Correspondences between olfactometry, analytical and electronic nose data for 10 indoor paints

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Odour characterization is necessary to evaluate perceived indoor air quality. Electronic nose technology seems interesting face to time-consuming sensory analysis with trained panels. In order to understand what type of information is processed by the sensors, their response to 10 paints frequently used indoors were compared to the odor intensity evaluated by 13 trained panelists (olfactory matching method) and the analytical composition of the samples. Significant differences among individuals were found, whereas sensors display strong redundancy. Interaction of irritating sensation with olfaction was observed. Analytical and sensor responses do not take into account the multidimensionality of olfactory information. However, similitudes between some sensors and individuals have been found. The necessity of sensor technology hybridization arises in order to take into account the totality of sensory information, as well as the need to integrate more sensitive systems based on mass spectrometry.

Introduction

In indoor environments, individuals are submitted to different types of pollution, whether physical, biological or chemical, naming bioeffluents, furnitures and equipments, building materials, outdoor air and transformation of primary pollutants [1]. These are susceptible to act against individual comfort and health. Some of these pollutions are detectable by means of our chemical senses (olfaction and general chemical sensitivity), allowing to react accordingly to prevent any annoyance. Possible reactions depend on pollution sources that can be punctual (kitchen, smoke, etc.) or continuous (building materials, walls and floor coverings). The first type can be generally reduced or eliminated. On the contrary, a background pollution arises from continuous sources that gives no opportunity other than to quit or stay and thus develop sensory annoyances, especially olfactory ones.

Olfactory annoyances have been considered as the causes of different symptoms related to Sick Building Syndrome [2,3]. In fact, odours are the interface between the individual and the environment and represent an alert signal for any change that could be benign or annoying. Olfaction is thus the first detection system of the pollution level [4-6]. Odours are associated with the apparition of symptoms, but no causal effects have been found [7].

Thus the determination of perceived indoor air quality implies an odour characterization. Improving indoor air quality requires a diminution of sensory impact and so, a control of odour intensity from continuous sources, especially building sources. Currently, three ways are available to measure odour, *i.e.* chemical analysis that gives information on the stimulus, sensory evaluation giving details of the response and electronic nose measurement that assigns a signature to a stimulus.

Chemical analysis allows the quantification of any chemical found in the stimulus. When it is coupled with sniffing, some odorous compounds can be identified. But the knowledge of any odorous compounds does not give any insight on the global odour, as no interaction model was found that can predict it from the constituting compounds.

On the other hand, sensory evaluation is a measurement of global odour. It gathers preference analysis based on the hedonic modality of odour, descriptive analysis for the determination of odour quality and olfactometry to measure odour intensity. Several differences between individuals have been observed for the three types of evaluation, respectively cultural, perceptive and semantic, or perceptive only (respectively) [8-11]. However, sensory analysis remains until now the only way to characterize an odour, although it can not be used in a continuous way. Furthermore, standardized methods are always under heavy discussion and no agreement arises internationally.

That's why, search for faster and cheaper methods is growing, that could be used continuously. These are gathered under the general terms of electronic nose whose architecture tries to mimic the olfactory one [12]. It can be described in four steps, *i.e.* stimulus delivery, transduction, feature extraction and pattern recognition. Transduction is the step where all available systems differ according to the

sensor technology used [13,14]. Depending on the type of sensors used, different patterns can be obtained for the same stimulus. With different kind of responses, questions remain to be answered:

– What is the pertinent information retained by the sensors?

– Does it correspond with olfactory perceptual information?

In order to bring some information on these questions, an experiment was conducted on ten paint samples commonly used in indoor environment. These building products were assessed by olfactometry for the olfactory perceptual information, by chemical analysis for the analytical information and by an electronic nose based on conducting polymer sensors for the artificial information. Among all sensor technologies, conducting polymer sensors show good kinetic properties at ambient temperature and a wide diversification of polymer types, features related to those of olfactory receptors [15]. Patterns relative to each kind of information were processed the same way. Response spaces and clusters among subjects, sensors and compounds were interpreted.

Experimental

Sample preparation

Ten commercially purchased white paints were used : 3 alkyd paints, 6 latex paints and one wood paint. Each paint is largely used indoors and vary according to the resin monomer or the color quality (dull, gloss...). A 400 µm thick humid film was applied for each sample on a rigid odorless polyester substrate 185 µm thick (9 × 25 cm) using an Erichsen 360 model film applicator. Ten replicates of each sample were realized and left to equilibrate at ambient conditions (22.5 ± 0.2 °C and 45 ± 0.5 % relative humidity) for 48 hours. Loading ratio and drying time were determined following previous experiments, in order to remain in the human and instrumental sensitivity ranges. It cannot be compared with realistic indoor use. Thickness and weight of each dry film were measured (Tab. I).

