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Selection of Odorants for Memory Tests on the Basis of Familiarity, Perceived Complexity, Pleasantness, Similarity and Identification

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Abstract

In a procedure for the selection of two equivalent sets of familiar and two equivalent sets of unfamiliar odours for use in odour memory studies, 24 naïve subjects were first asked to rate the familiarity, perceived complexity and pleasantness of 54 *a priori* unfamiliar odours and 57 *a priori* familiar odours and to identify the latter. After selection of the 40 most familiar and the 40 least familiar odours, the subjects sorted each of these two sets into groups of similar odours. Their results were analysed by multidimensional scaling and cluster analysis and each set was divided into two recognition sets that had the same degree of similarity between target and distractor odours and that had similar values of familiarity, pleasantness, perceived complexity (familiar and unfamiliar sets) and identifiability (familiar sets). Finally, recognition tasks were performed in order to check the equivalence in memory performance of both the two familiar and the two unfamiliar recognition sets.

Introduction

Recognition tasks are commonly used for studying odour memory. In a first acquisition stage subjects smell target odours that they then have to recognize among distractor odours in a second recognition stage. The present paper describes an odour selection procedure for recognition experiments. This procedure was used for selecting two equivalent sets of familiar odours and two equivalent sets of unfamiliar odours in order to study the impact of different learning and/or retrieval procedures on recognition performance using within-subject designs in later experiments (Sulmont *et al*., 1998; Sulmont and Senouci, 1999).

Several odour characteristics may influence recognition performance. An earlier study (Rabin and Cain, 1984) showed that odours that were identified more accurately during the acquisition stage were also more accurately recognized during the recognition stage. That study also found a correlation between odour familiarity and recognition performance. No relationship was found between pleasantness and recognition performance (Lawless and Cain, 1975), but many studies have observed a strong relationship between pleasantness and familiarity (Jellinek and Köster, 1979, 1983; Issanchou *et al*., 1987; Porcherot, 1995; Ayabe-Kanamura *et al*., 1998). To our knowledge, the impact of odour complexity on recognition performance has never been studied, but the fact has been pointed out that the perceived complexity of a stimulus partly determines the arousal potential of this stimulus (Berlyne, 1960). Thus, the perceived complexity of an odour might influence the strength of the mnesic trace of this odour by attracting the attention of the subject towards it. Finally, the similarity of odours has been shown to have a strong influence on recognition performance (Engen and Ross, 1973; Lawless and Cain, 1975; Jones *et al*., 1978). These last authors found a correlation between judgements of similarity and the confusions in a recognition task. The more the distractor odours were similar to the target odours, the more they were confused during the recognition stage.

These different odour characteristics (idendifiability, familiarity, pleasantness, perceived complexity and similarity) were taken into account in the selection of two equivalent recognition sets of familiar odours and two equivalent recognition sets of unfamiliar odours. The selection procedure consisted of three steps. The aim of the first step was to select 40 odours rated as familiar and 40 odours rated as unfamiliar by subjects with no previous experience in sensory analysis or odour research. Odour pleasantness, odour perceived complexity and familiar odour identifiability were also measured during this step. The aim of the second step was to divide each set of 40 odours into two recognition sets that had the same degree of similarity between the target and distractor odours and that had similar values of familiarity, pleasantness, perceived complexity (familiar and unfamiliar sets) and identifiability (familiar sets). The aim of the third step was to check whether each of the two familiar sets on one hand and each of the two unfamiliar sets on the other gave rise to a same range of recognition performance.

Step 1: selection of 40 familiar odours and 40 unfamiliar odours

Materials and methods

Usually, odour familiarity is measured by a scale ranging from 'not familiar' to 'very familiar' (Rabin and Cain, 1984; Issanchou *et al*., 1987) and odour perceived complexity is measured by a scale ranging from 'few odour notes' to 'many odour notes' (Jellinek and Köster, 1979, 1983; Issanchou *et al*., 1987). However, the fact that familiarity and, in particular, perceived complexity could include several subdimensions was pointed out in an earlier study (Porcherot, 1995). That author proposed several scales for measuring each of these dimensions and their questionnaire was adopted in the present experiment and its validity will be discussed.

Since recall of odour names is very difficult (Lawless and Engen, 1977), the identifiability of familiar odours was evaluated by a multiple-choice procedure.

Subjects

Twenty-four subjects with no previous experience in sensory analysis and no self-reported problems in their sense of smell were recruited. They were balanced for gender and age: young subjects (four females and four males of mean age 23 years and range 20–25 years), middle-aged subjects (four females and five males of mean age 39 years and range 35–44 years) and elderly subjects (four females and three males of mean age 68 years and range 64–73 years). The subjects were paid for their participation.

Odorants

Two approximately equally sized sets of odorants were selected: a set of 54 odorants supposed to have an unfamiliar odour, i.e. an odour not present in the subjects' daily environment and a set of 57 odorants supposed to have a familiar odour, i.e. an odour often smelled in the subjects' everyday life. This latter set consisted of essential oils, food and non-food flavours, food and non-food products and monomolecular chemicals (Table 1), whereas the unfamiliar set contained single molecules and mixtures of a few monomolecular chemicals (Table 2).

Each odorant was diluted in order to obtain a solution similar in odour intensity to a solution of butan-1-ol at 0.20 ml/l. This concentration was chosen because it has a weak intensity and, thus, limits olfactory adaptation during tests. The odorants were diluted in mineral oil with the exception of alcohol vinegar, bleach, Viandox® and caramel, which were diluted in distilled water. The odorant concentrations are presented in Tables 1 and 2.

