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Autonomic Nervous System Responses to Odours: the Role of Pleasantness and Arousal

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Abstract

Perception of odours can provoke explicit reactions such as judgements of intensity or pleasantness, and implicit output such as skin conductance or heart rate variations. The main purpose of the present experiment was to ascertain: (i) the correlation between odour ratings (intensity, arousal, pleasantness and familiarity) and activation of the autonomic nervous system, and (ii) the inter-correlation between self-report ratings on intensity, arousal, pleasantness and familiarity dimensions in odour perception. Twelve healthy volunteers were tested in two separate sessions. Firstly, subjects were instructed to smell six odorants (isovaleric acid, thiophenol, pyridine, L-menthol, isoamyl acetate, and 1–8 cineole), while skin conductance and heart rate variations were being measured. During this phase, participants were not asked to give any judgement about the odorants. Secondly, subjects were instructed to rate the odorants on dimensions of intensity, pleasantness, arousal and familiarity (self-report ratings), by giving a mark between 1 (not at all intense, arousing, pleasant or familiar) and 9 (extremely intense, arousing, pleasant or familiar). Results indicated: (i) a pleasantness factor correlated with heart rate variations, (ii) an arousal factor correlated with skin conductance variations, and (iii) a strong correlation between the arousal and intensity dimensions. In conclusion, given that these correlations are also found in other studies using visual and auditory stimuli, these findings provide preliminary information suggesting that autonomic variations in response to olfactory stimuli are probably not modality specific, and may be organized along two main dimensions of pleasantness and arousal, at least for the parameters considered (i.e. heart rate and skin conductance).

Introduction

Pleasure and arousal have been identified as the principal dimensions of affective response to the environment (Mehrabian and Russell, 1974). These authors constructed a set of verbal texts describing different situations, and a scale for rating them (the Semantic Differential Scale). When applied to materials describing common events, the first two factors explaining most of the variance were pleasure and arousal. In this case, pleasure is defined as the degree to which one has favourable feelings towards a situation, while arousal is defined as the degree to which one feels excited in the situation. In order to evoke affective states in a laboratory setting, some authors have assembled sets of pictures (Lang *et al*., 1998a), sounds (Bradley and Lang, 1999b), odorants (Bensafi, 2001) or words (Bradley and Lang, 1999a) chosen to elicit a range of positive, neutral or negative affective states. In such studies, subjects had to rate the pictures, sounds, odorants or words for pleasure and arousal. Results indicated that the shape of the distribution is very similar across all sensory modalities: arousal ratings increase with emotional valence (either positive or negative). Taken as a whole, the results are consistent with the hypothesis that emotion stems from two underlying neural systems, appetitive (for positive affective states) and defensive (for negative affective states), that each vary in arousal. This organization can be expected to be the same for all modalities. Besides these subjective evaluations, it is possible to study objectively the activation (in term of emotional arousal) of these neural subsystems implied in positive and negative emotions, by recording peripheral and central brain reactions in response to affective stimuli (Lang *et al*., 1997).

Perception of emotional stimuli can thus lead to explicit reactions such as verbal responses, and to implicit output such as variations in the autonomic nervous system. In the visual modality, many studies (Greenwald *et al*., 1989; Lang *et al*., 1998b) using affective stimuli showed that skin conductance level covaries directly with reports of arousal, whatever the sign (positive or negative) of pleasantness. With regard to heart rate variation, it has been shown that pleasantness plays a major role in determining cardiac response during perception (Lang *et al*., 1993).

In the olfactory modality, it has been demonstrated that skin conductance can be modulated by the perception of an odorant (Van Toller *et al*., 1983; Robin *et al*., 1999). More specifically, skin conductance variations were found to be associated with odorant concentration: odorants at weak concentration evoked lower skin conductance than did more strongly concentrated odorants (Uryvaev *et al*., 1986). In addition, it has been shown in other studies that electrodermal response variations (skin resistance and ohmic perturbation duration) could be modulated by odour pleasantness (Alaoui-Ismaïli *et al*., 1997a,b). In these studies, other dimensions such as the intensity, arousal or familiarity of the odours were not taken into account. Another study, by Braüchli *et al*., also showed a variation in skin conductance level as a function of odour pleasantness, but not of arousal (Braüchli *et al*. 1995). Findings with regard to heart rate variation are similar: generally, unpleasant odours evoke an increase in heart rate, while pleasant ones lead to a decrease (Braüchli *et al*., 1995; Alaoui-Ismaïli *et al*., 1997a,b).

