both a smelling task (control condition: a task in which subjects had only to inhale odors) and a pleasantness judgment, but not during a familiarity judgment. These results suggest that subjects involuntarily categorize odors by their pleasantness. © 2002 Published by Elsevier Science Ireland Ltd.

Keywords: Human emotion; Olfaction; Autonomic nervous system; Pleasantness; Heart rate

Several studies indicate that emotional and olfactory processing are closely linked [10,17,32,41]. It is well known that odors can induce positive and negative affects [11] which can modulate mood [35–37], cognition [16,18,39], behavior [27], autonomic parameters [29], and cerebral activity on electrophysiological recording [20,26] or neuroimagery [38].

Pleasant and unpleasant odors provoke different autonomic reactions: skin conductance (SC), heart rate (HR) [1,2,6] and startle reflex [12,13,28] are affected by odor pleasantness. Moreover, an experiment using olfactory evoked potentials [21] has suggested differential cerebral processing of pleasant versus unpleasant odors. Functional magnetic resonance imaging [15] and positron emission tomography-scan [41] studies found that pleasant and unpleasant odors activate different respective neural networks. Differences in the processing of pleasant versus unpleasant odors have also been shown by using response times [4]. Subjects had to perform four tasks: detection, intensity, hedonic and familiarity judgments. It was shown that unpleasant odors were processed significantly faster than pleasant and neutral ones only during hedonic judgment. The specificity of the hedonic judgment was also shown by a neuroanatomical finding [42] that the brain areas involved in intensity judgment and hedonic judgment are different: while the right orbito-frontal cortex was involved for both tasks, the hypothalamic area was specifically activated during hedonic judgment.

Many studies suggest that hedonic categorization in olfaction is probably the most important criterion for odor grouping [34], and that olfactory stimuli are experienced primarily in terms of their hedonic tone [14]. This view is in line with the theory of emotion proposed by Zajonc [40] that affective evaluations of environmental stimuli happen quickly, and are more primitive than cognitive evaluations. This theory challenges the view of Lazarus that the primitive evaluation of a stimulus is first of all cognitive [25].

The aim of the present study was to examine whether affective categorization of odor stimuli can be considered as involuntary. To study this question, we used autonomic responses that a priori are not under the subject's control. Thus, the hypothesis of the involuntary character of the

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hedonic categorization in olfaction could be verified if, in the absence of any given instruction, subjects produced autonomic responses that reflected an affective categorization. We tested this hypothesis by comparing HR and SC in three conditions. In the first condition, subjects had to inhale odors without any judgement, in the second they had to inhale odors and to perform an affective judgement, and in the third they had to inhale odors and to perform a familiarity judgement. The hypothesis would be verified if the autonomic responses in conditions 1 and 2 were the same.

Subjects were 18 healthy undergraduate and graduate students (ten women and eight men; mean age, 27.16 ± 6.08 years) from the Claude Bernard University in Lyon (France). Five of them were smokers and all were right-handed (Edinburgh Laterality Inventory [31]). Before starting the experiment, subjects had to fill in a consent form. All declared that they had no olfactory problems.

Participants were comfortably installed in a 7 × 7 × 4 m room, in a semi-reclined seated position. The room was ventilated prior to the experiment in order to avoid odor accumulation. A sniff detector was inserted in either the left nostril (for half of the subjects) or the right nostril (for the other half of the subjects) during the whole session. The concerned nostril was thus closed. Odors were presented in 15 ml flasks (opening diameter, 1.7 cm; height, 5.8 cm; filled with 5 ml of liquid). Flasks were presented for the duration of an inhalation (about 1 s) at a distance of around 1 cm from the unclosed nostril. Thus, half of the subjects were stimulated in the left nostril, and the other half were stimulated in the right nostril. When the subject smelled a flask, the sniff detector allowed the time when the odor was smelled to be precisely detected on the recordings.

After the recording system was installed, the experiment began with a rest period of 3 min. Afterwards, subjects had to perform three tasks: a smelling task (to smell odors, without any judgment); a pleasantness judgment (to decide whether the odor was pleasant or unpleasant); and a familiarity judgment (to decide whether the odor was known or unknown to them). Neither verbal nor motor responses were required from the subjects: tasks were performed mentally. Subjects were instructed to sniff the flask when the experimenter placed it under the unclosed nostril.

For each task, the experimenter presented three flasks: an empty one (EMP); one containing a pleasant scent (cineole (CIN), menthol (MEN) or isoamylacetate (ISO)); and a third containing an unpleasant odor (thiophenol (PHO), isovaleric acid (IVA) or pyridine (PYR)). Odor hedonic tone had been tested in a previous study [4]. For the same task, the flask containing CIN was always presented with the flask containing PYR and with an empty flask. The other associations were MEN–IVA–EMP, and ISO–PHO–EMP.

The inter-trial interval was 2 min. The task presentation order was counterbalanced according to a Latin square between subjects, and the flask presentation order for each task was randomized for each subject.

