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Perceptual Interactions between Characteristic Notes Smelled above Aqueous Solutions of Odorant Mixtures

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Abstract

Twenty-two experienced panelists rated odor intensity of aqueous solutions of citral, octen-1-ol-3, and hexanal. The panel assessed unmixed components and mixtures (9 binary and 4 ternary). In sensory sessions dedicated to mixtures ($n = 6$), evaluation was focused on one target odor, presented at a fixed concentration. All components had lower odor intensity on mixed presentations. In many cases, information obtained from simpler systems was not extended to complex mixtures. In a mixture, the competition between odorant molecules on qualitative aspects (dominance/suppression) imbalanced components contribution, anticipated from the quantitative distribution. Hexanal appeared to be the potentially weaker odorant in paired combinations, whereas octen-1-ol-3 had a lower relative impact on ternary systems. Suppression of the odor of octen-1-ol-3 and a concomitant increase in the odor of hexanal was common to all ternary mixtures. Reciprocal inhibition of octen-1-ol-3 and citral odors through perceptual interactions was suspected. Mutual suppression is suspected to have eased the perception of hexanal intensity.

Key words: aroma balance, masking, mixed odorants, odor intensity, odor suppression

Introduction

Making fast decisions is generally based on overall impressions, which combine quantitative and qualitative factors (Laing et al. 1984). Integration is a strategy favored in the processing of sensory signals. This is supported by reports (Laing and Francis 1989; Laing and Glemarec 1992) on the achievements of people who are presented complex stimuli. In the past, objective studies on perception mostly aimed at discovering the logical relationship between the intensity of a perception and the concentration of a stimulus. The overall odor intensity produced by the association of odorants was modeled by assuming the aggregation of individual contributions. Many predictive mathematical models (see Atanasova, Thomas-Danguin, Chabanet, et al. 2005, for references) were proposed. Some models compute intensities perceived from the unmixed components (psychological models), whereas others combine weighted individual contributions in a single integrated psychophysical function (psychophysical model) assigned to the mixture. According to Cain et al. (1995), psychological models show apparent accuracy but lack explanatory power, whereas psychophysical models overestimate perceived intensity but hint at the qualitative interactions.

The proposed models do not satisfactorily account for odor suppression and qualitative dominance in mixtures (Atanasova, Thomas-Danguin, Chabanet, et al. 2005). This may result from the attribution of an excessive influence to quantitative variables (individual intensity and rate of impact aggregation) on elaboration of the models. Perceived overall intensity, although a major indicator in the characterization of an odorant mixture, is not the most pertinent determinant of all aspects of the variation. Physicochemists and/or biologists need to further explore many theoretical and practical aspects of semiqualitative variation (for instance, hypoaddition and dose additivity).

The statement by Cain et al. (1995) that "the question of whether pairs of odorants differ in how they add has received little direct attention" points to a crucial lack in the current knowledge. Beyond modeling overall intensity, the real challenge may consist of understanding how individual components maintain their identity when mixed. The predictive model proposed by Olsson (1994, 1998) was acknowledged by Atanasova, Thomas-Danguin, Langlois, et al. (2005) as the only model available for dealing with both the qualitative and the quantitative characteristics of a mixture. Reliable prediction of the characteristics of a mixture, from odor intensity of the unmixed components, implies that all odorants consistently arrange according to indisputable constant rules. If the latter condition cannot be verified, would it not be wiser to describe the system based on experimental data? In other words, evolution of perceived intensity of individual components, together with quantitative or qualitative modification of the mixture composition, is viewed as the tangible application of the ruling principles. The present experiment deals with the evaluation of the respective impacts of components' presentation (single vs. mixed) and mixture composition (identity of the components) on perceived intensity of specific odorants.

Materials and methods

Samples

Stock solutions of citral (lemon note), hexanal (''crushed grass'' note), and 1-octen-3-ol (''mushroom'' note) were prepared from chemicals supplied by International Flavors and Fragances (Dijon-Longvic, France) and ultrapure water (Millipore Systems, Saint Quentin en Yvelines, France). Samples were prepared from the stock solutions by appropriate dilution with ultrapure water on the day before the sensory measurements. Samples (20 ml) were poured into 128-ml odorless brown glass flasks closed by plastic screw caps. Flasks were kept overnight at ambient temperature (19–20 °C) to complete vapor phase equilibration prior to odor evaluation.

Panel and training

Fourteen women and 8 men (mean age: 36.5 years, range: 23–52) were recruited from the 45-member sensory panel working at the research center. All of them were volunteers, and 18 of them had previous experience in evaluating the odor intensity of aqueous solutions of pure odorants. They were trained in sensory and verbal identification of the odorants to be tested and in using the rating scale. At the end of the training program, mock tests were carried out under experimental conditions.