After that time, each film was put in Tedlar® bags (500 × 800 mm) thermally sealed and filled thereafter with 25 liters N50 grade nitrogen from Air Liquide. The bags were then stored for 24 hours in the dark before being sent to the test laboratory, assessed by the electronic nose equipment, and analyzed by gas chromatography.

Sensory Analysis

Intramodality matching has been applied to assess the odour intensity of the 10 paint films [16,17]. A reference ratio scale using 8 dilution steps of *n*-Butanol (99.8 % purity, Sigma-Aldrich) was used. Two hundred milliliters of *n*-Butanol in distilled water were introduced in home-made Tedlar® bags (50 µm thickness, 500 × 400 mm) and further filled with 10 ± 0.2 liters Nitrogen N50 grade. The bags were then

Table I. Mean thickness and weight of ten replicates of paint films after 48 hours. Standard deviations (sd) are indicated.

Paint Code	Resin	Quality	Thickness (µm ± sd)	Weight (g ± sd)
CAM	Acrylic	Mat	127 ± 11	4.77 ± 0.31
CGPS	Alkyd	Satin	129 ± 16	5.09 ± 0.43
LMAM	Acrylic	Mat	149 ± 10	4.58 ± 0.14
APUS	Polyurethane	Satin	87 ± 11	2.90 ± 0.19
L2AM	Acrylic	Mat	94 ± 12	3.74 ± 0.46
OGPB	Alkyd	Gloss	185 ± 39	5.21 ± 0.39
CAB	Acrylic	Gloss	100 ± 12	3.00 ± 0.18
TGPS	Alkyd	Satin	119 ± 14	4.14 ± 0.25
CAS	Acrylic	Satin	102 ± 11	3.47 ± 0.27
CVAM	Vinyl-acrylic	Mat	136 ± 08	4.93 ± 0.21

stored the same way as the samples. The 8 dilution steps follow a 2-fold geometric progression from 40 ppm vol/vol to 5120 ppm vol/vol (respectively 3 to 360 ppm in the gas phase). Gas phase concentrations were measured with an infrared photo-acoustic analyzer Brüel & Kjaer at 2950 cm^{-1} wave number. The results were compared with the estimated concentrations from vapor pressure data. Measured data appear to be closely related to estimated data.

The sensory tests were realized in a standard test room regulated at 20 ± 0.5 °C [18]. The evaluations were performed at evening during one hour for each ten subject group. Twenty individuals out of thirty have been chosen after 2 ranking tests of 8 unknown dilutions of *n*-Butanol (2-fold geometric progression). Spearman correlation coefficients were used to estimate the performance of each panelist. Individuals showing statistically non significant coefficients (95 % confidence level) were rejected as those not motivated enough. The five men and fifteen women selected had an age tendency of 45 years with a minimum of 24 and a maximum of 63 years old. They belong to no particular social class and get some money compensation for each test. Six were known smokers but were asked not to smoke thirty minutes before the beginning of each test.

Six training tests were used to teach each subject how to match unknown *n*-Butanol and Methylethylketone (99.8 % purity, Sigma-Aldrich) samples with the reference scale. A 3 minutes delay between each sample was observed to avoid adaptation phenomena that could alter olfactory evaluation. They were allowed to set the samples beyond minimum and maximum scale values assigning a multiplicative factor (e.g. ten times more than dilution step 8) or between two successive steps. The standards were known to the panelists by their ranking value (1 to 8). The results show an underestimation of the unknown samples but a globally good ranking ability of the subjects (according to significant Spearman correlation coefficients at 1 % confidence level).

The data were transformed in decimal logarithm (log C_G) for all data treatment. So that the estimation of a sample between e.g. steps 4 and 5 corresponds to half the corresponding logarithm addition.

Electronic nose

Twenty eight reliable sensors out of a 32 conducting polymer sensor array (Aromascan 32S instrument) were used to assess the gas phase emission of each paint sample. The reference bag contains only the polyester substrate. All measures were made at 25.8 ± 0.3 °C (line temperature), with 6 ± 0.3 mg.l^{-1} absolute humidity. The sensors were kept at a constant temperature of 35 ± 0.01 °C. The presentation order of the samples was randomized to avoid sensor memory effects. The data acquisition protocol consists of :

– 30 seconds reference line;

– 180 seconds sample line;

– 120 seconds purge (saturated vapor from a 98/2 distilled water / n-Butanol solution);

– 180 seconds reference line (return to the baseline).

For some latex paints (APUS, CAB and CAS), the response level was so high that several purges were needed to return to the baseline. Some artefacts were observed at the switching of the valve between reference and sample line. In order to remove them, a time derivation of the data was done that allowed the separation of the artefact from the signal, due to differences in kinetics. An increase in noise level was observed so that data were filtered by using Matlab Signal Processing Toolbox (Mathworks Inc.). The maximum signal value was then retained for each sensor and corresponds to their greatest rate of response to a particular paint.