Even though well established in the visual modality, the link between self-report ratings (of pleasantness and arousal, for example) and autonomic variations (such as heart rate and skin conductance) remains unclear in the olfactory modality. This question was therefore addressed in the present experiment. Given that the above-mentioned studies have indicated in other modalities a clear relationship between heart rate variation and pleasantness on the one hand, and skin conductance variation and arousal on the other [see also Bradley (Bradley, 2000), for a review], these were the parameters we chose to measure in our study. As the perception of an odour can lead to several kinds of judgement, we also considered assessments of odour intensity and odour familiarity.

The present paper will focus on two objectives. The first concerns the correlation of self-report ratings of pleasantness, intensity, arousal and familiarity with variations in autonomic nervous system parameters. In the olfactory modality, while it seems that pleasantness is a good predictor of heart rate variation, it is less clear whether skin conductance variation is influenced by either odour pleasantness or odorant concentration, or both. As skin conductance variations are modulated by arousal in the visual modality, such possible interdependence in the olfactory modality was looked for here. The second objective is related to the correlation between the dimensions of intensity, arousal, pleasantness and familiarity. The question of the degree of independence between odour dimensions has been addressed in the literature. For example, Henion (Henion, 1971) considered the intensity and hedonic dimensions as a single dimension, while other authors did not go along with this idea (Moskowitz *et al*., 1974, 1976; Doty, 1975). We therefore analysed the correlations between these dimensions, so as to see whether any of them varied together.

With this aim, we designed an experiment in which subjects had to smell odorants while skin conductance and heart rate were being recorded. Afterwards, we examined correlations between odour dimensions as given in the subjective reports on the one hand (pleasantness, intensity, arousal and familiarity) and autonomic variations on the other hand (skin conductance and heart rate variations).

Materials and methods

Subjects

The subjects were 12 healthy undergraduate and graduate students (six women and six men, mean age = 26.16 ± 3.07) from the Claude Bernard University of Lyon (France). Five of them were smokers.

As some studies have indicated differences between left-handers and right-handers during various olfactory tasks (Toulouse and Vaschide, 1899; Frye *et al*., 1992; Hummel *et al*., 1998), only right-handers were tested in this study. Handedness was tested by a French version of the Edinburgh Laterality Inventory (Oldfield, 1971). In this test, subjects were instructed to specify which hand they used in the following 10 everyday tasks: writing, drawing, sewing, using a pair of scissors, brushing one's teeth, using a knife, using a spoon, using a broom, lighting a match and opening a box. To this end, they had to put crosses in the appropriate column (left hand or right hand) of a form. If they performed the task usually with this hand, they were to put one cross in the appropriate column. If they performed the task only with this hand, they were to put two crosses in the appropriate column. Finally, if they performed the task with either hand, they were to put a cross in each column.

Before the experiment began, the experimenter explicitly asked the subjects whether they had any olfactory problems, and none declared any. All subjects gave informed consent.

Odours

Six odorants (isovaleric acid, thiophenol, pyridine, L-menthol, isoamyl acetate, and 1–8 cineole) were used in the experiment. The criteria for odorant selection were that they should be pure compounds and selected from among those used in a previous study (Bensafi *et al*., 2001). Five odorants of the set were diluted in mineral oil. Menthol (crystallized) was diluted in diethylphtalate. Table 1 indicates the odour names, their codes and dilutions. In order to have approximately the same molar concentration for each compound, the dilutions noted in Table 1 were used.

The six odorants were presented in 15 ml opaque flasks (aperture diameter: 1.5 cm; 5 ml of solvent). Each odorant was absorbed on a piece of polypropylene (3 × 7 cm) to ensure a better exchange with the air.

Apparatus and data processing

Heart rate and skin conductance were recorded with a PROCOMP+ system (Thought Technology, Montreal, Canada). A photoplethysmographic probe (3.2 cm/1.8 cm, LED type photodetector), placed on the thumb of the non-dominant (i.e. left) hand, was used to assess heart rate

Table 1 List of the odours, their codes, dilutions and concentrations obtained in liquid phase

Product	Code	Dilution	Concentration (M)
Isovaleric acid	IVA	1/6250	1.47×10^{-3}
Thiophenol	PHO	1/6250	1.56×10^{-3}
Pyridine	PYR	1/6250	1.98×10^{-3}
L-Menthol	MEN	150 mg/5 ml	9.98×10^{-2}
Isoamyl acetate	ISO	1/100	6.70×10^{-2}
1–8 Cineole	CIN	1/100	5.97×10^{-2}

in beats per minute (bpm). Skin conductance 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 (Dawson *et al*., 2000). Sampling rate was 4 Hz for heart rate and 32 Hz for skin conductance. Difference scores were calculated by subtracting the mean rate for the 1 s preceding flask presentation (baseline) from that for the 8 s after stimulation. For skin conductance responses, so as to examine spontaneous fluctuations (especially skin conductance amplitude variations) during a short 8 s period immediately after presentation of the olfactory stimuli, tonic rather than phasic recording was used.