Sensory tests

Testing sessions were held between 9:00 AM–9:30 AM and 11:00 AM–11:30 AM on Tuesdays. Panelists were instructed to avoid smoking or eating (drinking water was acceptable) for at least 1 h before the session. At the beginning of the tests, the panelists were presented coded samples (3-digit random numbers) in individual booths illuminated by artificial white light. To minimize adaptation effects, panelists had to wait for at least 30 s before moving on to the next sample. The Fizz (version 1.20g) acquisition package (Biosystemes, Couternon, France) was used to generate questionnaires, to collect (scanner read) data, and to standardize (0–10 from the left end) raw data.

The experiment was conducted in 2 rounds, as shown in the diagram in Figure 1. The first round intended to precisely characterize the related variation of odor intensity and the concentration of single odorants. Panelists attended 3 sessions in which they had to evaluate the odor intensity of 5 dilutions of each odorant, presented at the concentrations shown in Table 1. The set assigned to each panelist consisted of a warm-up sample (isoamyl acetate, 2 mg/l in water) and 18 coded samples (5 + 1 duplication in each odorant series), arranged according to a presentation plan based on Latin squares, excluding presentation of the same odorant in more than 2 successive samples. Panelists unscrewed the flask and sniffed the sample. They rated the difference in odor intensity perceived on the tested and the reference sample (water). Panelists recorded their evaluation by marking on a 10-cm continuous line (ranging from ''very low'' at the left end to ''very high'' at the right end) and described the odor with their own words. Intensity data, calculated from the regression, were analyzed according to psychophysical models (See Mathematical Modeling below), and odorant concentrations that elicited intensity levels ''2'' and ''4'' (full scale = 10) were selected as the base concentrations for the second round.

Before each session in the second round, panelists were instructed to focus their attention on a specified odor; this target odor was presented first at level 4. Panelists were instructed to identify the target odor in 9 samples. As the first question, they were asked whether they had perceived the target odor in the sample. If the answer was ''yes,'' they further rated on an unstructured scale the difference in odor intensity of the sample (vs. water). Finally, they reported any other note they had perceived.

The experimental design used for sample presentation in the second round is shown in Table 2 and Figure 1. Panelists attended 6 sessions (3 specified odorants × 1 replication). Each session was dedicated to a specified target odor held constant at level 4 in the samples. The 9 samples were arranged according to Latin squares, excluding a similar association of nontarget components being contained in adjacent samples. On the whole, experiments involved 3 single-component solutions, 9 binary and 4 ternary mixtures (encoding of samples is found in Table 3) that contained at least one odorant at the nominal concentration 4.

Headspace measurements

Odorant concentration in the stock solutions was checked throughout the sensory tests by means of headspace measurements. Experimental measurement of air/water partition coefficients of single and mixed odorants was carried out on measuring vapor concentration above the related aqueous solutions. Aliquots (400 μl) of the vapor phase (50 ml), equilibrated for 20 h at 20 °C over 15 ml of solution contained in a sealed flask, were manually sampled and injected in the splitless mode into a gas chromatograph (Hewlett-Packard