The odorants were prepared 1 week before the first session. The odorous solutions were poured into 60 ml brown glass flasks (12.5 ml per flask). Each flask contained a 110 × 55 cm piece of absorbent tissue (absorbent sheet type P110, OSI, France) in order to increase the exchange area between the solution and the flask air. The flasks were stored at 5°C except flasks of Viandox® and surimi flavour, which were stored at –10°C in order to avoid bacterial contamination. One hour before sessions they were placed at 20.5 ± 0.5°C. A three-digit random number coded each flask, which was different in each session.

The subjects were instructed to open the jar and smell the odorant by breathing normally, without sniffing. The subjects were allowed to smell the odorants as many times as they needed while completing the tests. A break of 30 s was imposed on the subjects after each odorant in order to prevent olfactory adaptation. If a subject perceived no odour when smelling an odorant, he or she did not complete the test for this odorant.

Measurement of familiarity, perceived complexity and pleasantness

The subjects were asked to rate the familiarity, perceived complexity and pleasantness of each odour during three sessions of ~80 min duration.

After smelling an odorant, the subjects answered questions on eight items: four on familiarity, three on perceived complexity and one on pleasantness. They gave their answers on 12 cm linear scales labelled at each end of the scale. The familiarity items [familiar (this odour is unfamiliar/very familiar), oftenmet (do you smell this odour rarely/very often), known (this odour is composed of unknown product(s)/well-known product(s)) and memories (this odour recalls you few memories/many memories)] and complexity items [complex (this odour is simple/complex), describe (this odour seems to you easy to describe/difficult to describe) and notes (this odour is composed of few odour notes/many odour notes)] were chosen from the questionnaire mentioned above (Porcherot, 1995). The familiarity item 'this stimulus is unknown/very known' used in the earlier study (Porcherot, 1995) was changed to 'this odour is composed of unknown product(s)/well-known product(s)'. Indeed, some unfamiliar odours could be perceived as unusual mixtures of familiar odours (for example, a mixture of garlic and strawberry). No item definition was provided to the subjects, who were encouraged to answer according to their own interpretation. Odour pleasantness was measured by the question 'Do you like this odour?' with answers 'not at all/a lot' (liking).

The presentation order of the items was the same for all odorants and all subjects. In order to limit the number of pages of the questionnaire, two items appeared on each page, but items measuring the same concept were never presented consecutively. The presentation order of the 111 odorants followed a Williams Latin square design. Thirty-one odorants were evaluated during the first session and 40 during the second and third sessions.

Table 1. List of odorants supposed to have a familiar odour

Odorant	Abbreviation	Expected label	Concentration	
			Step 1	Step 2
(-)Carvone	MIN	mint	2.50 ml/l	2.50 ml/l
(2*E*,6*Z*)Nona-2,6-dienal	CUC	cucumber	0.01 ml/l	0.01 ml/l
(*E*)Anethole	ANI	anise	0.60 ml/l	0.60 ml/l
(*E*)Cinnamaldehyde	CIN	cinnamon	1.00 ml/l	1.00 ml/l
(*Z*)Hex-1-en-3-ol	GRA	grass	0.05 ml/l	0.20 ml/l
Alcohol vinegar		vinegar	100.00 ml/l	
Allyl isothiocyanate	MUS	mustard	0.25 ml/l	0.25 ml/l
Apple flavour[a]	APL	apple	0.50 ml/l	0.50 ml/l
Banana flavour[b]	BAN	banana	0.50 ml/l	0.50 ml/l
Bitter almond flavour[c]	ALM	bitter almond/paste	2.00 ml/l	2.00 ml/l
Bleach		bleach	5.00 ml/l	
Blue cheese flavour[d]		cheese	0.25 ml/l	
Buchu (essential oil)[e]	BUC	cat's urine/blackcurrant	0.50 ml/l	0.50 ml/l
Butane-2,3-dione	BTT	butter	0.05 ml/l	0.05 ml/l
Cherry flavour[a]	CHE	cherry	0.20 ml/l	0.20 ml/l
Chocolate flavour[a]		chocolate	0.50 ml/l	
Coffee flavour[a]	COF	coffee	0.40 ml/l	0.40 ml/l
Ethanol 90-95%		alcohol	10.00 ml/l	
Ethylfenchol	EAR	earth	0.20 ml/l	0.20 ml/l
Eucalyptus (essential oil)[f]	EUC	eucalyptus	1.00 ml/l	1.00 ml/l
Eugenol		clove	0.50 ml/l	
Garlic (essential oil)[g]	GAR	garlic	0.10 ml/l	0.10 ml/l
Geraniol		rose	0.10 ml/l	
Honey flavour[a]		honey	1.00 ml/l	
Incense (essential oil)[e]		incense	1.00 ml/l	
Isovaleric acid		sweat/foot	0.01 ml/l	
Lardon flavour[h]	SMO	smoked	undiluted	undiluted
Laurel (essential oil)[e]	LAU	laurel	0.30 ml/l	0.30 ml/l
Lavender fragrance[a]	LAV	lavender	1.00 ml/l	1.00 ml/l
Leather fragrance[a]		leather	2.00 ml/l	
Leek (essential oil)[e]	LEE	leek	1.00 ml/l	0.40 ml/l
Lemon (essential oil)[f]	LEM	lemon	2.50 ml/l	2.50 ml/l
Lily of the valley fragrance[a]	LIV	lily of the valley	0.50 ml/l	0.40 ml/l
Liquid caramel[c]	CAR	caramel	500 g/l	1 kg/l
Liquorice flavour[a]	LIQ	liquorice	0.50 ml/l	0.50 ml/l
Methional		potatoes	0.025 ml/l	
Methyl salicylate	MOU	mouthwash	5.00 ml/l	3.00 ml/l
Musk fragrance[a]		musk	0.10 ml/l	
Naphthalene		mothballs	0.07 ml/l	
Nutmeg (essential oil)[e]	NUT	nutmeg	1.00 ml/l	1.00 ml/l
Oct-1-en-3-ol	MUH	mushroom	0.05 ml/l	0.05 ml/l
Octanoic acid		goat	2.50 ml/l	
Olive oil	OLI	olive oil	undiluted	undiluted
Orange flavour[a]	ORA	orange/grapefruit	1.00 ml/l	2.00 ml/l
Parsley (essential oil)[e]		parsley	7.50 ml/l	
Peach flavour[i]	PEA	peach	1.00 ml/l	1.00 ml/l
Pepper (essential oil)[h]		pepper	2.00 ml/l	
Pine (essential oil)[j]	PIN	pine	0.50 ml/l	0.50 ml/l
Rum		rum	10.00 ml/l	
Strawberry flavour[a]	STR	strawberry	0.50 ml/l	0.50 ml/l
Styrene		plastic	0.05 ml/l	
Surimi flavour[k]		crab	10.00 ml/l	
Thyme (essential oil)[f]	THY	thyme	0.40 ml/l	0.40 ml/l
Trimethylamine		fish	0.02 ml/l	
Vanillin	VAN	vanilla	0.10 ml/l	0.10 ml/l
Viandox®	MEA	meat stock	3.00 ml/l	3.00 ml/l
β-ionone		violet	5.00 ml/l	

