



Odor Hedonics: Connection With Emotional Response Estimated by Autonomic Parameters

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Abstract

The aim of this paper is to analyse the relationship between self-report hedonic evaluations and the physiological expression of emotion in response to odorants. We try to solve the following questions: (1) Is it possible to find any experimental evidence that the sense of smell is linked with emotion? (2) What kind of odorants can be distinguished by autonomic analysis? (3) Is there a link between hedonics and autonomic information? The effects of odorants on the emotional process were estimated, in terms of autonomic nervous system (ANS) activity. Fifteen subjects inhaled five odorants as olfactory stimuli: lavender (LAV), ethyl acetoacetate (EAA), camphor (CAM), acetic acid (AA) and butyric acid (BA). After inhaling the odorant, subjects were requested to fill out an 11-point hedonic scale to rate its pleasantness versus unpleasantness. ANS parameters were as follows: two electrodermal responses, skin potential (SP) and resistance (SR); two thermovascular parameters, skin blood flow (SBF) and skin temperature (ST); and two cardiorespiratory parameters: instantaneous respiratory frequency (IRF) and instantaneous heart rate (IHR). Simultaneous recording of six parameters showed that specific autonomic patterns were associated with each odorant. An analysis of variance made it possible to differentiate among the five odorants. Two-by-two odorant comparisons for autonomic responses using Tukey's HSD multiple comparison test only permitted differentiation between pleasant odorants (LAV and EAA) and unpleasant (AA and BA) ones, but camphor was differentiated from both pleasant and unpleasant odorants. Each odorant elicited responses in the different parameters, yet subjects responded through their preferential channels; an average of two channels was used by each subject. These results when compared with those obtained with other senses (visual and auditory), did not evidence the postulated preferential link between olfaction and emotion. A strong link between hedonics and ANS response could be demonstrated when considering each subject and mainly through his/her preferential channel(s); conversely a weak correlation (SR duration excepted) was obtained between inter-subjects' hedonic evaluation. It seems that for a given population the autonomic response reflect the odor valence only through some parameters related to the main preferential channel(s) and thus the global autonomic pattern has to be considered. *Chem. Senses* 22: 237–248, 1997.

Introduction

The olfaction–emotion relationship was discussed by Van Toller (1988), who noted that in spite of the popular belief in the ability of fragrances to affect emotional state, and in spite of the apparent potency of pheromonal olfactory effects in animals, theorists have largely ignored any role that odorants might play in human emotions. In fact, the most prevalent theory on human emotion stresses the influence of the social context (Schachter and Singer, 1962) and socially learned interpretations. The role of the ‘primitive’ sense of smell is ignored except in behavioral analysis (Lawless, 1991). Most previous results were obtained with subjects self-reporting mood changes. Subjects gave their impressions on inhaling odorants and judged them using a hedonic scale (Rotton *et al.*, 1978; Rotton, 1983; Ehrlichman and Halpern, 1988; Ludvigson and Rottman, 1989; Knasko *et al.*, 1990). Little relevant psychophysiological research has existed until recently on the link between olfaction and emotional arousal (Van Toller, 1988; Ehrlichman and Bastone, 1992). Reliable methods for studying this relationship were lacking, since few psychophysiological recording during the presentation of the odors have been described. Electrodermal responses have been the most widely used psychophysiological recorded response. Nevertheless, except for Borsanyi *et al.* (1962), these studies have been anecdotal in style and content, and no attempts were made to isolate subjects perceptually to allow them to concentrate on the odorant being presented as described by Van Toller (1983). Van Toller and his colleagues attempted systematically to evaluate the use of skin conductance as a psycho-physiological index of olfactory stimulation.

The connection between olfaction and emotion could be evaluated by the emotional response (ER) itself, because it is claimed that olfactory experience is inextricably linked with emotional arousal. Anatomical connections testify to this preferential relationship with affect (Aggelton and Mishkin, 1986; Price 1987); complex and numerous central olfactory projections link to structures in the limbic system, in particular amygdala and hippocampus, implicated in the modulation of emotion. The olfactory sense has direct and unequivocal links with this critical integrating brain system (Van Toller, 1988).

Long postulated, this relation has never been verified because ER measurements have been lacking. Among

the different methods proposed to estimate ER, ANS responses, recorded in real time, are the most suitable. More recently, however, new concepts characterizing ANS functioning have been put forward (Ekman *et al.* 1983; Wallin and Fagius, 1986; Vernet-Maury *et al.*, 1990). Moreover, the autonomic system has remarkable properties of ‘supersensitivity’ and stimulation of one part of the system can serve to ‘tune’ other parts (Gellhorn, 1967).

Today, the ANS may be considered a highly and rapidly activated system, capable of differentiating among emotions. In terms of basic emotion (Ekman and Friesen 1978), the evaluation of ER associated with autonomic responses was undertaken by Ekman *et al.* (1983) using facial expression. It was stated that these responses can differentiate among groups of emotions. The results of Brauchli *et al.* (1995) showed higher autonomic arousal in response to unpleasant odorants versus pleasant ones. This distinction between pleasant and unpleasant odorants agrees with previous behavioral statements (Schlosberg, 1941; Schleidt *et al.*, 1988) and facial mimics analysis (Vrana, 1993; Soussignan *et al.*, 1995). Recently, our team demonstrated that ANS response can distinguish each basic emotion (Collet *et al.*, 1997).