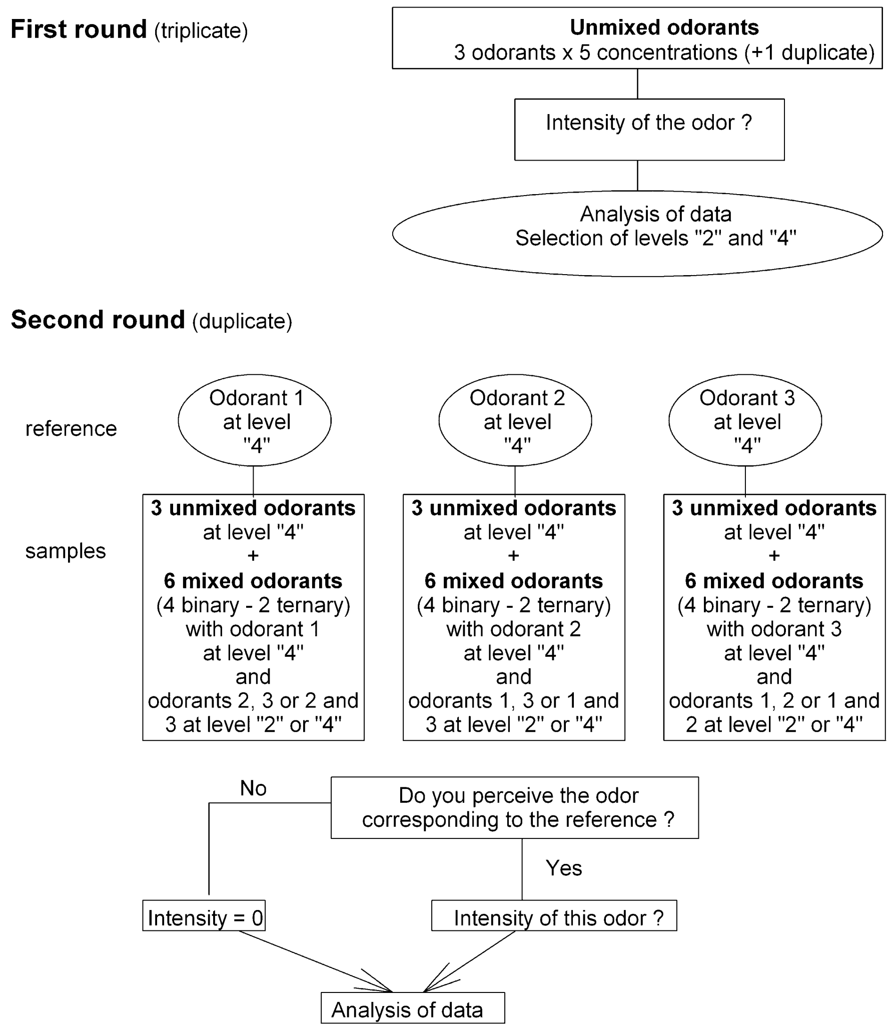

Figure 1 Flow diagram of the experimental procedure.

5890; Hewlett Packard, Böblingen, Germany). The inlet port, fitted with an 800 μl double-taper splitless liner, was set at 200 °C. Oven temperature programming (50 °C for 2 min, 10 °C/min up to 140 °C), flame ionization detection (250 °C), a HP5 capillary column (30 m, diameter: 0.32 mm, film thickness: 0.52 μm), and hydrogen carrier gas were used.

Table 1 Solutions of odorants evaluated in the first round

Odorant	Concentrations in water (mg/l)				
Hexanal	0.21	0.51	1.28	3.20[a]	8.01
Citral	0.38	1.02	2.75	7.42[a]	20.02
1-octen-3-ol	0.15	0.45	1.33	4.01[a]	12.03

[a]Presentation duplicated.

Data analysis

Mathematical modeling

Perceived intensity as a function of concentration of unmixed odorants in vapor was modeled using Fechner's ($I = A \ln(C) + B$; Fechner 1860) and Stevens' ($I = kC^n$; Stevens 1957) psychophysical equations and Hill's ($I = I_0 + (I_m - I_0)C^h/C_{ip}^h + C^h$); Hill 1913) equation. I is the perceived intensity, C the concentration of odorant in the vapor phase, I_0 and I_m are perceived intensities at null and maximal concentrations, and C_{ip} is the concentration at the inflection point. The odorant-specific parameters of these models (A and B; k and n; I_0, I_m, C_{ip}, and h) were calculated by nonlinear regression using the Solver option from Microsoft Excel 2000 by minimizing the sum of the squared differences. In Hill's equation, I_0 and I_m were restrained within the 0–10 interval in order to keep the overall range of variation consistent with the rating scale used by the sensory panel.

Statistical techniques

Variance was analyzed using the FIZZ treatment package (version 2.00c, Biosystemes). Collections of data corresponding

Table 2 Typical array of sample sets presented in the second round

Rank of presentation	Nominal intensity of odor notes		
	Odor 1 (target)	Odor 2	Odor 3
1	4		
2		4	
3			4
4	4	2	
5	4		2
6	4	4	
7	4		4
8	4	2	2
9	4	4	4

to intensity ratings of the target odorants by the 22 panelists were processed. A Newman–Keuls test was used to compare means; $P < 0.05$ was applied throughout as the level representing significant difference.

Results and discussion

Single odorant solutions

Odor intensity increased with odorant concentration in the air (Figure 2), showing a steeper variation with citral than the other 2 components. Adjustment of Fechner's, Stevens', and Hill's model equations to the observed variation was assessed. Coefficients of the best-fitting equations are listed in Table 4. Fechner's and Hill's equations suited experimental data better, particularly those of citral and 1-octen-3-ol. Stevens' equation yielded overestimated intensities of the 2 odorants toward the ends of the variation range, with strikingly large deviation at low concentration (175% and 70%, respectively). Parameters dealing with "model-constrained concentrations" (detection threshold or inflexion, namely B, k, and C_{ip}) were affected close values in the equations for citral and 1-octen-3-ol, whereas hexanal and 1-octen-3-ol were attributed close values for parameters controlling the "slope of variation" (namely A, n, and h) in agreement with the visual evidence shown in Figure 2. Nominal concentrations eliciting 2 (low) or 4 (medium) odor intensity were calculated from model equations, Table 5 shows the concentration values obtained by means of Fechner's model. The rise from 2 to 4 on the intensity scale involved a 5-fold increase of the concentration of hexanal or 1-octen-3-ol and a 3-fold increase in that of citral. All the panelists gave consistent odor intensity ratings on solutions at the level 4 concentration, whereas a fair proportion of the panelists underrated the odor intensity of level 2 dilutions. Despite the failure of some individuals, statistics acknowledged the reliability of the group as a whole on assessing odor intensity at these 2 levels of all odorants. On average, the sensory panel rated the odor intensity of the presented level 4 solutions slightly above the "4" mark. Differences between measured and nominal intensity were tested. As they were never proven significant, the same component concentrations were used throughout subsequent experiments as the reference concentrations.