Procedure

The study was divided into two parts. Firstly, subjects were instructed to smell odorants, while autonomic parameters were being recorded. For this, participants were comfortably seated in a room (7 × 7 × 4 m), in a semi-reclined position. The room was ventilated prior to the experiment in order to avoid odorant accumulation. After the recording system had been installed, the experiment began with a rest period of 3 min. Afterwards, six odorized flasks were presented. The experimenter instructed the subjects not to move or to speak during this first session. Their task was only to smell odorants without any overt response. The inter-trial interval was 2 min. This range of interval is typically used in studies using odorants and recordings of autonomic parameters (Robin *et al*., 1999; Rousmans *et al*., 2000; Brand and Jacquot, 2001; Bensafi *et al*., 2002). Given that six different odorants were presented, and that each was presented once only, it is very unlikely that any habituation effect could happen. Flask presentation order was randomized for each subject. Flasks were presented 1 cm from the right nostril, with a presentation time of ~1 s. A sniff detector was inserted in the non-stimulated nostril (which was subsequently closed). Subjects were instructed to sniff the flask when the experimenter placed it under the open nostril. When the subject smelt a flask, the sniff detector allowed the time when the odorant had been smelt to be precisely detected on the autonomic recordings. Skin conductance and heart rate were recorded concurrently.

We used here single-nostril rather than both-nostril stimulation. It is likely that the volume of air breathed in is relatively reduced with this paradigm, and therefore the autonomic responses could be expected to be also reduced. However, a recent study by Brand and Jacquot indicates that this is not the case: no difference in skin conductance amplitude variation was observed whether odorants were presented to one nostril (either the right or the left) or to both nostrils (Brand and Jacquot, 2001).

It may be noted that in order to minimize any influence due to the flask being seen by the subjects during the odorant presentation, the experimenter instructed them to focus their attention on a point placed in front of the subject on the wall of the experimental room. As this did not prevent subjects' locating objects in their visual field, the experimenter instructed them to sniff the flask when it was detected under the nostril. A training run before the first session enabled all subjects to manage to sniff at the moment when the experimenter placed the flask under their nostril, without moving their eyes.

Secondly, after the recording session (first session), subjects smelt each flask again and had to evaluate the odour on 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). It may be noted that, for this session, judgement of arousal refers to the possible effect of the odorant on the subject's own subjective state of arousal. Actually, subjects were instructed to answer the following question: 'Please judge your feeling when you smelled the odorant by giving a mark between 1 (not at all arousing) to 9 (extremely arousing)'. Subjects thus smelt the same odorant several times and assessed each dimension separately. As it is very likely that unilateral presentation of odorants can lead to a decrease in the psychological dimension (in particular, perceived intensity), subjects were instructed to smell the odorants with both nostrils.

Results

Two kinds of analyses were performed on the data (processed by odorant). To address the first objective, odour ratings (intensity, arousal, pleasantness and familiarity) were each correlated with heart rate variation on the one hand and skin conductance variation on the other. To fulfil the second objective, we inter-correlated the odour assessments (intensity, arousal, pleasantness and familiarity) provided by the subjects in the second session. A Pearson correlation test on SYSTAT 7.0 (SPSS Inc., Chicago, IL) was used for the analysis. Intensity, arousal, pleasantness and familiarity ratings of odorants given by the subjects during the experimental session are illustrated in Table 2.