Moreover, new sensors and measurements for ANS activity have been developed (Dittmar, 1989; Vernet-Maury *et al.*, 1991; Dittmar *et al.*, 1992), permitting measurement of six parameters simultaneously recorded in real time and with no interference between parameters. Parallel analysis of variables of different kinds (electrical and thermovascular) allow a definition of new indices (Dittmar *et al.* 1991, 1995; Vernet-Maury *et al.* 1995a).

The use of novel and reliable recording methods permitted characterization of each individual’s emotional reactivity to odorants.

In the present study, phasic autonomic responses induced by odorants were analyzed by attempting to answer the following questions:

1. Is olfaction different from the other main senses and does it have any special relationship to emotions?
2. What kinds of odorants can be separated by autonomic analysis and does this go further than the ‘like–dislike’ dimension?
3. Is there a correlation between autonomic measurements and hedonic estimations?

Materials and methods

Subjects and odorants

Fifteen healthy, non-smoking, volunteer students served as subjects (three men and 12 women, aged from 22 to 28 years, mean = 25 years). These were individually involved in an olfactory test session lasting 35 min.

They were asked to inhale five diluted odorants in mineral oil: acetic acid: AA (1/1000), butyric acid: AB (1/1000), camphor: CAM (1/100), ethyl acetoacetate: EAA (1/100) and lavender: LAV (1/100). After inhaling the odorant, subjects were instructed to identify the odorants and to mask them on an 11-point hedonic scale [from highly pleasant (0) to highly unpleasant (10)].

The output from the polygraph enabled the experimenter to synchronize odor presentation with the inhaling part of the breathing cycle.

Procedure

Prior to experimental sessions, subjects were informed verbally about the procedure: odorants would be delivered every 2 min from an olfactometer (Figure 1). Subjects were seated in a comfortable chair, alone, isolated from the experimental device (ANS recording plus olfactometer) and were aware that an odorant was to be delivered through a facial mask, but did not know when. The odorants were not specified but subjects were told that they would be fully debriefed at the end of the experiment. Given the variability of threshold concentrations (Devos *et al.*, 1990), the concentration of odorants presented to the subjects was adjusted to a level ~20–100 times higher than the odorant group threshold concentration. At this concentration, odorants were expected to be clearly recognizable (this point being verified before each experiment) without stimulating trigeminal nerve structures. The order of the odorants was randomized differently for each subject.

Olfactory stimulation

Odorants were delivered through the device represented in Figure 1. Compressed air (5.1 l/min), purified by passing through different kinds of filters, fed the flasks containing odorants diluted in mineral oil. Pressure on the plastic flask (PF) permitted delivery of odorants to the subject's facial mask with two outflows near nostrils. Because of the plastic material, no noise appeared at the moment of odorant delivery. Between each pair of signals, a continuous purified air flow was delivered.

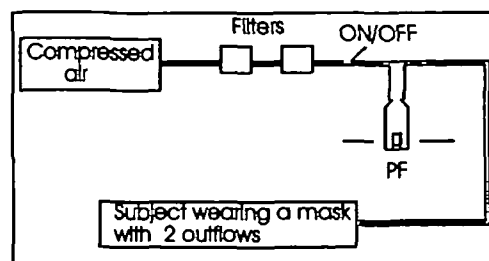


Figure 1 Specific air-delivery device. Compressed air (5.1 l/min), purified by passing through different kinds of filters, fed the flask containing odorants, diluted in mineral oil. Pressure on the plastic flask (PF) permits delivery of odorants to the subject's facial mask, presenting two outflows.

Autonomic nervous system parameters

ANS phasic responses were considered (tonic responses have been previously studied (O. Alaoui-Ismaïli *et al.*, unpublished data).

Throughout the olfactory test, six ANS parameters were simultaneously recorded in real time. They were: skin potential (SP) and skin resistance (SR) (electrodermal response); skin blood flow (SBF) and skin temperature (ST) (thermovascular parameters); plus two cardiorespiratory parameters: instantaneous respiratory frequency (IRF) and instantaneous heart rate (IHR).

Skin resistance (SR)

SR was recorded using 25 mm² Ag/AgCl round electrodes (Clark Electromedical Instruments E 243), placed on the second phalanx of the index and the third digit of the non-dominant hand, held by adhesive tape. Electrode positioning was in compliance with traditional recommendations (Fowles *et al.* 1981). Resistance was measured by a 15 µA DC current. As the amplitude of responses depends on the pre-stimulation value (Wilder, 1962), a more reliable index was defined: the time during which the subject responds to a stimulus, without referring to the initial value (or tonic level) is called the ohmic perturbation duration (OPD) index. This OPD skin resistance index reveals the emotional load of the stimulation (Vernet-Maury *et al.* 1995a).

Skin potential (SP)

SP (mV) was recorded using Beckman 78 mm² electrodes, fixed by double-sided adhesive tape. Electrode positioning and electrode cream complied with traditional recommendations (Fowles *et al.*, 1981). The active electrode was placed on the hypothenar eminence of the subject's

non-dominant hand (after alcohol-ether cleaning of the skin). The reference electrode was placed 10 cm higher on the wrist (on the equidistant line of the median plane and the outer extremity of the forearm).