Table 3 Encoding of samples evaluated in the second round

Intensity level bound to components concentration			Sample code
Hexanal	Citral	1-octen-3-ol	
4			H4
	4		C4
		4	O4
4	2		H4C2
4		2	H4O2
4	4		H4C4
4		4	H4O4
2	4		C4H2
	4	2	C4O2
2		4	O4H2
	2	4	O4C2
	4	4	O4C4
4	2	2	H4C2O2
2	4	2	C4H2O2
2	2	4	O4H2C2
4	4	4	H4C4O4

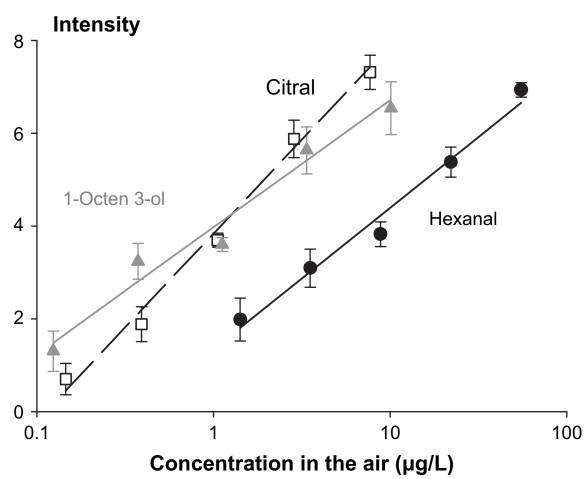

Figure 2 Odor intensity as a function of the concentration of the single odorant in air. (symbols: filled = hexanal; gray = 1-octen-3-ol; open = citral; error bars correspond to standard deviations; lines show adjustment to the Fechner's equation).

Table 4 Parameters calculated for the Fechner's, Stevens', and Hill's models from 18 intensity measurements on each odorant

Model	Fechner	$I = A \ln(C) + B$		Stevens	$I = kC^n$		Hill	$I = 10C^h/C_{ip}^h + C^h$	
	A	*B*	SSD/r^2	*k*	*n*	SSD/r^2	C_{ip}	*h*	SSD/r^2
Hexanal	1.325	1.339	2.35/0.953	1.956	0.320	1.85/0.963	16.37	0.539	2.03/0.960
Citral	1.757	3.969	2.53/0.975	3.400	0.415	7.85/0.922	2.025	0.870	2.19/0.978
1-octen-3-ol	1.191	3.833	4.46/0.926	3.704	0.276	7.03/0.883	2.437	0.530	4.90/0.919

SSD, sum of the squared difference. Concentrations (C; C_{ip}) in the air are expressed in μg/l.

It came out in the second round of the sensory evaluation that duplicate presentation of a fixed concentration of an unmixed odorant did not yield equal intensity ratings. As shown in Figure 1, one sample of the unmixed target note, labeled "reference," was available to the panelists throughout the session, whereas a duplicate, identified by a 3-digit code, was included in the set of samples on test. Compared with the coded duplicate, intensity of the reference sample obtained systematically higher ratings (Table 6). The difference (22% on the average) was significant for 1-octen-3-ol and citral. Although reliable on the whole, a panel may not produce consistent sensory estimation of similar stimulations, as reported previously (Cain et al. 1995; Brossard et al. 2002). When faced with an unknown, subjects can feel less self-confident (Laing and Francis 1989). Uncertainty attached to the anonymous coded sample has caused panelists to use larger moderation in odor quantification. The trend is likely common to panels involved in quantitative blind evaluations of samples, whereas it is ignored by model equations built on the implicit belief that an identical stimulus results mechanically in an identical fixed effect. Systematic deviation in measured odor intensity, as evidenced by the level 4 solutions, may originate from subjective factors of the panelists. Only intensity data of the 3-digit coded blind samples were further considered.

Mixed odorant solutions

Constant air/water partition coefficients were measured on solutions of the odorants (hexanal: 6.9×10^{-3}; 1-octen-3-ol: 8.4×10^{-4}; citral: 3.9×10^{-4}) either presented singly or mixed. Addition of other odorants to solutions of unmixed odorants had no impact on their partial pressure in the gas phase. On the other hand, their perceived odor intensity was consistently lowered (Figure 3). The magnitude of the decrease differs from one component to the other and appears to be related to the qualitative composition of the pair of components and, in most cases, to their concentrations.