Chemical analysis

One liter from each sample headspace was pumped through a cartridge filled with Tenax TA adsorbent (Perkin Elmer) at a rate of 100 ml min^{-1}. An ATD400 autosampler (Perkin Elmer) was used to desorb the cartridges at 270 °C with helium at a rate of 10 ml min^{-1} (N60 grade, Air Liquide). Extracts were cryofocused in a quartz tube filled with Tenax TA at –30 °C before being flash injected at 40 °C s^{-1} up to 300 °C inside the capillary column. This temperature was maintained during 30 minutes in order to completely desorb all compounds from the cryotrap. An Hewlett-Packard HP5890 Series II gas chromatograph was used to quantify and identify the extracted volatile compounds, provided with two parallel capillary columns (BPX5, 50 m, 1 µm, 0,32 and 0,22 mm i.d.) linked to a flame ionization detector and a HP5971A mass spectrometer fitted with an electron impact ionization source and a quadrupole (adapted from [19]). Temperature programming was initially 40 °C up to 250 °C maintained for 8 minutes at a rate of 5 °C min^{-1}. Helium was used as carrier gas with a constant inlet pressure of 0.21 MPa.

Data processing

Three data matrices (100 × 20 individuals, 100 × 28 sensors, 100 × 38 compounds) were obtained and processed using the variable patterns (panelist, sensor or volatile organic compound). First, repeatability was evaluated for each variable according to the linear correlation between the ten replicated patterns. Variables that did not yield a significant correlation (at 5 % risk) between replicates were eliminated. As such, the results of seven individuals and eleven compounds were discarded. The replicates were replaced by their mean value. Second, the reduced matrices (10 × 13, 10 × 28, 10 × 27) were normalized in order to avoid intensity differences between paint samples.

Correspondence analysis [20] was used with each matrix to define a reduced dimensional space where information dispersion remains observable and where distances between points are representative of their covariance. This factor analysis is based on χ^2 metrics which is a relative measure of similitude [21]. Thus, proportional patterns are considered similar in this space, although they are different in an Euclidean space.

Hierarchical clustering using Ward's method was used to complement correspondent analysis. All processing was realized with SPAD version 3.5 software (CISIA, France).

Results

Olfactometry

Repeatability of each subject was determined to be in the range 12-34 % for the retained individuals. These values corresponds to the linear correlation between the 10 replicated patterns.

The results show a wide variation of sensitivity among subjects, confirmed by variance analysis. As such, the major difference between individuals was observed for the polyurethane paint APUS, and the least for the alkyd paints CGPS, TGPS and OGPB. Panelist P7 displays the most differences in sensitivity between paints, contrary to individual D3. Significant linear correlation and anti-correlation were found among the subjects. For example, the patterns of panelists J10 and N17 are closely related, as opposed to the patterns from subjects J10 and R16 (Fig. 1). Correlation matrix between paints presents two separate groups, alkyd and others.