Electrodermal potential variations were measured by the SYDER code (Dittmar *et al.* 1991) which permits classification of elementary responses according to their form sign (+ or -) and duration. As far as potential variations were concerned, only this index permitted analysis, the other measurements being less satisfactory or even redundant. According to this code, three positive and three negative skin potential forms (A, B and C) were considered.

Skin blood flow (SBF)

This was assessed using the original Hematron patented sensor (Dittmar, 1985). The non-invasive sensor was placed on the skin with adhesive tape (thenar eminence of the non-dominant hand).

The transducer consisted of a disc 25 mm in diameter and 4 mm thick. The measuring surface in contact with the skin was made up of two parts: the reference area at the periphery of the disc, and the measurement area at the centre of the disc. The temperature difference between these two areas was measured using 16 thermocouple junctions. A very low thermal inertia flat heater was located in the central part of the disc. A proportional, integrative and derivative device controlled the heating power in order to maintain a constant temperature difference of 2°C, between the central area and the periphery. The size and shape of the heater were designed in such a manner that a thermal field was induced in the capillary network. The power necessary to maintain the temperature difference constant depends on skin blood flow: heat is transferred through the skin and washed out by the blood flow. At all times, electric power is proportional to the heat evacuated by the tissue blood flow (Dittmar, 1989).

Blood flow in capillaries undergoes microchanges reflecting the variations of emotional load (Vernet-Maury *et al.*, 1991).

SBF variations were measured by the difference (positive or negative) between pre- and post-stimulation values expressed in $\text{mW}/\text{cm} \times ^\circ\text{C}$, and by the duration of oscillations perturbation expressed in seconds (Vernet-Maury *et al.*, 1991). This new index is called non-oscillatory duration.

Skin temperature (ST)

This was measured by a slow inertia thermistor (10 K3 MCD2 Betatherm). A 4 mm² sensor was placed in the middle of the palm of the non-dominant hand with non-caustic glue. A variation of $\sim 1/1000^\circ\text{C}$ can be detected under such conditions. Even if the ambient temperature varies in greater proportions (tonic evolution), a phasic response of $\sim 1/1000^\circ\text{C}$ may easily be observed, given the very weak signal/noise relationship in the measurement and recording chain (Delhomme *et al.*, 1991). The amplitude and duration of responses were measured. With regard to the different subjects' thermal balance, amplitude variation was measured by the difference between the tonic temperature level and the phasic variation, using the disrupted slope of the graph. For the same reason, duration was measured from the onset of the phasic response to this disrupted slope of the graph.

Instantaneous respiratory frequency (IRF)

This was recorded from an oblong thermistor (length 10 mm, diameter 3 mm), placed at the entrance of the left nostril with hypoallergenic adhesive tape. The processed signal gives the instantaneous respiratory frequency on the basis of the difference in temperature between inhaled and exhaled air.

The subject only felt the presence of the sensor for a few minutes, then forgot the appliance.

Instantaneous heart rate (IHR)

IHR was recorded from three silver electrodes in a precordial position. The D2 derivation signal (interval between two consecutive R waves) was processed and delivered in the form of instantaneous heart frequency. The smallest appreciable variation was 0.5 of a beat per min and the calibrated scale ranged from 0 to 200 beats per minute.

Recording system

The six measured signals were recorded by an 80286 microcomputer (Toshiba T3200). Signal sampling was carried out by a 16-bit data acquisition card (ADAC 5508HR) at a frequency of 8 Hz. Signals were recorded in parallel by a six-channel potentiometric DC recorder (YTSE 460 type BBC) to allow rapid visual inspection of recordings and quality control of experimentation.

Data analysis

Signal analysis software

A special software package was devised and developed for rapid analysis and processing of the recorded data. The interactive software permits calculation of all indices (including waveform pattern recognition of skin potential responses). The software features have other uses such as amplification and attenuation of signals and zooming. A digital signal processing library of functions was designed and added to the software in order to allow processing of all types of artefacts and to filter random noise whenever present in the recorded signals (Rada, 1993; Rada *et al.*, 1995).

Statistical analysis

The χ^2 test was used to analyse skin potential percentages obtained from the whole population and for each odorant.

A MANOVA was conducted to test the effect of the five odorants (AA, BA, CAM, EAA and LAV) on autonomic parameters (SR, ST, SBF and IHR). Tukey's HSD multiple comparison test permitted comparison of two-by-two odorant pairs for all autonomic parameters.

Four ANOVAs were conducted to test the effect of the five odorants on each autonomic parameter. Tukey's HSD multiple comparison test permitted comparison of two-by-two odorant pairs for each autonomic parameter.

The Mann-Whitney test was used to compare the number of autonomic channels used by each subject in response to olfactory stimulation and to non-olfactory stimulation.

Friedman's variance test plus the Wilcoxon test were used to analyse the hedonic data.

Spearman's rank correlation coefficient was used to analyse the relation between the hedonic score and the autonomic estimation according to each subject's preferential channel. This relation for the whole population, was analysed using the Pearson correlation coefficient with Bonferroni corrections.