[a]Sentosphère (France); [b]Systems Bio-Industries (France); [c]Malilé (France); [d]International Flavors & Fragrances (France); [e]Sanoflor (France); [f]Lozano (Spain); [g]Laboratoire CRMN, Toulouse (France); [h]home made preparation; [i]Givaudan (France); [j]Coopération Pharmaceutique Française, Melun (France); [k]Proextrait Lyraz, Fresnes (France).

Table 2. List of odorants supposed to have an unfamiliar odour

Odorant	Abbreviation	Concentration (ml/l)	
		Step 1	Step 2
1,1-Dimethyl-2-phenylethanol[a]	DPE	10.00	10.00
1-Methyl-4-isopropyl-benzene[a]	MIB	1.00	1.00
1-Phenylethyl acetate[a]	PAC	1.00	1.00
2,6-dimethylhept-5-enal[a]	DHA	0.50	1.50
2-Methyl-6-methylene octan-2-ol[a]	MMO	2.00	2.00
2-Phenylethyl ethyl ether[a]	PEE	1.00	0.70
2-Phenylethyl pentyl ether[a]	PPE	1.00	2.00
3,4,5,6,6-Pentamethyl hept-3-en-2-one[a]		0.20	
3,7-Dimethyloctanenitrile[a]	DON	3.00	4.00
4-Methoxy-1-methylbenzene[a]	MMB	0.25	0.25
4-Methylacetophenone	MAP	0.25	0.25
4-Phenylbutan-2-one[a]	PBO	2.00	2.25
5-methyl heptan-3-one oxime[a]	MHO	1.00	1.00
Adoxal (2,6,10-trimethyl undec-9-enal)[a]	ADO	5.00	7.50
Bornyl acetate	BOR	1.00	2.00
Buccoverte forte base[a]	BFB	2.00	2.00
Butan-1-ol	BUT	0.20	0.45
Calone (7-methyl (2H,4H)-1,5,benzodioxepin-3-one)[a]		1.50	
Cashmeran (1,1,2,3,3-Pentamethyl-6,7-dihydro-(5H)-indan-4-one)[a]		1.00	
Citrowanil (2-ethenyl-2-methyl benzenepropanal)[a]	CIW	0.25	0.50
Cyclabute (4,7-methano-2-methyl-3a,4,5,6,7,7a-hexahydro-(1H)-inden-5-yl propanoate)[a]	CYC	5.00	7.50
Damascenone	DAM	5.00	5.00
Dec-9-en-1-ol[a]	DEO	2.00	2.00
Decan-2-one	DEC	1.00	1.50
Diethyl malonate	DMA	5.00	5.00
Ethyl-2-ethyl-6,6-dimethylcyclohex-2-en-1-yl carboxylate[a]	EDC	5.00	5.00
Floralozone (4-ethyl-2,2-dimethyl benzenepropanal)[a]		4.00	
Galbanum (artificial essence)[a]		0.50	
Galbex 183®[a]	GAL	5.00	5.00
Heptan-2-one[a]	HEP	0.20	0.20
Herbac (1-acetyl-3,3-dimethyl cyclohexane)[a]	HER	0.25	0.25
Hex-2-enal	HEX	0.05	0.10
Isobutyl quinoline[a]	QUI	1.00	1.00
Lilestralis (4-tertiobutyl-2-methyl benzenepropanal)[a]	LIL	3.00	6.00
Linalool[a]		0.50	
Linalool oxyde[a]	LOX	5.00	5.00
Linalyl acetate	LIA	5.00	7.50
Menthyl acetate	MEN	0.40	0.40
Methyl anthranilate[a]		0.25	
Methyl benzoate[a]	MBE	0.10	0.10
Nonyl acetate	NON	0.40	0.40
Octan-1-ol	OCT	0.25	0.25
Petylyn[a]	PET	1.00	1.00
Physeol (2-Ethoxy-2,6,6-trimethyl-9-methylene bicyclo[3.3.1]nonane)[a]	PHY	2.00	4.00
Piperonal (3,4-Methylenedioxy benzaldehyde)	PIP	5.00	5.00
Plicatone (1,4-Methano-7-methyl-(2H)-octahydronaphthalene-6-one)[a]	PLI	4.00	4.00
Terpinyl acetate	TER	1.00	1.00
Tridec-2-enenitrile[a]	TDN	0.40	0.50
Tridecan-2-one	TRI	2.50	2.50
Verdox (2-Tertiobutyl cyclohexyl acetate)[a]		10.00	
Vetival (4-Cyclohexyl-4-methyl pentan-2-one)[a]	VET	2.00	4.00
Vigoflor (Perhydro spiro[2-furane-2,5′-(4′,7′-methano)indene])[a]	VIG	2.00	2.00
Viotril[a]		0.10	
α-Ionone[a]	ION	0.25	0.25

[a]Provided by International Flavors & Fragrances (The Netherlands).