Correspondence analysis of the 10 × 13 matrix proposes a three-dimensional space for 87 % of the total inertia. The principal plane covers 70 % of the global variance and is presented in figure 2. The first factor distinguishes mat paints from alkyd paints and the pair of subjects R16/B18 from J10. This opposition of individuals is due to different evaluation of mat samples. The second factor is mainly caused by the difference of appreciation from panelist P7 and the pair R14/B18 towards APUS sample and alkyd
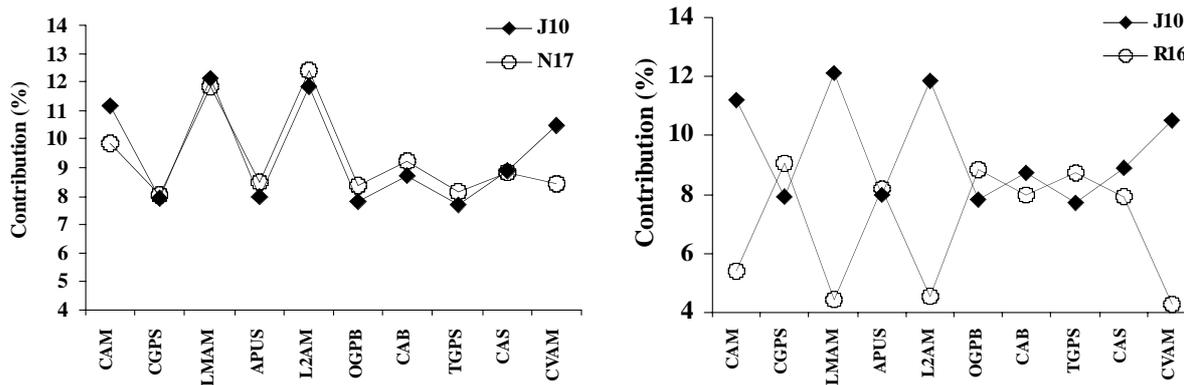
Figure 1. Maximum covariance (left) observed between contribution profiles of two panelists to ten paints (r = 0.85) and maximum anti-correlation (right) between two subjects (r = -0.96).
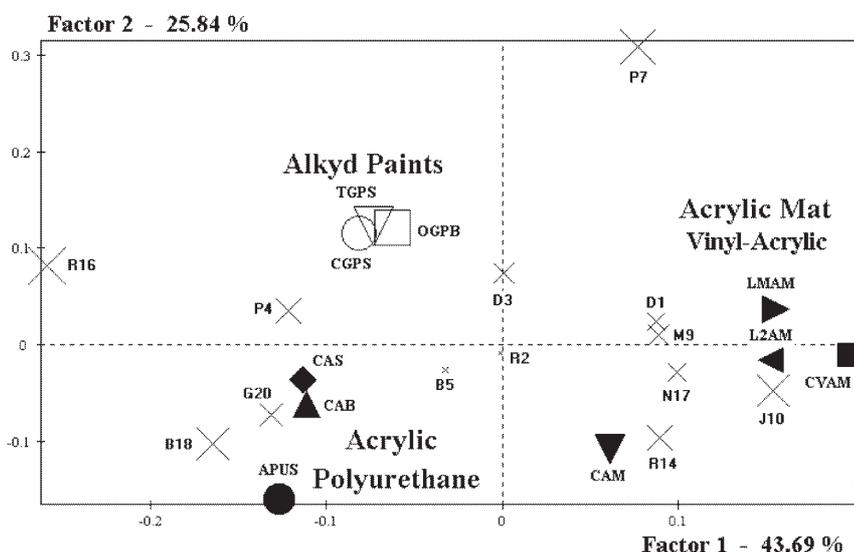

Figure 2. Principal plane from correspondence analysis of olfactometry data. Crosses represent the panelists and other symbols, the paints. Size of the symbols is proportional to the cos² of point projection to the plane.

paints. The third one is mostly explained by the opposition between the vinyl-acrylic and acrylic samples.

Hierarchical clustering on the three first factors proposes 3 groups of paints : Alkyd, Polyurethane and acrylic gloss or satin, and Acrylic or Vinyl-acrylic mat. Individuals cluster also in 4 groups of five, five, two and one subject (P7).

The panelist P7 is of great importance to the group, as when removed, only two groups of paints are found (alkyd against mat). This individual differentiates from the other by affecting very low notes to APUS/CAB/CAS samples, contrary to the others who judge them similar in intensity to the alkyd paints. The behavior of this subject is supposed to be due to a specific anosmia to odourous compounds from polyurethane sample or could be caused by a preference towards this sample that lowers the evaluation note. It has to be noted that the individual behaves normally during selection and training tests.

All subjects agree to define the alkyd samples as the most intense of all paints. As such, these are very close to each other in the tri-dimensional space. As regards the analytical composition of these paints, their proximity can be related to the presence of short-chained aldehydes that trigger the trigeminal nerve and give rise to chemical sensation of the irritating type in addition to olfactory sensation. Individually, all measured aldehydes remain under irritation threshold [22], but summing different sub-liminar stimuli can give rise to a global sensation [23].

Electronic nose

Data expressed as rate of sensor response were maximum for polyurethane and gloss or satin acrylic paints. Most of the sensors yields negative responses to the alkyd samples (Fig. 3). This behavior corresponds to an increase of conductivity in the polymer layer and has already been observed for samples containing carboxylic acids [24].
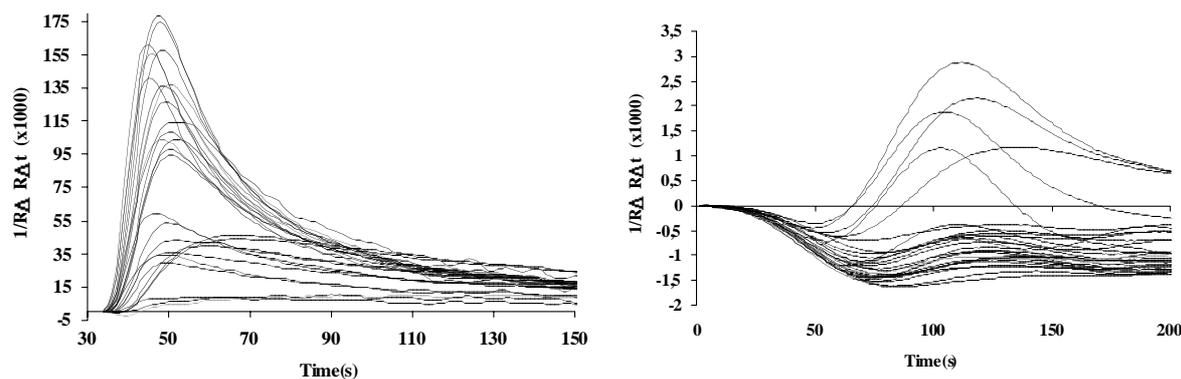
Figure 3. Filtered transient response of the sensor array to a polyurethane paint (left) and an alkyd sample (right).