Results

An example of a recording of the six ANS parameters is shown in Figure 2. Two electrodermal parameters can be seen: SP (increases) and SR (decreases); two thermovascular parameters: SBF (decreases) and ST (increases); and cardio-respiratory responses: IHR (tachycardia) and IRF

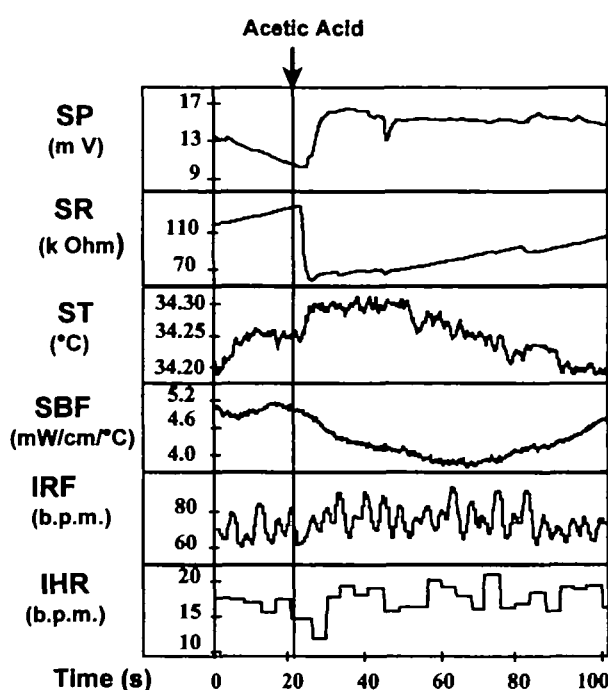


Figure 2 Example of a recording of the six autonomic nervous system parameters. Response to 'acetic acid': SP, skin potential increases; SR, skin resistance decreases; ST, skin temperature increases; SBF, skin blood flow decreases; IRF, instantaneous respiratory frequency decreases; IHR, instantaneous heart rate increases (tachycardia); bpm, beats per minute.

(dyspnea). Six phasic variations corresponded to responses induced by AA odorant.

Subjects' preferential channels

An individual analysis must be carried out in order to obtain the subject's preferential channel(s). In this study each subject responds through two channels, mean (standard deviation) value being 2 (0.79) (see Table 1).

Comparison with results obtained previously on non-olfactory stimulation (visual and auditory) (Deschaumes-Molinari *et al.*, 1992), reveals no significant difference, Mann-Whitney test ($Z = -0.90$, $P = 0.18$, NS).

ANS parameter responses to the five odorants

The χ^2 test was used to analyse skin potential results obtained from the whole population: unpleasant odorants (BA) and (AA) were significantly different from the three pleasant odorants (EAA), (LAV) and (CAM). BA and AA showed a majority of C-forms according to the Syder Code, while EAA, LAV and CAM were mainly associated with B-form responses.

A MANOVA was conducted to test the effect of the five odorants (AA, BA, CAM, EAA and LAV) on overall

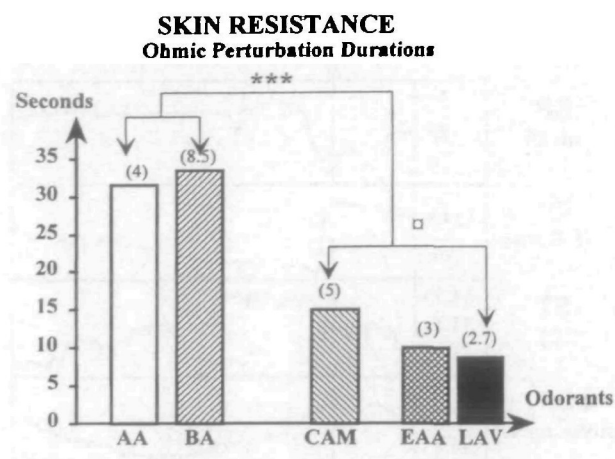


Figure 3 Median value of skin resistance perturbation duration from the 15 subjects. The longest response was recorded with unpleasant odorants and the shortest with pleasant odorants. Using Tukey's HSD multiple comparison test, only statistically significant differences are plotted. *** $P \leq 0.001$, ** $0.05 < P < 0.1$. Semi-interquartile ranges are plotted at the top of each column. AA, acetic acid; BA, butyric acid; CAM, camphor; EAA, ethyl acetoacetate; LAV, lavender.