Cain et al. (1995) also reported that the intensity of individual odorants was lower in mixed than in unmixed presentation. In many studies, binary mixtures have been composed of equally strong individual components. In line with the principle of "symmetry of the effect," proposed by Berglund and Olsson (1993), equal reciprocal impact on the associated components can be anticipated. In a study on paired woody and fruity notes of wine, Atanasova et al. (2004) questioned the principle of symmetry. They reported that in mixtures of equally strong impact components, the woody character clearly dominated the fruity note (Atanasova, Thomas-Danguin, Chabanet, et al. 2005). In the present study, the H4C4 mixture broke the symmetry principle. As shown in Figure 3A, addition of citral (C4) to hexanal (H4) produced an extensive masking of the latter, whereas, addition of H4 to C4 (Figure 3B) resulted in a limited hindrance of citral intensity.

Table 5 Odorants concentrations, calculated from the Fechner's function, associated to nominal intensity levels 2 and 4 (sample temperature: 20 °C)

Odorant	Concentration in air (μg/l)		Concentration in water (mg/l)	
	2	4	2	4
Hexanal	1.61	7.58	0.234	1.10
Citral	0.349	1.10	0.907	2.86
1-octen-3-ol	0.195	1.06	0.232	1.26

The rebuttal of the hypothesis of equivalence of reciprocal impacts of isointense components makes clear that further modeling of the perception must rely on an unquestioned hierarchy between odorants. The challenge is all the more difficult in that combination of sensory impacts may not readily comply with basic principles of rationality. In Figure 3A, addition of a fixed amount of citral, single or paired with 1-octen-3-ol, to hexanal decreased equally the odor intensity of hexanal, suggesting that 1-octen-3-ol had no practical impact. On the contrary, level 2 samples witnessed the decrease in odor intensity of hexanal when added to 1-octen-3-ol. The apparent lack of transitivity in odor dominance questions the reliability of ranking odorants on the grounds of rated sensory effectiveness. In the case of extreme dominance of one particular component, odor suppression, reputed to be an important basic phenomenon with practical consequences (Cain et al. 1995), may affect the other constituents. Among the factors allegedly responsible for odor suppression, some are assessed by means of instrumental measurements, namely temporality (Laing and Mac Leod 1992) and disparity in polarity (Atanasova, Thomas-Danguin, Chabanet, et al. 2005). This gives confidence that objective indicators, other than components' concentrations, could become valuable for characterizing sensory evidence.

Table 6 Influence of labelling (reference vs. sample) on intensity scoring of level 4 single-component solutions

Odorant	Intensity notation (/10)		Student test by pair
	Sample	Reference	Probability
Hexanal	4.13	4.87	0.070
Citral	4.54	5.53	0.010
1-octen-3-ol	4.48	5.59	0.006

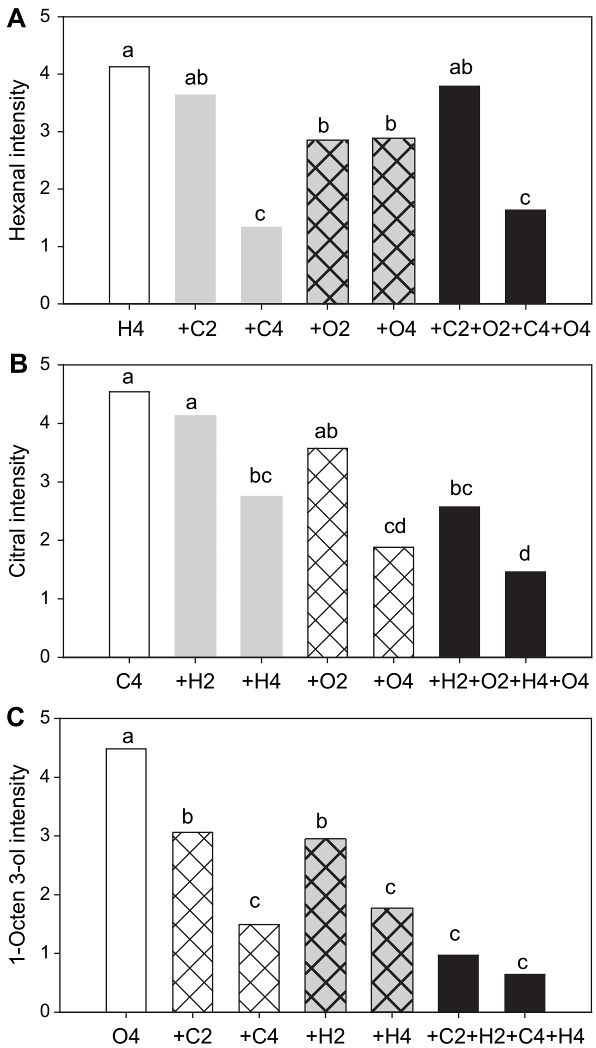

Figure 3 Mean intensity score of target notes assessed in odorant mixtures. Within a figure, bars with different superscript alphabets are significantly different ($P < 0.05$). Bars with the same fill pattern refer to related pairs of components.