Repeatability of sensors was between 8 and 14 %, as assessed by the linear correlation coefficient between the 10 replicated patterns. As such, none of the 28 sensors were discarded. A large redundancy was observed among the sensors, and two groups could be individualized. Variance analysis does not conclude in any significant differences between sensors (p = 0.12). Correlation matrix confirms the two groups of 4 and 24 sensors. The first group presents positive responses to alkyd paints, contrary to the others. Paints could also be easily distinguished between alkyd and others.

Correspondence analysis yields in a mono-dimensional space accounting for 99 % of the global variance (Fig. 4). The categories found by correlation analysis are strengthened by hierarchical clustering on the first factor.

Chemical analysis

Compound concentrations for each paint were expressed in parts per billion (Tab. II). Some branched or cyclic alkanes were difficult to identify and thus were regrouped in one unique variable, as well as all aromatic hydrocarbons. It appears that most of the compounds belonging to alkyd paints were not present in the other samples, and *vice versa,* so that the matrix contains most zeros. A rank transformation was performed in order to ease data manipulation. Pattern repeatability was then assessed by Spearman rank correlation and leads to 11 compound variables being discarded (2-(2-methoxypropoxy)-1-propanol, heptane, nonane, decane, undecane, dodecane, tridecane, tetradecane, undecanal, triethylamine, aromatics). Repeatability values for the 27 other compounds were between 1 and 34 %.

Redundancy between compounds has been observed in a same group, e.g., pentane pattern tightly follows propanal pattern. Variance analysis concludes in significant differences between compounds and two distinct clusters appears in the correlation matrix of variable patterns, alkyd paints and related compounds against the other samples.

Correspondence analysis provides a two-dimensional space accounting for 82 % of total inertia (Fig. 5). Alkyd paints are distinguished from the other in the first factor, corresponding to the opposition between
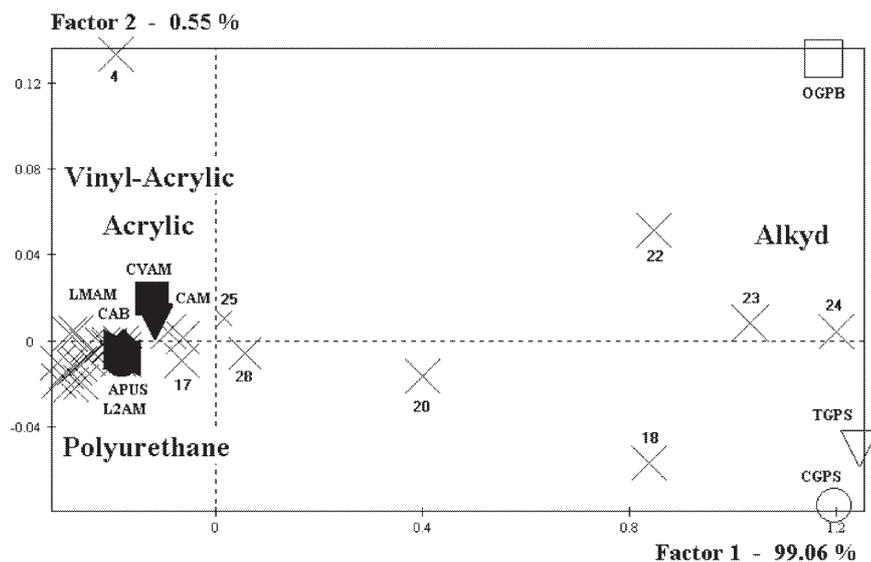

Figure 4. Principal plane from correspondence analysis of electronic nose data. Crosses represent the sensors and other symbols, the paints. Size of the symbols is proportional to the cos² of point projection to the plane.

Table II. Mean concentrations (ppb) of volatile organic compounds (VOC) for each paint.