SKIN BLOOD FLOW Non Oscillatory Duration

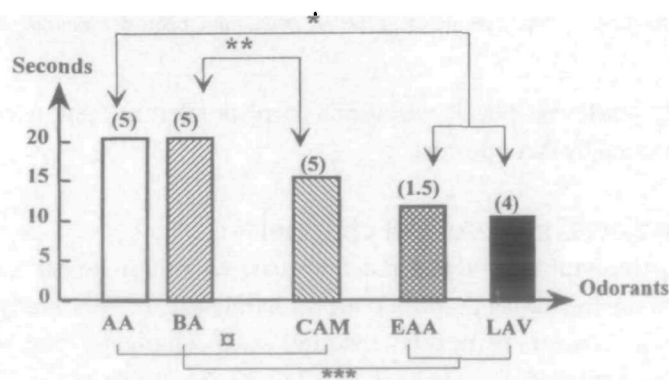


Figure 4 Median value of skin blood flow duration responses from the 15 subjects. The longest responses were recorded with unpleasant odorants and the shortest with pleasant odorants, Camphor odorant being intermediate. Using Tukey's HSD multiple comparison test, only statistically significant differences are plotted: ** $0.001 < P < 0.01$; * $0.01 < P < 0.05$. Semi-interquartile ranges are plotted at the top of each column. AA, acetic acid; BA, butyric acid; CAM, camphor; EAA, ethyl acetoacetate; LAV, lavender.

autonomic parameters (SR, ST, SBF and IHR). The five odorants were significantly different [$F(4, 280) = 60.2$, $P < 0.0001$]. All post hoc tests were conducted using Tukey's HSD. To summarize: the discriminating ANS parameters for each pair of odorants are plotted in Table 2. None of these parameters made it possible to differentiate BA from AA and EAA from LAV.

Table 1 Preferential channel distribution for each subject (1–15)

Subjects	SP	SR	ST	SBF	IHR
S1		×	×		
S2		×	×	×	
S3	×	×			
S4			×		
S5		×		×	×
S6		×			×
S7		×	×	×	×
S8					
S9		×			
S10	×				×
S11		×			×
S12		×			×
S13				×	
S14				×	
S15					

Parameter(s) for which the variation is above the group average is given. SP, skin potential; SR, skin resistance; ST, skin temperature; SBF, skin blood flow; IHR, instantaneous heart rate.

Table 2 Global autonomic analysis in response to five odorants

	Butyric acid	Camphor	Ethyl acetoacetate	Lavender
Acetic acid	NS	***	***	***
Butyric acid		***	***	***
Camphor			†	**
Ethyl acetoacetate				NS

Two-by-two odorant comparisons for autonomic responses using Tukey's HSD multiple comparison test from the whole population and global autonomic analysis. ** $0.001 < P < 0.01$; *** $P < 0.0001$; †tendency; $0.1 < P < 0.05$; NS: non-significant.

Four ANOVAs were conducted to test the effect of the five odorants on each autonomic parameter:

1. SR [$F(4, 70) = 31.84$, $P < 0.0001$]; SBF, [$F(4, 70) = 8.63$, $P < 0.0001$]; IHR [$F(4, 70) = 27.97$, $P < 0.0001$]; and ST [$F(4, 280) = 0.47$, NS]. The three autonomic parameters (SR, SBF and IHR) permitted to differentiate eight odorant pairs. Tukey's HSD multiple comparison test permitted comparison of two-by-two odorant pairs for each autonomic parameter (see Table 3).
2. SR distinguished among seven odorant pairs from 10. Pleasant odorants showed short duration responses while unpleasant ones elicited long-lasting responses (Figure 3). Medians (\pm semi-interquartile range: s.i.r.) in seconds are: LAV (8 ± 2.7), EAA (10 ± 3), CAM (15 ± 5), AA (32 ± 4) and BA (33 ± 8.5).

Table 3 Different autonomic parameters allowing to distinguish among odorants

	Butyric acid	Camphor	Ethyl acetoacetate	Lavender
Acetic acid		SR*** IHR*** SBF†	SR*** SPf** IHR*** SBF*	SR*** SPf† IHR*** SBF*
Butyric acid		SR*** IHR** SBF**	SR*** SPf* SBF*** IHR***	SR*** SPf† IHR*** SBF***
Camphor			SPf†	SR† IHR**
Ethyl acetoacetate				

Two-by-two odorant comparisons for each autonomic responses. Using Tukey's HSD multiple comparison test: SR, skin resistance responses evaluated by the ohmic perturbation duration index; SBF, skin blood flow response evaluated by the non-oscillatory duration index; IHR, instantaneous heart rate response evaluated by amplitude variation. Using a χ^2 test: SPf, skin potential response evaluated by elementary form code. Only statistically significant differences are plotted. *0.01 < P < 0.05; **0.005 < P < 0.01; *** P < 0.0001; †0.05 < P < 0.1.

3. SBF duration in seconds permitted distinction among six odorant pairs. Two pleasant odorants: LAV (10 ± 4 s), CAM (15 ± 5 s) and EAA (12 ± 1.5 s) from unpleasant odorants: BA (20 ± 5 s) and AA (20 ± 5 s). However, it did not permit differentiation among pleasant odorants (Figure 4).
4. IHR variations permitted distinction among seven odorant pairs, pleasant odorants such as LAV (-9 ± 4), EAA (-6 ± 8) and CAM (-4 ± 7) inducing mainly bradycardia from the unpleasant odorants BA (10 ± 3.5) and AA (10 ± 3) which all mainly induced tachycardia (Figure 5).

From the previous statistical analysis of these six autonomic parameters, a response pattern was built for each odorant and for each subject. Median values of parameters characterizing the whole population are plotted in Figure 6.

Hedonic scores and autonomic responses

Values given by the 15 subjects to the five odorants are located on an 11-point scale (Figure 7).