A major effect of reciprocal sensory impacts in odorant mixtures is to loosen the link between mass concentration of the target component in the gas phase and perceived intensity. Measured intensity was plotted against the molecular fraction of the odorant in the gas phase (Figure 4) as an alternative to representation as intensity versus absolute concentration. The absolute concentration of the target odorant was maintained at a fixed level in all samples. Figure 4 then represents the intensity variation of the target reference, contaminated to different extents by combinations of the other odorants.

The odorants studied yielded very different patterns. The "odor of hexanal" was lost as soon as hexanal accounted for less than 80% of the vaporized molecules (Figure 4A), whereas the "odor of citral" was still detected when citral

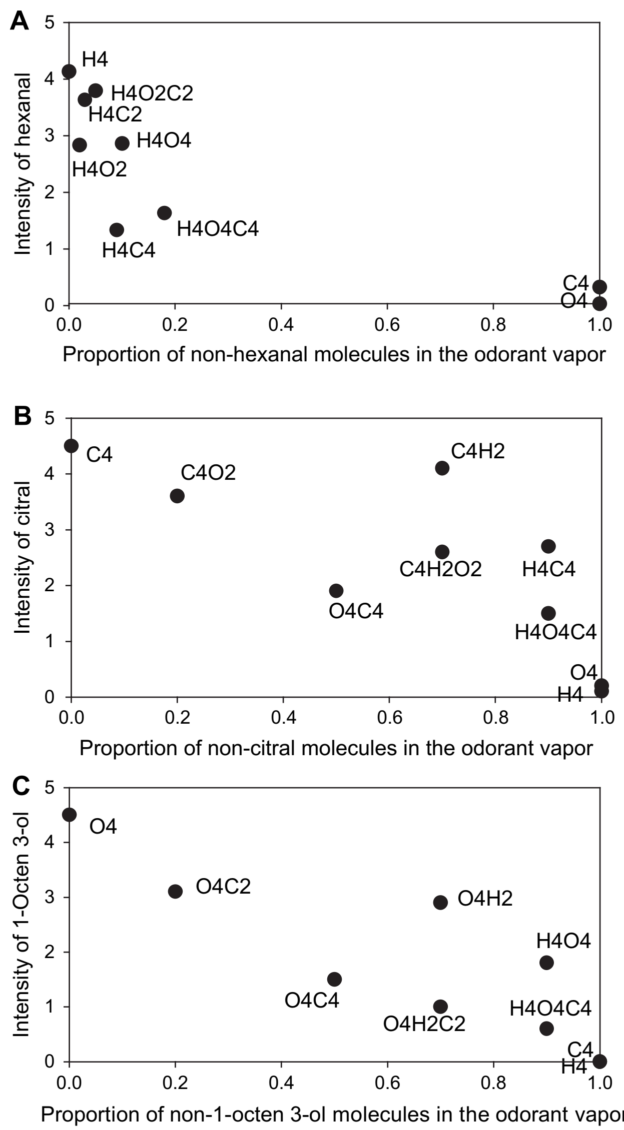

Figure 4 Intensity of target odor note, produced by a fixed quantity of the odorant, mixed with different proportions of other odorant vapors.

accounted for 10% (Figure 4B). Depending on the target odorant, substitution in the same given proportion lowered the odor intensity of the component to a very different extent. From model equations, it was calculated that dilution of the unmixed components, in a proportion equal to the substitution, would have produced much smaller intensity differences between the individual components. Varying the absolute or the relative concentration of individual components of mixtures does not result in equivalent impacts on odor intensity. Whereas variation of intensity with the absolute concentration is driven on one single dimension (less/more), variation involving changes in the relative concentrations must account for the quantitative and qualitative aspects.

Ideally, probability for trapping a component's molecule at a fixed location on a given span of time should be equally depressed by dilution of the unmixed and a proportional lowering of the relative concentration of the mixed component. Figure 5 shows that, in most cases, the intensity of the odor of citral in mixtures of equivalent dilutions decreased less than anticipated from model equations. Differences in the measured odor intensities suggest that overall perception involves other factors that are currently undetermined, despite formal equality in the supply of incident citral molecules. These factors, which have different impacts on citral and the other odorants, are most likely "qualitative" factors (for instance, components' association coefficients with receptor sites, if different). Qualitative aspects can also be observed to a larger extent by the odor of citral fading caused by 1-octen-3-ol (Figure 5) compared with equally strong hexanal. As suspected above from the lack of transitivity of odor prevalence, the potential for pertinent transposition of characteristics assessed from pure components to mixtures is very limited. The true impact has to be approached through an integrated grading of the sensory influences of all mixture components.