	CAM	CGPS	LMAM	APUS	L2AM	OGPB	CAB	TGPS	CAS	CVAM
1,2-Propanediol	6	0	8	240	36	0	49	0	123	14
2-Butoxyethanol	1	0	1	3	1	0	2	0	2	1
Butylcarbitol	1	0	1	2	2	0	8	0	5	1
2-(2-methoxy-1-methylethoxy)1-Propanol	2	0	2	87	3	0	2	0	2	1
2-(2-methoxypropoxy)1-Propanol	1	0	1	64	2	0	6	0	2	1
Texanol™	0	0	1	0	0	0	4	0	7	0
Butane	0	50	0	0	0	168	0	46	0	0
Pentane	0	368	0	0	0	1336	0	356	0	0
Hexane	0	90	0	0	0	169	0	332	0	0
Heptane	2	55	1	1	1	103	1	45	1	0
Octane	4	19	2	20	3	46	7	23	3	3
Nonane	1	1	1	1	1	2	1	2	1	0
Décane	1	1	1	2	2	7	2	2	1	1
Undecane	0	1	0	0	1	12	3	3	1	0
Dodecane	0	3	0	0	0	2	0	2	0	0
Tridecane	0	1	0	0	0	1	0	1	0	0
Tetradecane	0	0	0	0	0	0	0	0	0	0
ALKANES	20	43	12	17	27	154	124	79	13	8
Propanal	0	921	0	0	0	2740	0	1100	0	0
Butanal	0	51	0	0	0	121	0	230	0	0
Pentanal	0	108	0	0	0	202	0	180	0	0
Hexanal	0	224	0	0	0	213	0	381	0	0
Heptanal	0	2	0	0	0	10	0	7	0	0
Octanal	0	2	0	0	0	10	0	2	0	0
Nonanal	0	3	0	0	0	13	0	4	0	0
Decanal	0	5	0	0	0	4	0	4	0	0
Undecanal	0	0	0	0	0	0	0	0	0	0
1-Pentanol	0	4	0	1	1	12	1	8	1	0
Triethylamine	1	0	0	22	0	0	0	0	0	0
AROMATIC HYDROCARBONS	4	7	4	4	4	12	5	7	5	5
Butyric Acid	0	0	0	0	0	9	0	3	0	0
Pentanoic Acid	0	1	0	0	0	3	0	3	0	0
Hexanoic Acid	0	3	0	0	0	9	0	6	0	0
Heptanoic Acid	0	1	0	0	0	23	0	4	0	0
Octanoic Acid	0	0	0	0	0	19	0	2	0	0
MethylHexanoic Acid	0	0	0	0	0	19	0	1	0	0
EthylHexanoic Acid	0	1	0	0	0	7	0	1	0	0
2-Ethoxyethyl Acetate	0	0	0	0	0	0	0	0	0	1

aldehydes/carboxylic acids and glycol/glycol ethers. The second factor separates the vinyl-acrylic paint from any of the other, as it is the unique sample that contains 2-ethoxyethyl acetate. Hierarchical clustering on the 2 first factors proposes 3 classes of paints and related compounds, *i.e.*, alkyd, vinyl-acrylic, and all other acrylic and polyurethane.

Global Space

Alkyd paints (and related compounds) supposed to induce irritating sensation were removed from this study, in order to observe purely olfactory relations between sensory, electronic and analytical variables. The three matrices were transformed in ranks and integrated in a global 7×51 matrix, avoiding heterogeneous units effect. Correspondence analysis leads to a four-dimensional space, accounting for 84 % of the total variance (Fig. 6). The paints cluster in 5 groups, *i.e.,* Polyurethane (APUS), Vinyl-acrylic (CVAM), Acrylic mat (CAM), the pair CAB-CAS and the other pair LMAM-L2AM. Both pairs gather samples provided by the same manufacturer.