Friedman analysis of variance ($F = 41.7$, $P < 0.0001$) plus the Wilcoxon test distinguished three groups of odorants (Table 4):

1. A very pleasant odorant: LAV (1.4 ± 1.7).
2. Two weakly pleasant odorants situated in the middle of

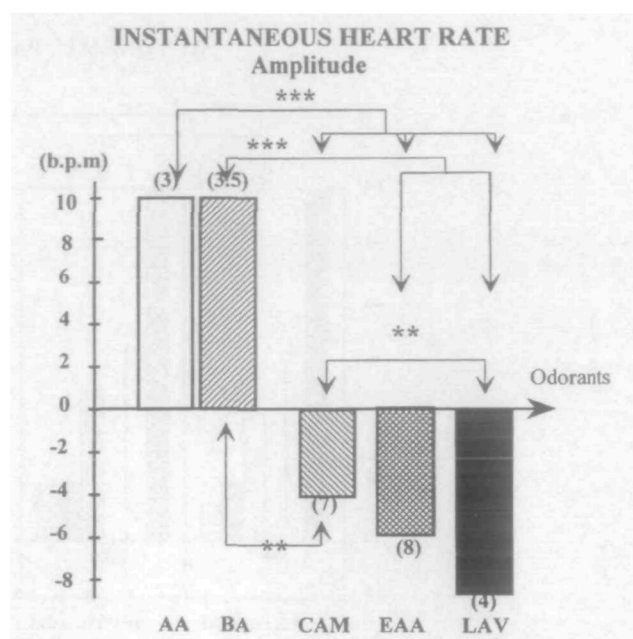


Figure 5 Median value of instantaneous heart rate amplitude from the 15 subjects. A negative variation was observed mainly during pleasant odorant inhaling and a positive variation was obtained during unpleasant odorant inhaling. Using Tukey's HSD multiple comparison test, only statistically significant differences are plotted. *** $P \leq 0.001$; **0.001 < P < 0.01. Semi-interquartile ranges are plotted at the top of each column. AA, acetic acid; BA, butyric acid; CAM, camphor; EAA, ethyl acetoacetate; LAV, lavender.

the scale EAA (2.6 ± 1.6) and CAM (4 ± 1.8). These were very pleasant to some subjects and indifferent or slightly unpleasant to others.

3. Two unpleasant odorants: AA (8.3 ± 1.3) and BA (8.8 ± 1.5).

Autonomic correlations

Intra-subjects analysis

The Spearman rank correlation coefficient was used to compare each subject's hedonic evaluation with each autonomic parameter. Table 5 summarizes these results, it shows that a correlation is evidenced for each subject but the involved autonomic parameter was different from one subject to another. A high correlation was found between the number of preferential channels used by subjects (see Table 1): nine SR, four ST, five SBF, six IHR and the number of occurrences each parameter correlated with hedonic evaluation (see Table 5): $r = 1$, $P < 0.05$.

Inter-subjects analysis

The Pearson correlation coefficient was obtained between the ANS and hedonic evaluation for all odorants. Analysis

AUTONOMIC PATTERNS OF FIVE ODORANTS.

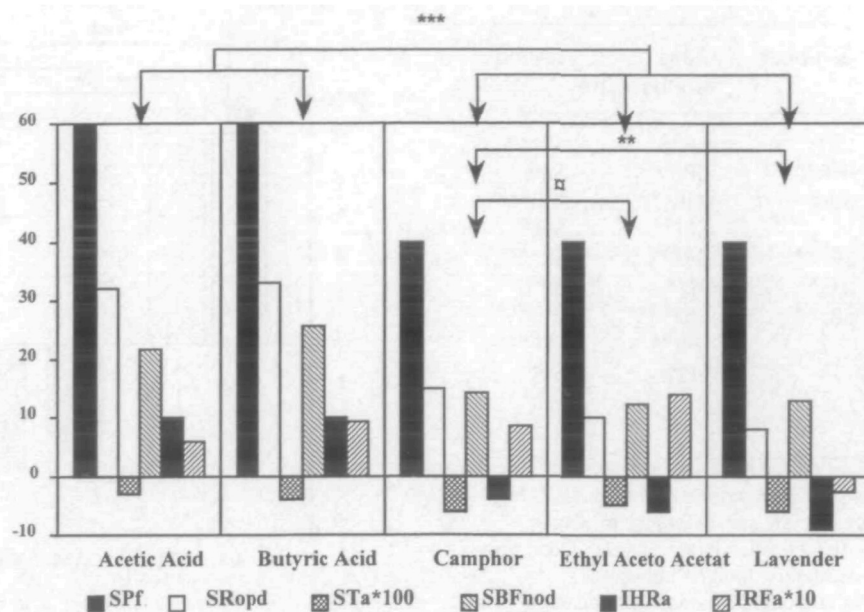


Figure 6 Pattern of autonomic responses related to each odorant on the part of all subjects. Two-by-two comparisons revealed that autonomic responses distinguished between pleasant and unpleasant odorants. Skin resistance (SRopd) and skin blood flow (SBFnod) are expressed through their temporal indices (unit being second) respectively, ohmic perturbation duration (opd) and non-oscillatory duration (NOD). To compare these patterns, some units have been normalized: skin temperature (STa), analysed by amplitude variation (a), should be multiplied by 100 to assess the exact values in °C. Instantaneous respiratory frequency (IRFa), analysed by amplitude variation (a), should be multiplied by 10 to assess the exact values in b.p.m. (IHRa) instantaneous heart rate estimated by amplitude variation (a). Arbitrary units have been used in skin potential (SPf) estimated by elementary form code (f): 60 in C-form; 40 in B-form. Wilcoxon test: *** $P < 0.001$; ** $P < 0.02$; NS, non-significant.