First, with regard to autonomic data, correlations be-

Table 2 Mean evaluations and standard deviation of intensity, arousal, pleasantness and familiarity for each odour (CIN, PHO, IVA, ISO, PYR, MEN). Evaluations of odours were given by using a scale between 1 (not at all intense/arousing/pleasant/familiar) and 9 (extremely intense/arousing/pleasant/familiar)

	Intensity		Arousal		Pleasantness		Familiarity	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
CIN	5.3	1.5	5.2	1.5	6.7	1.9	7.3	1.7
PHO	8.9	0.8	7.8	1.1	1.5	0.9	4.1	2.6
IVA	7.6	1.7	6.9	1.9	1.7	0.9	5.6	2.3
ISO	6.9	1.9	5.9	2.2	7.3	1.5	6.7	2.2
PYR	4.8	2.4	4.4	2.6	3.4	1.7	4.3	2.5
MEN	5.0	2.2	5.0	3.0	7.1	1.9	7.3	2.7

tween skin conductance variation and each of the odour dimensions gave the following results: (i) $r = -0.452$ ($n = 6$) between pleasantness and skin conductance ($P > 0.05$); (ii) $r = -0.267$ ($n = 6$) between familiarity and skin conductance ($P > 0.05$); (iii) $r = 0.799$ ($n = 6$) between intensity and skin conductance ($P = 0.057$); (iv) $r = 0.862$ ($n = 6$) between arousal and skin conductance ($P = 0.027$). These results thus indicated that arousal (and maybe intensity) was positively correlated with skin conductance variation: the more arousing (and intense) a stimulus, the more the skin conductance level increased. Figure 1 illustrates this result. Concerning heart rate variations, correlational analysis between heart rate and each of the odour dimensions gave the following results: (i) $r = 0.230$ ($n = 6$) between arousal and heart rate ($P > 0.05$); (ii) $r = -0.575$ ($n = 6$) between familiarity and heart rate ($P > 0.05$); (iii) $r = 0.170$ ($n = 6$) between intensity and heart rate ($P > 0.05$); (iv) $r = -0.817$ ($n = 6$) between pleasantness and heart rate ($P = 0.047$). From these results (illustrated in Figure 2), it seems that pleasantness is the best dimension for predicting heart rate variation. Finally, correlations between heart rate and skin conductance variations indicated a trend for a positive significant correlation ($r = 0.754$; $n = 6$; $P > 0.05$).

Second, the correlation coefficients between odour dimensions indicated a positive significant correlation between intensity and arousal ($r = 0.986$, $n = 6$; $P = 0.002$). The inter-correlations between pleasantness and familiarity ($r = 0.856$, $n = 6$; $P > 0.05$), intensity and pleasantness ($r = -0.6$, $n = 6$; $P > 0.05$), intensity and familiarity ($r = -0.45$, $n = 6$; $P > 0.05$), arousal and pleasantness ($r = -0.620$, $n = 6$; $P > 0.05$) and arousal and familiarity ($r = -0.410$, $n = 6$; $P > 0.05$) did not reach statistical significance.

Discussion

The goal of the present study was to determine (i) whether a correlation exists between autonomic variations and subjective reports of odour intensity, arousal, pleasantness and familiarity, and (ii) the relationship between these odour dimensions.

Concerning the first objective, two results are discussed below. The first finding, which clearly replicated previous results, was that heart rate was correlated with reports of pleasantness. As noted above, this significant correlation has also been found in the visual modality, where heart rate is dependent on stimulus affect value (Lang *et al.*, 1993). Affective categorization is considered the most important criterion in odour grouping (Schiffman, 1974), explaining why some authors consider odour hedonic tone as the

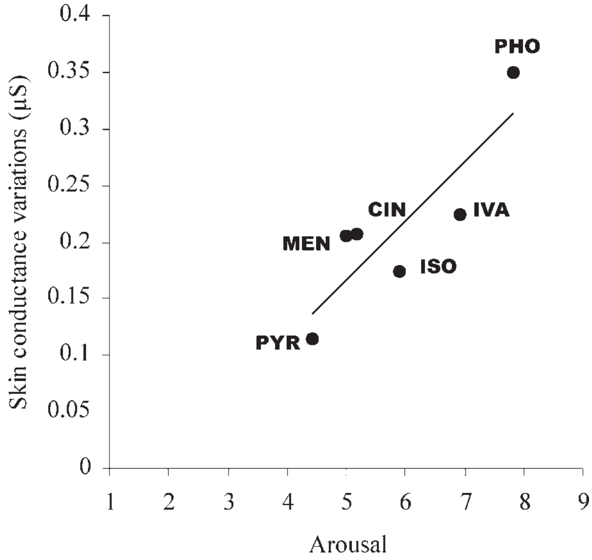

Figure 1 Skin conductance amplitude variations (in microsiemens, or µS) as a function of arousal provoked by odours. Each point corresponds to an odour.