Hierarchical clustering realized on the first four factors proposes 4 groups of variables gathering individuals,
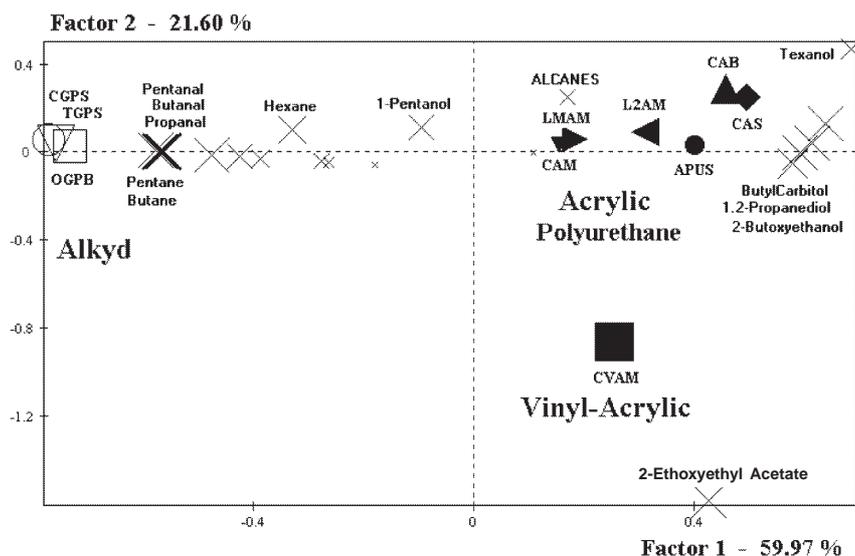
Figure 5. Principal plane from correspondence analysis of analytical data. Crosses represent the compounds and other symbols, the paints. Size of the symbols is proportional to the $\cos^2$ of point projection to the plane.
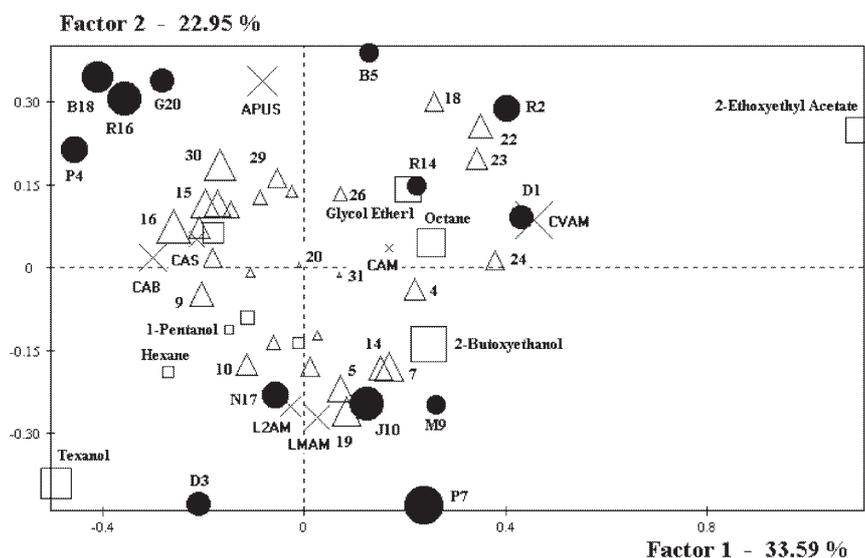

Figure 6. Principal plane from correspondence analysis of global data. Crosses represent the paints; black disks, panelists; open triangles, sensors; open squares, compounds. Size of the symbols is proportional to the $\cos^2$ of point projection to the plane.

subjects and sensors (Fig. 7). The proximity of subjects with compounds supposes a similitude in the classification of paints. Thus, panelist R14 is close to a glycol ether, meaning that he owns olfactory receptors to this ligand type. As such, groups of individuals could be interpreted as different categories of olfactory receptors. Observed associations are dependant of the analytical information collected that has to be improved in terms of sensitivity and molecule identification.

Sensors close to subjects could correspond to related receptor mechanisms, e.g., sensor 19 and panelist J10 display a similitude in the classification of paints (Fig. 8). This could indirectly inform on the structure of olfactory receptors.

Discussion

Differences in the olfactory sensation have been found between individuals. They seem to possess their own population of olfactory receptors which determine their sensitivity to different odourous compounds. This was emphasized in a previous experiment by Berglund *et al.* displaying different sensory spaces for each individual [10]. This could be explained by individual odour experience that induces selective expression of olfactory receptors from a common genome, as observed in rats [25].

The sensory space which includes olfactory and irritating sensations has three dimensions. The first could be interpreted as an hedonic factor between the less odourous mat

Figure 8. Similitude in the classification of non alkyd paints between panelist J10 and sensor 19.
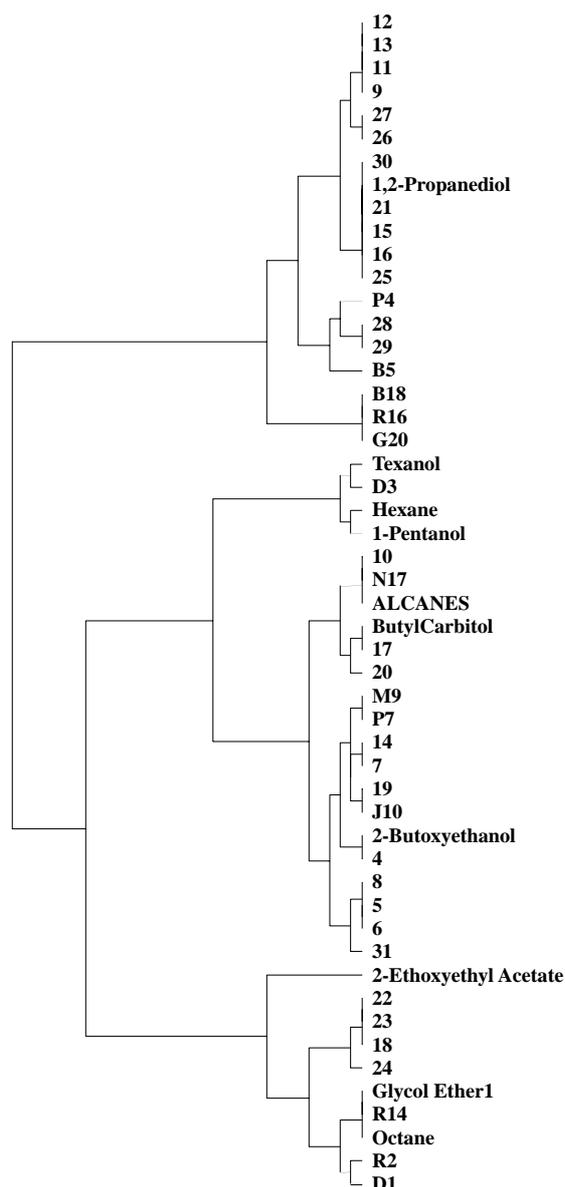