Previously, Patte and Laffort (1979) introduced an indicator of the nominal relative impact of individual components (A and B) paired in a mixture of odorants (AB). The indicator, named "τ value," was calculated from the intensities (R_A and R_B) measured from the unmixed components; numerical values are obtained from the ratio (R_A (or R_B)/($R_A + R_B$)). A and B share a common τ value (0.5) when equally strong individual components are paired. Olsson (1994) proposed a substitution for R_A and R_B in the ratio; the intensities were measured from the mixture (R'_A and R'_B), and the related indicator was named "τ′ value." Equality of τ and τ′ values for a given odorant in a binary system states conformity of the real to the intended intensity balance of the paired components. In other words, if mixing has impacted the intensity of the individual odorants, the quantitative changes that affected the components were proportional. Then, relevant prediction of a complex system can be made from known characteristics of the individual components. τ and τ′ calculated for mixed (binary and ternary) isointense (level 4) odorants are presented in a ternary diagram on Figure 6. Whatever mixture composition, τ and τ′ were not equal, indicating imbalanced interactions between the components. 1-octen-3-ol displayed consistently lower τ′ values than the associated odorants, suggesting partial odor suppression on mixed presentation. Incidental effects on the mixed components upset the even balance composed of isointense odorants. At the moment, cross-connections (on temporal and hedonic aspects) between the mixed components are omitted by available models.

Samples containing citral mixed with other isointense components were mapped in Figure 7. Segment lines connecting H4C4 to H4O4C4 (assessment of hexanal odor) and O4C4 to H4O4C4 (assessment of 1-octen-3-ol odor) intersected

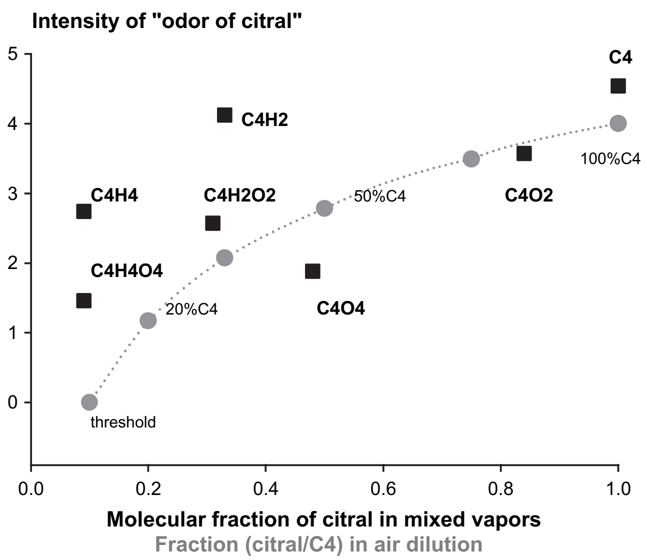

Figure 5 Intensity of odor of citral on mixed and unmixed presentations of citral, plotted against molecular dilution of C4 vapors.

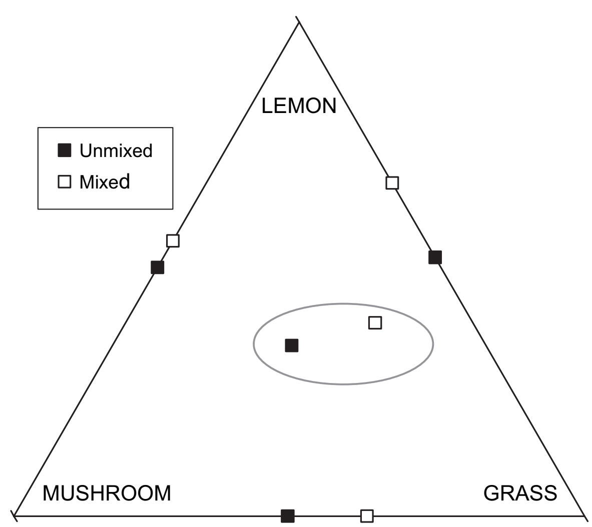

Figure 6 Map of mixtures of isointense components, according to τ (calculated from unmixed data) and τ′ (measured from mixed systems).