After the recording session, subjects smelled each flask again and had to evaluate the odor according to four dimensions—intensity, arousal, pleasantness and familiarity—by giving a mark between 1 (*not at all intense/arousing/pleasant/familiar*) and 9 (*extremely intense/arousing/pleasant/familiar*). Subjects thus smelled the same odor several times while assessing each dimension separately.

HR and SC were recorded with a PROCOMP + system (Thought Technology, Montreal, Canada). A photoplethysmographic probe (3.2 cm/1.8 cm, photodetector LED type), placed on the thumb of the non-dominant (i.e. left) hand was used to assess HR in beats per minute (bpm). SC amplitude in microsiemens (μS) was recorded by two circular Ag/AgCl electrodes (diameter, 1 cm) placed on the third phalanx of the forefinger and of the middle finger of the non-dominant hand, according to previous recommendations [8]. The sampling rate was 4 Hz for HR and 32 Hz for SC. Difference scores were calculated by subtracting the mean rate for the 8 s preceding flask presentation from that for the 8 s after stimulation.

The odor evaluations provided by the subjects after the recording session underwent a MANOVA for the following factors: odors (six: CIN; MEN; ISO; PYR; IVA; and PHO); and tasks (four: intensity; arousal; pleasantness; and familiarity). Concerning the autonomic data, a MANOVA was performed on tasks (three: smelling; pleasantness; and familiarity), and odor hedonic tone (three: empty; pleasant; and unpleasant) as 'within factors', and side of stimulation (two: right nostril; and left nostril) and gender (two: women; and men) as 'between factors'. We assessed the effects of the gender and side of stimulation factors because many studies have found firstly that women are more sensitive than men on many olfactory tasks [9,18], and secondly that affective and cognitive odor evaluations can differ according to the nostril stimulated [19].

Post-hoc analyses (Bonferroni Tests) were also made by comparing means pairwise. We planned, for each task (smelling, pleasantness and familiarity), to compare HR and SC variations in three pairs of conditions: (1), pleasant odor versus control condition (air); (2), unpleasant odor versus control condition; (3), pleasant odor versus unpleasant odor. Given that many studies indicate that the perception of an unpleasant odor can induce heart-rate acceleration as compared with the perception of a pleasant odor or a control condition (air) [1,2,6], we hypothesized that, during the smelling task, HR and SC variations would be greater when the subjects smelled an unpleasant odor than when they smelled a pleasant one or only air. The same autonomic pattern would be obtained during the pleasantness judgement, while such differences would not be observed during the familiarity judgement. With regard to the other factors (gender and side of stimulation), two hypotheses were made: firstly, that women would show greater odor effects in their autonomic variations than men, since there is some evidence that women are more sensitive to odor hedonic tone [18]; and secondly, given that affective evaluations of odors differ according to the side of stimulation (right or left

Table 1
Mean values and standard deviations of the evaluations of the six odors used during the experiment[a] according to intensity, arousal, pleasantness and familiarity

	Intensity Mean	SD	Arousal Mean	SD	Pleasantness Mean	SD	Familiarity Mean	SD
MEN	5.38	2.25	5.61	2.19	7.38	1.88	8.44	1.91
CIN	6.33	1.90	6.27	2.05	6.72	1.77	8.00	2.00
ISO	6.50	1.46	6.44	1.50	6.44	1.72	7.88	1.84
PYR	4.72	2.21	4.00	2.11	2.88	1.84	3.33	2.16
PHO	8.00	1.57	6.55	2.72	1.61	1.24	4.83	2.81
IVA	7.16	1.97	5.94	2.77	1.61	0.91	5.00	2.27

[a] MEN, CIN, ISO, PYR, PHO and IVA.

nostril) [19], it was hypothesized that autonomic variations would likewise differ according to the nostril stimulated.

Firstly, with regard to odor ratings, the results indicated a significant main effect of odors ($F_{(5,85)} = 20.119$; $P < 0.001$), a significant main effect of tasks ($F_{(3,51)} = 12.362$; $P < 0.001$) and a significant interaction between odors and tasks ($F_{(15,255)} = 17.112$; $P < 0.001$). Pairwise comparisons gave the following results: (1), CIN was more pleasant ($P < 0.001$) and more familiar than PYR ($P < 0.001$) but did not differ in intensity and arousal ($P > 0.05$); (2), MEN was more pleasant ($P < 0.001$) and more familiar than IVA ($P < 0.007$) but did not differ in intensity and arousal ($P > 0.05$); and (3), ISO was more pleasant ($P < 0.001$) and more familiar than PHO ($P < 0.001$) but did not differ in intensity and arousal ($P > 0.05$). Therefore, in each triplet, flasks differed in pleasantness and familiarity, but not in intensity and arousal. The results are summarized in Table 1.