Identification of odours

The subjects were asked to identify the odour of the 57 odorants supposed to be familiar during a session of ~90 min.

After smelling an odorant, the subjects had to find the name of its odour amongst a list of 68 descriptors sorted in alphabetical order. This list contained 60 expected labels, i.e. labels that were supposed to be the names of the familiar odours (Table 1) and eight distractor labels. With regard to the chemicals the expected labels were the names usually associated with their odour (for example, mushroom for oct-1-en-3-ol), with regard to the essential oils and flavours the expected labels were the names given by the manufacturer and with regard to the natural products the expected labels were the names of the product (bleach, olive oil, etc.). Three labels were added to the initial list of 57 expected labels because the odour of three odorants could be identified by two names. According to our experience essential oil of buchu could be perceived either as 'odour of cat's urine' or as 'odour of blackcurrant', orange flavour could be perceived either as 'odour of orange' or as 'odour of grapefruit' and bitter almond flavour could be perceived either as 'odour of bitter almond' or as 'odour of paste' (a particular adhesive *colle blanche* in French). The distractor labels were coconut, exotic fruit, lilac, musty, onion, polish, soap and tomato. The presentation order of the odorants followed a Williams Latin square design. No identification was asked for the 54 odorants supposed to have an unfamiliar odour as no expected label was available for their odours.

Experimental conditions

The tests were conducted in a sensory room equipped according to a known standard (AFNOR, 1987). A red light was used during odorant evaluation in order to mask potential colour differences. The room temperature was 20.5 ± 0.5°C. The subjects answered questionnaires on the FIZZ data acquisition system (FIZZ software, Biosystèmes, Couternon, France). The three sessions for measuring familiarity, perceived complexity and pleasantness and the identification session took place on separate days.

Data analysis

All statistical analyses were conducted using SAS/STAT® (SAS, 1989).

Responses on the 12 cm linear scales for measurement of familiarity, perceived complexity and pleasantness were converted into scores varying from 0 (left of the scale) to 100 (right of the scale). Individual scores were averaged per item and per odorant.

When a subject associated the odour of an odorant with its expected label, the answer was scored as correct. The frequency of correct identification was determined for each odorant.

Results and discussion

Measurement of familiarity, perceived complexity and pleasantness

Selection of relevant indices of familiarity and perceived complexity. Linear regressions performed between the familiarity items (familiar, known, oftenmet and memories) showed a strong correlation between those items ($R^2 > 0.85$ and $P < 0.001$). One could argue that, due to the fixed order of item presentation, a response to one item may have systematically influenced the response to a later one. Namely, if one claimed to experience an odour quite often (item oftenmet), one might be inclined to claim that many memories were associated with it (item memories). However, a high correlation between familiarity items by using different random orders of items was also found in another study (Porcherot, 1995). A global index of familiarity (familiarity) was calculated by averaging the scores of the items oftenmet, memories, known and familiar.

A strong negative relationship was found between the item describe and the index familiarity, indicating that an odour perceived as easy to describe was also perceived as familiar ($R^2 = 0.91$ and $P < 0.001$). The subjects may have understood the question 'this odour seems to you easy to describe/difficult to describe' in the sense of 'do you know the name of this odour?' In other words, this question would measure a familiarity dimension (the subjects' feeling of knowing the odour's name) rather than a psychological complexity dimension (the subjects' feeling of being puzzled when smelling the odour). These results led us to remove the item describe in further odour selection.

No relationship was found between the items complex and notes, indicating that these items measure different dimensions of perceived complexity ($R^2 = 0.03$ and $P > 0.05$). According to an earlier study (Berlyne, 1960) complexity increases with the number of elements and the dissimilarity between perceived elements and inversely varies 'with the degree to which several elements are responded to as a unit', i.e. with a subject's ability to arrange the perceived elements in a meaningful unit. Our results suggest that the item notes reflects the number of perceived notes in an odour, while the item complex reflects the degree to which a subject is able to interpret an odour meaningfully. On the basis of these results, the items complex and notes were taken into account separately in further odour selection.

In summary, the familiarity of an odour appears to be unidimensional, while the perceived complexity of an odour seems to include at least two dimensions: the number of perceived odour notes and a subject's ability to interpret an odour meaningfully. Since no item definition was provided to the subjects, one could claim that the words 'simple' and 'complex' (item complex) and the notion of 'odour notes' (item notes) were too ambiguous to warrant a uniform interpretation by the subjects. It was recently proposed that the perceived complexity of an odour should be measured by the question 'this odour is ordinary/surprising' (Lévy, 1998). That author found a strong correlation between this question and the question 'this odour is simple/elaborated', which is close to our complex question. However, more work is needed in order to specify further whether the item complex or the question proposed above (Lévy, 1998) leads to the most reliable results and to determine whether naïve subjects are able to rate the number of perceived odour notes.