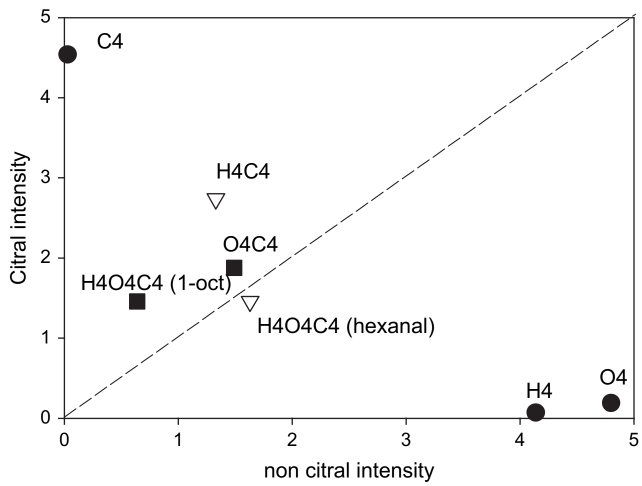

Figure 7 Mixtures containing isointense components mapped according to the intensity plot of their individual notes. Filled squares refer to "odor of 1-octen-3-ol" and open triangles to "odor of hexanal."

at a right angle. This suggested that the panel used independent indicators for assessing odor intensity of hexanal and 1-octen-3-ol. Odor quality was viewed as the more likely specific contributor. Attribution of a distinctive odor note (sensory tag) to the individual component by the panelists was assumed reasonable. An overview of the quantitative and qualitative impacts of interactions between odor notes can be observed from the respective location of the ternary H4O4C4 and the binary parent samples on the map. Addition of hexanal (H4) to O4C4 depressed the intensity of citral (slightly) and 1-octen-3-ol (severely), whereas addition of 1-octen-3-ol (O4) to H4C4 hindered citral intensity (severely) but tended to increase hexanal intensity. This latter evidence may seem to conflict with the constant odor fading observed on pairing single components. In fact, ternary systems involve many qualitative aspects not applicable to parent binary systems, making the contradiction more symbolic than actual. Investigating temporal effects, Jinks and Laing (1999) stated the difficulty of pertinent extrapolation of data from binary to more complex systems. In fact, it must be realized that "quality" in odorant mixtures is directed by both the number and the identity of the mixed components. For example, odor suppression in mixtures involves either intrinsic quality (e.g., dominance of the woody over the fruity note) or components' distributions (i.e., the higher the number of mixed components, the lower the odds for correct discrimination).

The combined implication of individual characteristics and mixture peculiarities (number of associated components) increase incertitude in the application of stable general rules. Paying attention to apparent artifacts can help in finding information about peculiar effects.

Hexanal concentration, contained in the reference sample H2, made only 20% of the unmixed reference H4. In the second round, at constant H4 absolute concentration, decreasing the proportion of hexanal in mixed vapors by 20% (Figure 4A) produced an almost complete suppression of the "odor of hexanal." Causes for this striking difference in the sensory performance of hexanal, under the mixed and the unmixed presentation, were not clearly identified. The trend in perception of a higher intensity of "odor of hexanal" from H4C4O4 rather than H4C4 (Figure 4A) was not anticipated. The binary presentation elicited a higher proportion of hexanal in the headspace that would reasonably favor more active molecules docking to receptors. The lack of correlation of the intensity variation with the available vapor fraction must have arisen at a later stage in the evaluation process. It is clear that exportation of facts and conclusions from simpler to complex systems is never guaranteed. With unmixed components, odor intensity is mainly controlled by the flow of identical caught molecules, whereas with mixtures, the state of the balance between the different trapped components yields multidimensional information. In the former situation, integration of the overall signal is basically quantitative, whereas in the latter, integration of the primary signal is exposed to substantial alteration by perceptual interactions.

The ternary sample H4C2O2 is observed above H4O2 and close to H4C2 on Figure 4A. Hence, addition of citral (C2) to the binary H4O2 resulted in apparent restoration of the intensity of hexanal odor, similarly to the addition of O4 (Figure 7) to H4C4. In either ternary mixture, the odor of hexanal has taken advantage of the co-occurrence of citral and 1-octen-3-ol, suggesting reciprocal inhibition. On the other hand, conjunction of citral and hexanal produced almost total odor suppression of the third component as indicated in Figure 6 by the τ' value of 1-octen-3-ol in H4C4O4.

We would certainly have missed cross-effects attached to mixture complexity if we had restrained investigations to binary systems. Inversely, increasing the number of components expands the scope of accessible information (Laing 1994) and lowers the chance for stable recovery of a given emission, leaving a larger space for perception variation.

Conclusion

Opportunistic combination of the components' characteristics determines the perception of odor intensity on odorant mixtures. Perception effectively involves quantitative and qualitative characteristics of all the associated components. Progression toward sensible modeling of the respective role of components is hindered by the lack of an established hierarchy in odorants and incertitude on the stability of the human detector. Further modeling of the intensity of mixed components must not focus heavily on basic systems as the validity of information obtained on simple mixtures does not readily extend to complex ones. In particular, simulations based on unmixed components must be revisited because individual evaluations might miss the impact of perceptual interactions.

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