showed that SR and IHR responses of the whole population to each odorant were correlated to subjects' hedonic (SR, $r = 0.78$ and Bonferroni probability, $P < 0.0001$) (IHR, $r = 0.70$ and Bonferroni probability, $P < 0.0001$). Shorter durations in SR and decreases in IHR were associated with pleasantly connoted odorants and long durations and increases in IHR were associated to unpleasantly connoted odorants. SBF and ST were not correlated to subjects' hedonic evaluation in this population.

Discussion

For two decades, behavioural methods such as questionnaires or cross-cultural interviews (Schleidt *et al.*, 1988) have been used, proposing an indirect approach to the relationship between olfaction and emotion. A number of studies have explored the ability of odorants to influence cognition and behavior in ways similar to those produced by affective states (Rotton, 1983; Ehrlichman and Halpern, 1988; Baron, 1990).

Here an objective method was proposed to analyse some aspects of this question. Since 1983, only the use of skin

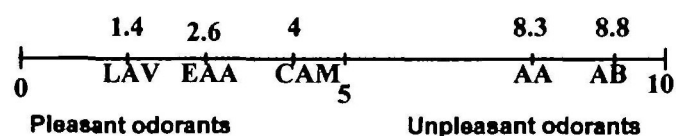


Figure 7 Five odorants situated on a hedonic axis. Mean results from 15 subjects. AA, acetic acid; AB, butyric acid; CAM, camphor; LAV, lavender; EEA, ethyl acetoacetate.

conductance response has allowed the elimination of some subjects as genuine anosmics (Van Toller *et al.*, 1983).

For the first time, preferential links between olfaction and emotion were analysed using autonomic measurements. Postulated for a long time, this relationship could not be taken as self-evident according to Ehrlichman and Bastone's review on this topic (Ehrlichman and Bastone, 1992) in the absence of appropriate research evidence. Our results demonstrate that the emotional load expressed by the number of 'used' channels induced by odorants is the same as that induced by auditory (Vernet-Maury *et al.*, 1990; Deschaumes-Molinario *et al.*, 1992) or visual (Collet *et al.*, 1994; Roure *et al.*, 1994) signals. Consequently, the emotional load induced by odorants is not different from that induced by non-olfactory stimulation, as it was

Table 4 Hedonic valence of the five odorants

	Butyric acid	Camphor	Ethyl acetoacetate	Lavender
Acetic acid	$\chi^2_r = 0.66$ NS	$\chi^2_r = -3.43^{***}$	$\chi^2_r = -3.33^{***}$	$\chi^2_r = -3.41^{***}$
Butyric acid		$\chi^2_r = -3.30^{***}$	$\chi^2_r = -3.24^{***}$	$\chi^2_r = -3.36^{***}$
Camphor			$\chi^2_r = -1.35$ NS	$\chi^2_r = -2.82^{***}$
Ethyl acetoacetate				$\chi^2_r = -2.28^{**}$

Two-by-two odorant comparisons for hedonic evaluation. Using the Wilcoxon test, *** $P < 0.001$; ** $0.01 < P < 0.05$; NS, non-significant.

demonstrated that when the emotional load increases, the number of autonomic channels used also increases (Deschaumes-Molinari *et al.*, 1992). Thus, as the supposed greater association between olfaction and emotion load is not direct, it may be postulated that odorants act as catalysts potentiating response to other stimuli (Van Toller, 1988); especially to invoke memories of past experiences often characterized by a strong, emotive connotation (Richardson and Zucco, 1989). Further experiments were undertaken to verify this point (Robin *et al.*, unpublished data).

A second major point was that from the six ANS parameters, recorded four parameters permitted odorant differentiation and two did not. The latter were respiratory frequency and skin temperature. The fact that respiratory variations did not yield such information could be related to the voluntary aspect of odorant inhaling. The non-significant variation of skin temperature, usually considered as a discriminative variable (Deschaumes-Molinari *et al.*, 1992), could be explained by the specificity of the stimulus as described by Mulder (1973) and emphasized by Ekman *et al.* (1983). This point should be verified in further research using different odorants as stimuli and different populations.

In the present study, a major result is the distinction between pleasant and unpleasant odorants. Short duration skin potential responses (mainly B form) characterized pleasant odorants whereas long duration C form responses were observed with odors judged as unpleasant. An identical phenomenon, increased skin resistance response duration (measured by the ohmic perturbation duration index; Vernet-Maury *et al.*, 1995a), was observed. Thus, an increased duration of autonomic patterns might characterize an unpleasant odorant inhaling experience.