Relationships between familiarity, perceived complexity and pleasantness. A strong correlation was found between the indices familiarity and liking indicating that odours rated as familiar were liked, while odours rated as unfamiliar were disliked (Figure 1). In fact, the link between familiarity and pleasantness judgement of non-odorous stimuli (Zajonc, 1968) as well as odorous stimuli (Jellinek and Köster, 1979, 1983; Issanchou *et al.*, 1987; Porcherot, 1995; Ayabe-Kanamura *et al.*, 1998) is well documented. More interestingly, the familiarity index is more strongly correlated with the complex index than with the notes index (Figure 1). The more an odour was rated as familiar the more it was rated as simple, while the number of perceived odour notes remained relatively independent from odour familiarity. An earlier study found a similar result (Porcherot, 1995). As mentioned in the previous paragraph, the item notes seems to reflect the number of perceived notes in an odour and the item complex seems to reflect a subject's ability to meaningfully interpret an odour. According to other work a subject's ability to arrange perceived stimuli in a meaningful unit depends heavily on the subject's knowledge about relationships between these stimuli (Berlyne, 1960). Hence, it is not surprising to find a stronger relationship between the indices familiarity and complex than between the indices familiarity and notes.

With regard to the relationship between familiarity and pleasantness, some odorants appeared to be quite dissociated from the others (the encircled odorants in Figure 1). The odours of bleach, trimethylamine, isovaleric acid and blue cheese flavour were disliked and at the same time were rated as familiar. These odorants were not selected in the final sets because their odours might have been perceived as very different from the other familiar odours and, thus, might have been easier to memorize and/or recognize during future recognition tests. Such outliers were not found with regard to the relationship between familiarity and perceived complexity indices.

Identification of odours

The frequency of correct identification varied from 0.92 for bleach to 0.0 for chocolate flavour (mean = 0.43 ± 0.06). Since nobody associated the odour of chocolate flavour with the label chocolate, but 21 and 17% of the subjects respectively associated this odour with the labels caramel and vanilla, this odorant was eliminated. Indeed, the odours

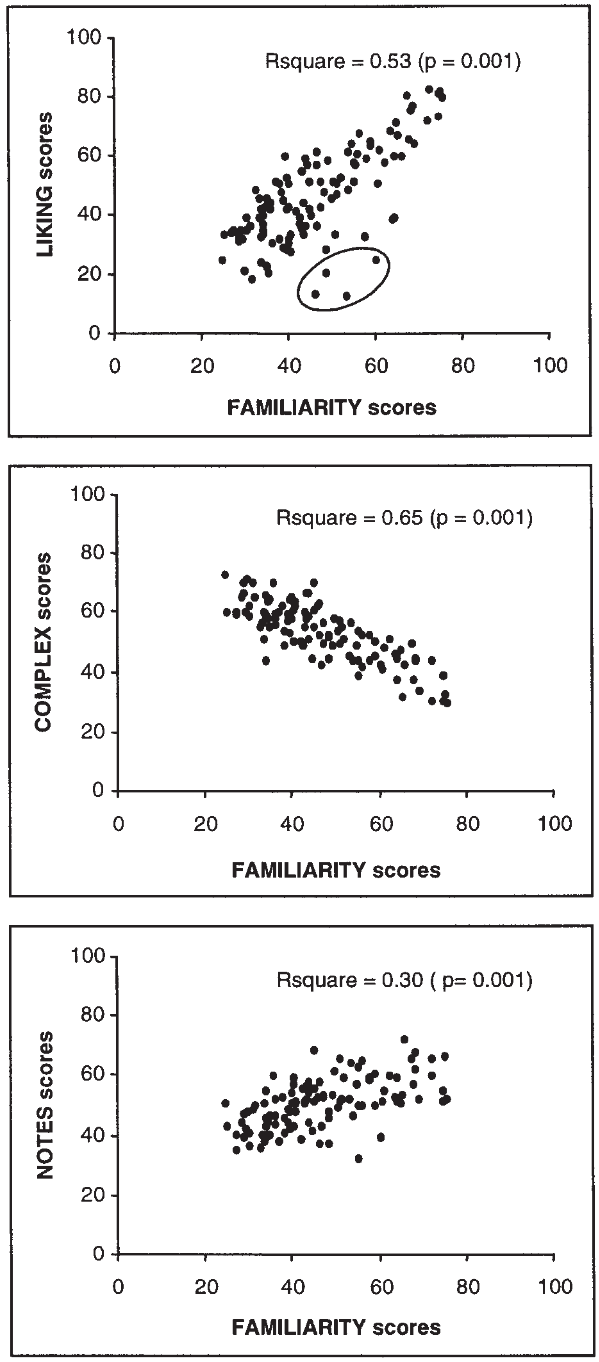

Figure 1 Relationships between the familiarity scores and the liking, complex and notes scores (individual scores were averaged per odorant).

of caramel (liquid caramel) and of vanilla (vanillin) were already included in the familiar set.

Specific hyposmia

Two odorants, geraniol and 3,4,5,6,6-pentamethylhept-3-en-2-one, were eliminated because approximately one-third of the subjects seemed to have a specific hyposmia for these odorants, namely 24 and 29% of the subjects did not perceive geraniol and 3,4,5,6,6-pentamethyl hept-3-en-2-one respectively. Geraniol has been previously reported to exhibit specific hyposmia in humans (Amoore, 1977), but so far no data on specific hyposmia for 3,4,5,6,6-pentamethylhept-3-en-2-one have been found in the literature. The percentage of non-perception was below 20% for each of the other odorants.