Secondly, concerning autonomic data, the MANOVA performed with SC data (see Table 2) revealed no effect of stimulation side ($F_{(1,14)} = 0.701$; $P = 0.416$), gender ($F_{(1,14)} = 1.647$; $P = 0.220$), task ($F_{(2,28)} = 0.306$; $P = 0.300$) or odor hedonic tone ($F = 0.476$; $P = 0.626$). Neither interactions nor mean comparisons reached significance. Pairwise comparison found no significant difference between HR and SC variations provoked by pleasant odor, unpleasant odor and air for each task ($P > 0.05$).

The MANOVA performed on HR data found no effect of the stimulated nostril factor ($F_{(1,14)} = 1.763$; $P = 0.206$), sex factor ($F_{(1,14)} = 0.218$; $P = 0.648$) or task factor ($F_{(2,28)} = 0.038$; $P = 0.963$). However, a significant main effect of the odor hedonic tone factor was observed ($F_{(2,28)} = 5.169$; $P = 0.012$).

Comparisons between means indicated that HR increased after stimulation with an unpleasant odor as compared with the no-odor condition ($P < 0.05$). No difference was observed between HR variations provoked by pleasant odor and no-odor conditions ($P > 0.05$). The difference between unpleasant and pleasant odor conditions was marginally significant ($P = 0.061$). Moreover, planned comparisons between means within the same task gave the following results: HR was increased by unpleasant odors compared with the no-odor condition during the smelling task ($P < 0.05$) and the pleasantness task ($P < 0.05$) but not during the familiarity task ($P > 0.05$). No difference was observed between the other conditions for each task ($P > 0.05$).

The first result of interest is the increase in HR with unpleasant odors. This is in line with several olfactory studies [1,2,6] that found the same autonomic patterns in response to unpleasant odors: HR is accelerated in a context of rejection. Such an observed effect of odor hedonic tone could not be attributed to a difference in intensity or arousal rating, given that odors differed only along two dimensions:

Table 2
Mean values and standard deviations of SC amplitude variations[a] and HR variations[b] according to the tasks[c] and odor hedonic tone[d]

Tasks	Smelling			Pleasantness			Familiarity		
Hedonic tone	P	AIR	U	P	AIR	U	P	AIR	U
SC variations (μS)									
Mean	0.224	0.242	0.193	0.286	0.259	0.263	0.289	0.311	0.277
SD	0.476	0.442	0.294	0.515	0.337	0.451	0.509	0.641	0.501
HR variations (bpm)									
Mean	0.977	−0.156	3.676	0.428	−0.586	3.511	0.346	1.462	1.479
SD	2.363	3.409	4.400	7.564	4.260	4.221	6.402	4.453	5.909

[a] Expressed in microsiemens, or μS.
[b] Expressed in beats per minute, or bpm.
[c] Smelling, pleasantness and familiarity.
[d] P, pleasant; AIR, no odor; U, unpleasant.

pleasantness; and familiarity. The lack of significant results concerning SC amplitude variation could be attributed to the fact that, in the olfactory modality, this parameter varies directly with reports of arousal rather than with pleasantness [3]: the more arousing an odor, the more it causes SC amplitude variation. This covariation between arousal and SC amplitude variation has also been observed in the visual and auditory modalities [5,22–24].

Our study failed to find effects either of the gender or side of stimulation factors. Therefore, given that the studies previously cited used subjective pleasantness ratings [19] or response time recording [18], the relationship between autonomic variations on the one hand, and subjective evaluations and response times on the other hand can not be established.

The second result of the experiment is that the psychophysiological response patterns of HR variations for both perceptual (smelling) and affective (pleasantness) tasks were similar: increased HR in response to unpleasant odors as compared with the no-odor condition. The third result is that psychophysiological patterns differed during a cognitive judgment (familiarity). One explanation of these results could be that the neural networks involved in cognitive and affective judgments are different and that, as compared with a perceptual judgment, cognitive judgment influences autonomic responses to pleasant and unpleasant odors, while affective judgment does not. Functional neuroimagery data are in agreement with such an assumption. They indicate that some limbic regions, such as hypothalamic areas, are activated specifically during affective judgment [42], but not during familiarity judgment [33].

Therefore, our results suggest that emotional judgment in olfaction is an involuntary categorization, and are in line with similarity judgment studies with multidimensional scaling, which indicate that the first dimension was related to the affective value of odors [34]. Finally, this study is in accordance with evidence of a dissociation between emotional and cognitive processes when emotional states are elicited by visual stimuli. Thus, electrophysiological studies report that, when subjects had to perform affective or cognitive evaluations on a visual target, different response patterns were observed [7], suggesting that those two kinds of evaluation involve different neural networks.

Thus, affective evaluation, although a conscious process, does not inhibit the autonomic rejection reactions recorded during passive smelling, whereas cognitive evaluation does. This is in accordance with research highlighting the fact that the emotion the stimulus elicits in the perceiver is a powerful basis of stimulus categorization [30]. Further experiments will be conducted to assess the influence of emotional states on subjects' categorization of olfactory stimuli.

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