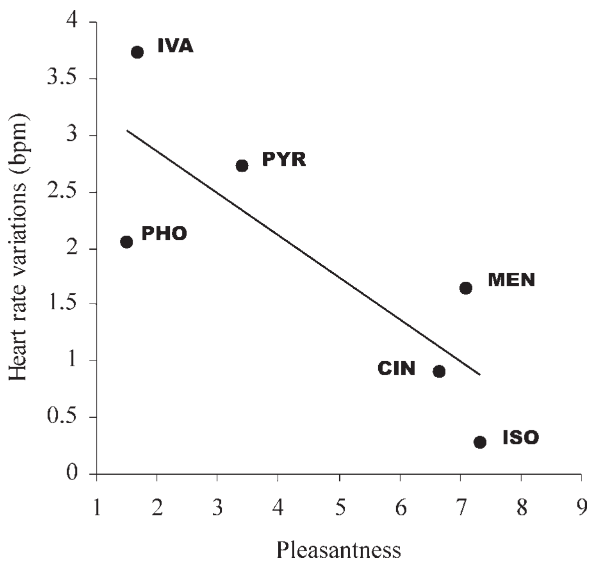

Figure 2 Heart rate variations as a function of pleasantness of odours. Each point corresponds to an odour. bpm, number of beats per minute.

most salient odour dimension (Ehrlichman and Bastone, 1992). The effects of pleasant and unpleasant odours can lead to positive and negative affective states, respectively (Ehrlichman and Halpern, 1988), at different speeds (Bensafi *et al.*, 2001), and act differentially on peripheral and central nervous responses [for a review, see Rouby and Bensafi (Rouby and Bensafi, 2002)]. Indeed, pleasant and unpleasant odours evoke different electrophysiological patterns (Kobal *et al.*, 1992; Kobal, 1994; Kline *et al.*, 2000) and activate brain structures differentially (Zald and Pardo, 1997; Fulbright *et al.*, 1998). Finally, further evidence for the existence of different effects is shown by startle reflex experiments: the amplitude of the reflex can be increased by unpleasant odours (Miltner *et al.*, 1994; Ehrlichman *et al.*, 1995, 1997) and decreased by pleasant ones (Ehrlichman *et al.*, 1997). We found in our study that heart rate was increased in a context of rejection (due to the presentation of unpleasant odours). This finding is in line with other studies in the olfactory modality showing heart rate acceleration when unpleasant odours are presented to human subjects (Braüchli *et al.*, 1995; Alaoui-Ismaïli, 1997a,b; Bensafi *et al.*, 2002).

Another result of interest was the observation that the arousal dimension was positively correlated with skin conductance amplitude variation: the more arousing an odorant, the more the skin conductance amplitude variations increased. As we have seen previously, this result is in line with other results that indicate a strong correlation between reports of arousal and skin conductance level for visual stimuli (Bradley, 2000). Given that the electrodermal system is innervated only by the sympathetic nervous system, this result suggests that these effects may index the reactivity of this autonomic system, which is greater for arousing than for non-arousing odorants. Autonomic level activation is very likely related to the activation of both trigeminal and olfactory nerves. Some odorants used in the present experiment had a trigeminal component (e.g. pyridine and thiophenol). This leads us to ask the question whether this autonomic activation was due only to trigeminal or olfactory nerve stimulation. The answer is probably both given that pyridine was the less arousing odorant, while thiophenol was the most arousing.

It has been generally shown in several studies using visual and auditory stimuli that males are more sensitive than females in their skin conductance response [for a review, see Bradley (Bradley, 2000)]: a larger proportion of males than females showed a significant correlation between arousal and skin conductance variation in the study by Lang *et al.* (Lang *et al.*, 1993). Given that a small sample of subjects was used in the present study, the probable gender effect was not analysed, and future experiments are needed to explore it.