Figure 7. Hierarchical clustering of variables in the global space (sensors are represented by numbers and subjects by numbers preceded by a letter).

paints and the others. It gathers olfactory and irritating information. The second is also an hedonic factor of individual P7, supposed to be a specific anosmic. It takes into account irritating sensation only. The third is a purely qualitative factor based on olfactory data solely. The multi-dimensional character of data, observed in the first step of olfactory processing, implies that several receptor mechanisms are involved in stimuli discrimination [26]. It is reinforced by expression study of cloned olfactory receptors [27].

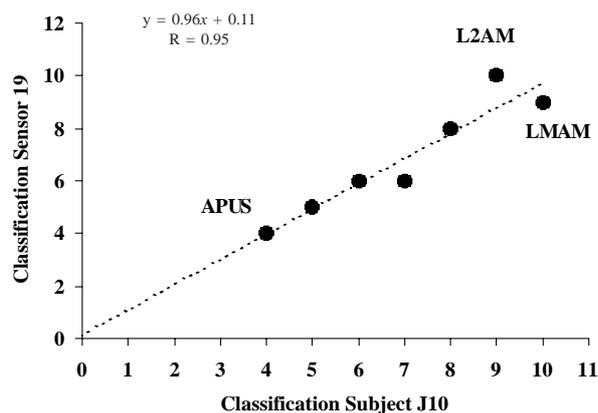The analytical space represents a subset of all volatile compounds in the headspaces. It differs from an olfactory chemical space which is only determined by odourous compounds. Its construction would need an olfactory evaluation of chromatographic effluents. Furthermore, sampling and analysis require an optimization in order to trap, quantify and identify all organic and inorganic volatile compounds that could be odourous, which was not the case.

Transient signal from sensors has proved to be valuable in the discrimination of paints. It displays rapid response without having to wait for stabilization of the steady-state signal. Few other studies have used this feature but they found an improvement in the discrimination level with other kind of sensor array [28,29].

Nonetheless, the interaction space between sensors and paint headspaces is strongly mono-dimensional, due to redundancy in conducting polymer sensors. The twenty eight sensors behave as a two-sensor array as regards the paint samples. They are not different enough to account for all olfactory information contained in the headspaces. But similitudes have been observed between some sensors and individuals (Fig. 8). Other studies have found good correlation between the mean value of an array of 20 conducting polymer sensors and odour units established by 8 panelists for agricultural malodours [15]. Another experiment has obtained good determination coefficient by principal component regression of values from an hybrid electronic nose against several sensory modalities assessed by 12 trained panelists [30]. Therefore, electronic noses seem to consider mono-dimensional criteria from the large olfactory space. Systematic application of a consensus between panelists (not always justified) reduces olfactory information, allowing strong correlation with electronic noses in prediction models.

In order to assess all olfactory information, a multiplication of transducer systems (*i.e.* sensor technologies) is needed, as each only uses a subset of the initial space [31,32]. The use of hybrid electronic nose has already proved to improve considerably complex samples discrimination [29]. Furthermore, current sensors display a lack of

sensitivity compared to the quantum efficiency of olfactory receptors [33]. This could be bypassed by the use of mass spectrometry as a virtual array sensor, where each ion channel represents a sensor [34,35]. However, this system displays a lack of discrimination between enantiomers, low sensitivity to compounds containing halogens or sulfur, and water interference in ionization of complex samples. Therefore, mass spectrometry alone cannot assess all olfactory information and need to be associated with other sensor technologies.

Conclusion

Future of electronic nose goes through a complexification of the peripheral level (transduction) in order to maintain the inherent multi-dimensionality of the pair sample-individual. Then only, can pattern recognition techniques fully be used to characterize the different processes involved in the olfactory sensation and its interpretation. Currently, none of these systems can replace human sensory evaluation but they help understand the complex olfactory information process. They can also alleviate human work in fields such as simple quality control. After deciphering the alphabet of odours, biomimetic systems (*i.e.* artificial noses) could appear that would be able to replace human olfaction in the future.

Acknowledgments

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