Selection of 40 familiar odours and 40 unfamiliar odours

After elimination of the odorants mentioned above, the 40 odorants with the highest familiarity scores and the 40 odorants with the lowest familiarity scores were selected as preliminary sets of familiar and unfamiliar odours respectively. Surprisingly, the familiar set contained some odorants that had been chosen by the experimenter as supposedly unfamiliar odours, namely buccoverte forte base, piperonal, α-ionone, petylyn, galbanum, 4-methylacetophenone, verdox and calone. A panel of 10 subjects trained in sensory profiling was asked to describe their odours in order to check their identifiability. Five of the odorants were associated with one or two consensual labels by the panel: rose or lily of the valley for buccoverte forte base, vanilla or almond for piperonal, violet for α-ionone [this label agrees with an earlier description (Fenaroli, 1971)], orange blossom or marshmallow for petylyn and bitter almond or toilet cleaner for 4-methylacetophenone. No consensual label was found for galbanum, verdox and calone. Consequently, they were eliminated from the familiar set and replaced by the three odorants with the highest familiarity scores not yet selected. The unfamiliar set contained some odorants that had been chosen by the experimenter as supposedly familiar odours, namely musk fragrance, methional, styrene, ethanol, naphthalene, octanoic acid, essential oil of pepper and essential oil of incense. Nevertheless, some subjects were able to identify their odours by their correct label. Consequently, these odorants were eliminated from the unfamiliar set and replaced by the eight odorants with the lowest familiarity scores not yet selected.

According to a Student's *t*-test, the familiarity scores of the odours of the familiar set (mean = 61.1 and $\alpha = 8.5$) were significantly higher than the familiarity scores of the odours of the unfamiliar set (mean = 35.3 and $\alpha = 5.2$) ($t = 16.4$ and $P < 0.001$). Nevertheless, the difference between the minimal familiarity score of the familiar set (46.7) and the maximal familiarity score of the unfamiliar set (43.9) was very small. The familiarity scores were distributed along a continuum rather than divided into two well-defined classes.

Step 2: division of each set of 40 odorants into two recognition sets

Materials and methods

The aim of this step was to divide each set of 40 odorants into two recognition sets that had the same degree of similarity between the target and distractor odours and that had similar values of familiarity, pleasantness, perceived complexity (familiar and unfamiliar sets) and identifiability (familiar sets). Odour similarities were measured by a sorting task for each set (Lawless, 1989; MacRae *et al.*, 1990).

Odorants

During the previous step the concentrations of the odorous solutions were chosen by the experimenter in order to obtain an approximately equal odour intensity for all odorants. However, a pre-test was carried out to procure iso-intense odorous solutions in order to reduce the influence of odour intensity on the sorting criteria and on memorization in later recognition tests. Ten subjects (nine females and one male with range 2–55 years) who were all experienced in sensory profiling were recruited. A range of five increasing concentrations of butan-1-ol (0.05 ml/l, 0.10 ml/l, 0.20 ml/l, 0.40 ml/l and 0.80 ml/l) was used as a reference. The subjects rated the odour intensity of each odorous solution on a 13-point scale, points 3, 5, 7, 9 and 11 of which respectively corresponded to the butan-1-ol solutions at 0.05, 0.10, 0.20, 0.40 and 0.80 ml/l. Odorous solutions rated as less intense than the butan-1-ol solution at 0.20 ml/l and odorous solutions rated as more intense than the butan-1-ol solution at 0.40 ml/l were re-prepared at higher or lower concentrations respectively. Three successive trials (rating and concentration adjustment) were necessary in order to reach these criteria for all solutions. The final concentrations are given in Tables 1 and 2. In addition to this pre-test, the odorous solutions' purity was checked by gas chromatography olfactometry (sniffing odours at the sniffing port of a gas chromatograph).

The odorants were diluted, stored and presented using the same procedure as that used during step 1.

Sorting task

The sorting task was performed by the 24 subjects recruited for step 1. Two sessions, of ~75 min duration took place on separate days, 1 month after step 1. Half of the subjects received the familiar set during the first session and the unfamiliar set during the second session and the other half proceeded in the reverse order. The subjects sorted the 40 odorants of a set into groups of samples having a similar odour during each session. They were allowed to form as many groups as they wanted, but at least two groups. To help them to perform this task, they could take notes about their sorting criteria. When the subjects had finished they were encouraged to review their groups and to check whether they were satisfied with the grouping they had made. The experimental conditions were the same as those used during step 1.

Data analysis

A similarity matrix was prepared for each set of 40 odorants by summing the number of times each pair of odorants was sorted into the same group over all subjects. The greater the number in a cell of the matrix was, the greater the presumed subjective odour similarity of the odorants intersecting at that location. The matrices were analysed by the non-metric multidimensional scaling (MDS) procedure of the SAS. The four-dimensional representation (fit of spatial representation = 0.91 and stress = 0.12) and the six-dimensional representation (fit of spatial representation = 0.82 and stress = 0.12) were selected for the familiar and unfamiliar sets respectively. A new matrix was prepared for each set with the 40 odorants in rows and their coordinates on the selected MDS dimensions in columns. These new matrices were submitted to a hierarchical clustering (the CLUSTER procedure of the SAS). Six and five clusters were chosen for the familiar and unfamiliar sets respectively.

Results and discussion

After step 2, four odorants of each set had to be removed for different reasons and, as a result, the final recognition sets only contained nine target and nine distractor odorants instead of the 10 target and 10 distractor odorants initially planned. Terpinyl acetate, linalyl acetate, nonyl acetate and 4-methoxy-1-methylbenzene were removed from the unfamiliar set, because gas chromatography olfactometry revealed that these odorants were impure. Essential oil of buchu was removed from the familiar set because 62% of the subjects did not perceive its odour during the sorting tasks (this was probably due to an error of dilution). As was mentioned at the end of step 1, the difference between the minimal familiarity scores of the familiar set and the maximal familiarity scores of the unfamiliar odour set was very small. In order to increase this difference between the sets, odorants of the familiar set which had obtained the lowest score of familiarity, i.e. (2*E*,6*Z*)nona-2,6-dienal, (*Z*)hex-1-en-3-ol and ethylfenchol, were removed.