With regard to the second objective, our results indicated no correlation between intensity, pleasantness and familiarity. These results are at variance with those of a recent study by Distel *et al.* (Distel *et al.*, 1999), which provided consistent evidence for a positive correlation between different kinds of judgement: intensity, hedonic strength and familiarity. The difference between this cross-cultural experiment and our own study could be due to our limited set of odorants. Of the six odorants (see Table 2), three were perceived as unpleasant by the subjects (thiophenol, pyridine and isovaleric acid) and three as pleasant (L-menthol, isoamyl acetate and 1–8 cineole). The lack of neutral odours probably increased the variation in emotional valence, and therefore led to non-significant results. Some of our results, however, are in accordance with Distel *et al.*'s study. They define hedonic strength as absolute ratings of pleasantness without regard to sign, that is regardless as to whether the odours are pleasant or not. Thus hedonic strength may refer to the emotional importance of the odour for a subject, something defined as arousal in our study and in homologous studies in at least three modalities, showing that arousal ratings increase with hedonic strength: pleasant and unpleasant pictures (Lang *et al.*, 1998a), sounds (Bradley and Lang, 1999b), odours (Bensafi, 2001) and words (Bradley and Lang, 1999a) are usually more arousing than neutral ones. Therefore, the observed correlation in the study by Distel *et al.* between intensity and hedonic strength is in line with our finding of a positive correlation between inten- sity and arousal, suggesting that these two dimensions tap similar phenomena in olfaction. The difference between the two judgements may reside only in the fact that intensity is an external value (an inherent property of the stimulus), while judgement as to arousal refers to the possible effect of the odorant on the subjective state.

We did not find any correlation between intensity and pleasantness. However, a frequent finding in odour hedonic research is an interaction between intensity and pleasantness: an increase in intensity generally leads to a decrease in pleasantness rating (Henion, 1971). Intensity judgement can be affected by several variables. Zellner and Kautz indicate that the odour of strawberry was rated as smelling stronger when coloured in red than when colourless (Zellner and Kautz, 1990). Hulshoff Pol *et al.* showed effects of context on odour intensity judgement: the intensity of odours (either weak or strong) smelt 25 min earlier influences subsequent odour intensity evaluations (Hulshoff Pol *et al.*, 1998). Another example of the influence of external variables is given by the study by Distel and Hudson (Distel and Hudson, 2001) showing that intensity judgement was highest when subjects were given the name of the odour by the experimenter. An additional variable is probably the method of odour administration. Indeed, it is very likely that intensity judgement is affected by single versus double nostril odour administration. Given that our study used single nostril administration, the volume of air breathed in was probably relatively reduced, and thus the odorant concentration delivered to the nose was probably also reduced. Therefore, it is possible that perceived intensity was likewise reduced, affecting the perception of pleasant and unpleasant odours differently. It is not, however, unanimously agreed that odour pleasantness is a linear function of odour intensity. Indeed, as noted above, Henion (Henion, 1971) suggested that odour intensity and odour pleasantness form a single continuum: judgements of pleasantness and intensity of amyl acetate were highly negatively correlated, but this hypothesis was untenable when other odorants were considered. Moskowitz *et al.*, testing the odour of butanol, found that for some subjects this odour became increasingly pleasant as its concentration rose, although most participants reported just the opposite (Moskowitz *et al.*, 1974). Moreover, Moskowitz *et al.*, using 32 odorants, suggested that relationships between the two attributes of intensity and pleasantness are more complex, and depend on the specific odorant used (Moskowitz *et al.*, 1976). They found at least four cases: (a) a positive correlation between inten- sity and pleasantness (e.g. benzaldehyde is neutral at a low intensity and becomes more pleasant as intensity increases); (b) a negative correlation (e.g. hexaldehyde, neutral at a low intensity and becoming more unpleasant as intensity increases); (c) a complex pattern (e.g. 3-hexanol, which is neutral at low intensity, pleasant at medium intensity, and unpleasant at high intensity); (d) no correlation between intensity and pleasantness (e.g. vanillin, pleasant at low, medium and high levels of intensity). Thus, these studies indicate that odour pleasantness is not always a function of odour intensity, and that relationships between these two odour attributes depend on the stimulus and the subject.

Actually, the present study did not test the effect of odour intensity on odour pleasantness for a given olfactory stimulus. Moreover, in order to reduce artefacts related to motion and tasks, subjects of this experiment were instructed to not move and no specific task was given to them immediately after they smelt the odorants. They were asked to estimate odour dimensions with both nostrils in a separate session. A future parametric experiment is therefore needed to explore the effect of the interaction between (i) odour intensity for a given stimulus, (ii) odour pleasantness, and (iii) the mode of stimulation, on autonomic variations. In conclusion, our study found strong correlations between (i) pleasantness and heart rate variation, (ii) arousal and skin conductance variation, and (iii) the arousal and intensity dimensions. Given that these correlations have also been found in studies using visual and auditory stimuli (Bradley, 2000), these results provide preliminary information suggesting that autonomic variations in response to olfactory stimuli are probably not modality specific, and may be organized along two main dimensions of pleasantness and arousal, at least for the parameters considered (i.e. heart rate and skin conductance).

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