Table 5 Comparison between subject hedonic evaluation and each autonomic parameter

Subjects	SR	ST	SBF	IHR
S1	NS	NS	NS	$r = 0.8\ddagger$
S2	$r = 0.90^*$	NS	NS	NS
S3	$r = 0.90^*$	NS	NS	$r = 0.90^*$
S4	$r = 0.97^{**}$	NS	NS	$r = 0.82\ddagger$
S5	$r = 1^{**}$	NS	NS	$r = 0.87\ddagger$
S6	$r = 1^{**}$	$r = 0.80\ddagger$	$r = 0.97^{**}$	$r = 0.95^{**}$
S7	$r = 1^{**}$	NS	NS	$r = 1$
S8	$r = 1^{**}$	NS	$r = 0.90^*$	$r = 0.97^{**}$
S9	$r = 0.97^{**}$	NS	$r = 0.92^*$	NS
S10	$r = 1^{**}$	NS	NS	$r = 0.80\ddagger$
S11	$r = 1^{**}$	$r = -0.80\ddagger$	NS	$r = 0.90^*$
S12	$r = 0.92^{**}$	$r = 0.90^*$	$r = 0.87\ddagger$	$r = 0.95^{**}$
S13	$r = 1^{**}$	NS	NS	NS
S14	$r = 0.90^*$	NS	$r = 1^{**}$	NS
S15	$r = 1^{**}$	$r = 0.82\ddagger$	NS	NS

The Spearman Rank correlation coefficient (r) was used to compare each subject's (S1–S15) hedonic evaluation with each autonomic parameter in response to five odorants. SR, skin resistance; ST, skin temperature; SBF, skin blood flow; IHR, instantaneous heart rate. NS, non-significant; \ddagger tendency; * $0.01 < P < 0.05$; ** $0.001 < P < 0.01$.

Shorter durations obtained with pleasant odorants are in accordance with results from Miltner *et al.* (1994), who found that H_2S odorant increased the startle-reflex amplitude while vanillin tended to reduce it. This startle reflex serves as a physiological indicator of emotional valence. Nevertheless, Miltner *et al.* (1994) found no difference in skin conductance responses between pleasant and unpleasant odorants. It should be noted that these authors used the classical conductance amplitude, while in the present experiment, the new OPD index (Vernet-Maury *et al.*, 1995a) allowed a better comparison of the emotional load induced by odorants to be made.

As far as pleasant odorants are concerned, autonomic responses evidenced a specific pattern associated with LAV and EAA: a short duration of electrodermal response, low skin blood flow responses and a decrease in heart rate. AA and BA were judged unpleasant odorants and presented a specific ANS pattern: a long duration of electrodermal responses, high skin blood flow responses and an increase in heart rate. CAM, while judged as pleasant, was situated between pleasant and unpleasant odorants and was highly differentiated from the two other pleasant odorants. Camphor is known to possess a trigeminal component (Doty *et al.*, 1978; Silver and Finger, 1991). It can be thus postulated that autonomic analysis can distinguish, among pleasant odorants and those with a trigeminal component.

However, this result was not obtained by subjects' self-reports when weak intensities were used. The unpleasant odours used in this study cannot add to this information because the two odorants used possess a trigeminal note.

The distinction between pleasant and unpleasant odorants found in this study agrees with previous behavioral statements (Schlosberg, 1941; Chatelain-Courtois, 1984; Schleidt, 1988) as well as those from facial mimics results (Vrana, 1993). Thus it seems safe to conclude, as did Tassinari (1985), that regardless of how the analysis is carried out, when odorants are involved, a strong and clear hedonic factor always emerges. For the first time physiological changes can be associated with unpleasant versus pleasant odorants through specific patterning of autonomic activity.

Comparisons between autonomic results and the subjects' hedonic estimation for all the odorants showed that a significative correlation was obtained only with skin resistance analysed through the new OPD index and heart rate. It is possible that another population would bring to the fore another autonomic parameter (Lacey *et al.*, 1953; Vernet-Maury *et al.*, 1990). Nevertheless, when each subject is analysed, a relation between hedonic self-reporting and autonomic estimation is always obvious. The weak

correlation evidenced by the whole population with the other autonomic parameters is in accordance with previous results (Brauchli *et al.*, 1995). Thus, unlike the physiological response obtained from olfactory evoked potential (OEP) by Kobal *et al.* (1991), the relation between each autonomic parameter response and self-reporting of hedonic tone is hazardous, being positive with one autonomic parameter and negative with others, according to the population's main preferential channel. Recent results showed that this correlation is very strong if autonomic response is traduced into basic emotions (Vernet-Maury *et al.*, 1995b and unpublished data).

These results are in accordance with the relation between the physiological response and the hedonic tone first pointed out by Kobal *et al.* (1991), studying ERS. As far as autonomic parameters are concerned, our results confirm those of Brauchli *et al.* (1995), as higher autonomic arousal was evidenced in response to presentation of an unpleasant odorant as compared with a pleasant one. In the same trend, results from Vrana (1993) failed to demonstrate this fact, but these studies were not related to odorant but to imagery manipulations and moreover they did not quantify conductance responses with the same index used by our team (Vernet-Maury *et al.*, 1995a).

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