The clusters obtained from the familiar and the unfamiliar sets are presented in Figure 2a and b respectively. The odorants of each cluster were divided over four subsets for each set, with two subsets of nine target odorants and two subsets of nine distractor odorants. For example, the four odorants of the second familiar cluster were divided over the four subsets at the rate of one odorant per subset. Table 3 presents the final recognition sets, i.e. the familiar recognition sets Fa and Fb and the unfamiliar sets Uc and Ud. Each recognition set comprised one subset of nine target odorants and one subset of nine distractor odorants. Table 4 shows the means of the familiarity, liking, complex and notes scores for each recognition set and the means of

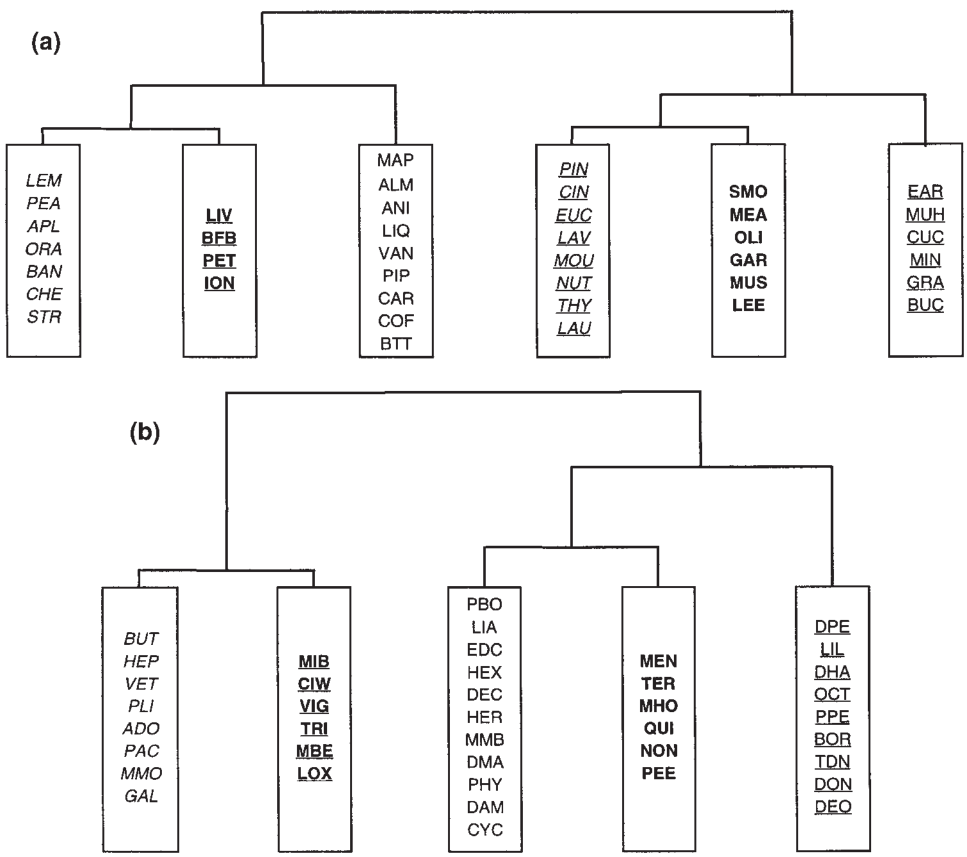

Figure 2 **(a)** Composition of the cluster groups for the familiar set. Full names of the odorants are given in Table 1. **(b)** Composition of the cluster groups for the unfamiliar set. Full names of the odorants are given in Table 2.

Table 3. Composition of the two familiar sets, Fa and Fb, and of the two unfamiliar sets, Uc and Ud

Set	Target odorants	Distractor odorants
Fa	*BAN*	*ORA*
	CHE	*PEA*
	LIV	**BFB**
	ANI	PIP
	MAP	CAR
	NUT	*LAU*
	PIN	*LAV*
	GAR	**OLI**
	MIN	MUH
Fb	*STR*	*LEM*
	PET	*APL*
	VAN	**ION**
	ALM	LIQ
	BTT	COF
	THY	*EUC*
	MOU	*CIN*
	MEA	**LEE**
	SMO	**MUS**
Uc	*PLI*	*ADO*
	PAC	*VET*
	MBE	**TRI**
	DAM	PBO
	EDC	HER
	MHO	DEC
	OCT	**PEE**
	PPE	DPE
	DEO	TDN
Ud	*BUT*	*MMO*
	GAL	*HEP*
	MIB	**LOX**
	CIW	**VIG**
	DMA	CYC
	HEX	PHY
	MEN	**QUI**
	DHA	LIL
	BOR	DON

The full names of the odorants are given in Tables 1 and 2. For each type of odorant (familiar or unfamiliar), odorants written in the same fashion belong to the same cluster (Figure 2a,b).

the frequency of correct identifications for each familiar recognition set. A Student's *t*-test performed by type of odour yielded no significant difference between either the two familiar recognition sets or the two unfamiliar recognition sets ($P > 0.05$).

Step 3: validation of the recognition sets

Materials and methods

Recognition tasks were performed in order to check whether sets Fa and Fb on the one hand and sets Uc and Ud on the other led to a same range of performance level.

Subjects

Twenty subjects who had not participated in the previous tasks were recruited. They were divided into two groups balanced for gender and age: group familiar (four females and six males with range 24–56 years) and group unfamiliar (four females and six males with range 25–51 years).

Recognition task

The subjects of group familiar performed two recognition tasks, one with set Fa and one with set Fb. The subjects of group unfamiliar performed two recognition tasks, one with set Uc and one with set Ud. The presentation order of the sets within each group was counterbalanced over subjects. A break of 1 week was taken between each task.

Each recognition task consisted of two sessions of ~30 min duration, 7 days apart. The subjects received the nine target odorants of a set during the first session (acquisition stage). The subjects were asked to answer to the questions familiar, complex, notes and liking (orientation task) for each odorant. The subjects were told to memorize the odours. The subjects then received 18 odorants in a randomized order during the second session (recognition stage). Half of the stimuli were the same as in the learning phase (target odorants) and half were new (distractor odorants). After smelling an odorant, the subjects had to say whether they had smelt its odour during the first session or not (yes/no).

As the recognition sets were to be used later for making a between-subject comparison on recognition performance, both the presentation order of the nine target odorants during the acquisition stage and the presentation order of the 18 target plus distractor odorants during the recognition stage were the same for all subjects.

The odorants were diluted, stored and presented using the same procedure as that used during step 1. The experimental conditions were the same as those used during step 1.

Data analysis

Recognition performances were determined according to signal detection theory (Banks, 1970), i.e. by computing the frequency of hits (target odours correctly recognized), the frequency of false alarms (distractor odours incorrectly recognized) and d' scores per subject and per recognition set. The index d' represents the index of detectability and it is obtained by the formula $d' = Z_{\text{hits}} - Z_{\text{false\_alarms}}$, where Z_{hits} and $Z_{\text{false\_alarm}}$ are the standard frequencies of hits and false alarms under the normal curve (Engen, 1971).

The difference in the d' scores, frequency of hits and frequency of false alarms between the two recognition sets was assessed by a related-sample Student's *t*-test for each group (familiar or unfamiliar).

Table 4. For each type of odour (familiar and unfamiliar), comparison of familiarity, liking, complex and notes scores, and of the frequency of correct identifications (familiar odours only) between the two final recognition sets (Student's *t*-test)

	Familiar odours			Unfamiliar odours		
	Set Fa	Set Fb	Student's *t*	Set Uc	Set Ud	Student's *t*
Familiarity	62.6 (σ = 7.8)	61.5 (σ = 8.9)	0.39 (ns)	34.7 (σ = 5.5)	35.1 (σ = 5.1)	–0.18 (ns)
Liking	62.2 (σ = 12.3)	58.8 (σ = 15.4)	0.75 (ns)	37.4 (σ = 7.1)	38.0 (σ = 8.9)	–0.23 (ns)
Complex	44.1 (σ = 7.4)	44.3 (σ = 9.2)	–0.07 (ns)	60.1 (σ = 5.4)	60.3 (σ = 7.0)	–0.10 (ns)
Notes	55.5 (σ = 5.7)	57.5 (σ = 7.2)	–0.93 (ns)	44.9 (σ = 6.6)	45.3 (σ = 6.6)	–0.18 (ns)
Frequency of correct identifications	55.8 (σ = 16.8)	47.7 (σ = 23.0)	1.12 (ns)			

ns, not significant.

Table 5. Means of *d′* score, frequency of hits and frequency of false alarms per recognition set

	Familiar odours			Unfamiliar odours		
	Set Fa	Set Fb	Student's *t*	Set Uc	Set Ud	Student's *t*
d′ score	1.70 ± 0.50	1.23 ± 0.55	1.77	0.94 ± 0.42	1.28 ± 0.49	–1.01
Frequency of hits	0.60 ± 0.11	0.75 ± 0.11	0.69	0.61 ± 0.06	0.59 ± 0.18	0.31
Frequency of false alarms	0.22 ± 0.11	0.33 ± 0.14	–2.53*	0.28 ± 0.11	0.15 ± 0.12	1.43

For each type of odour (familiar and unfamiliar), a related-sample Student's *t*-test was performed to determine whether means were significantly different (*$P < 0.05$; ** $P < 0.01$; *** $P < 0.001$).

Results and discussion

According to the results of a related-sample Student's *t*-test, no difference was observed between the familiar recognition sets or between the unfamiliar recognition sets, except for the frequency of false alarms of the familiar sets (Table 5). The frequency of false alarms for the set Fb was significantly higher than the frequency of false alarms for the set Fa.

In order to determine the reason for this, the frequency of false alarms was calculated for each familiar distractor odorant. The three odorants that were associated with the highest frequency of false alarms (50%) all belonged to set Fb: essential oil of eucalyptus, coffee flavour and apple flavour. The results of the identification task performed during step 1 showed that the odour of essential oil of eucalyptus (distractor odorant Fb) was identified 11 times as odour of mouthwash, which was a target odour of set Fb and that the odour of apple flavour (distractor odorant Fb) was identified four times as odour of strawberry, which was a target odour of set Fb. In order to reduce the frequency of false alarms of set Fb, apple flavour was exchanged with peach flavour (distractor odorant Fa) and essential oil of eucalyptus was exchanged with lavender fragrance (distractor odorant Fa). This last exchange should have increased the frequency of false alarms of set Fa. Indeed, according to the identification results, the odour of eucalyptus was identified seven times as odour of pine, a target odour of set Fa. It was hoped that these exchanges would harmonize the frequencies of false alarms between sets Fa and Fb. Unfortunately, no further check of this was possible under the circumstances.

Conclusion

Several odour characteristics (familiarity, pleasantness, complexity, identifiability and similarity) were taken into account in order to select recognition sets that had the same level of difficulty. The results of the third step pointed out another factor that might be taken into account in this procedure, namely the matrix of identification errors. Notwithstanding the limitations in the applicability of the resulting odour recognition sets outside the French culture, the selection procedure itself could be used anywhere. However, more work is needed in order to determine which factors are the best predictors of the range of recognition performances.

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