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Understanding the underlying dimensions in perfumers' odor perception space as a basis for developing meaningful odor maps

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Various low-dimensional perceptual maps of fragrances have been proposed in the literature, as well as sensory maps for the odor descriptors most frequently applied in perfumery. To reach a consensus, however, seems difficult, if at all possible. In the present study, we applied principal components analysis to two databases. The first contains numeric odor profiles of 309 compounds based on 30 descriptors. The loading plot corresponding to the relevant components was strikingly similar to the odor effects diagram proposed by P. Jellinek (1951), primarily on the basis of his long experience as a perfumer. We obtained similar results in our analysis of the second database, which comprises 66 descriptors and contains the semantic descriptions of 119 perfume materials. On the basis of the results of both analyses, a commercial map of fragrances is discussed. Our findings suggest that it is possible to develop standard sensory maps of perfumery odor descriptors, if a consensus is first reached regarding which odorants best represent particular odor qualities.

Odor Description and Perception: Basic Concepts

Various procedures have been proposed for describing odor character (for reviews, see Chastrette, 1998; Wise, Olsson, & Cain, 2000). Semantic methods are used frequently, because they generate data rapidly. Such methods consist of recording the words that come to mind when one smells a substance. Such words are called *odor character descriptors* or *odor aspect attributes*, and usually several are necessary for describing how a scent resembles other common odors.

Another method of odor description consists of using a numeric scale to rate the similarity between a test odor and a series of reference odorants chosen as standards for different descriptors (Schutz, 1964; Yoshida, 1975). A simplified method omits the use of reference materials in order to allow for a larger list of descriptors; instead, odor profiles are obtained by asking individuals to numerically rate attributes that describe an odor's character. Using this procedure, Dravnieks (1985) asked a panel of 120 individuals to smell 138 pure odorant chemicals and score each odorant according to the applicability of 146 descriptors. Because odor descriptions can be influenced by personal experience and subjectivity (Richardson & Zucco, 1989), the use of a panel is recommended in order to avoid bias in the assignment of odor profiles.

Whether semantic or numeric odor profiles are obtained for a representative set of compounds, the resulting database (i.e., the *odorant object space*) contains information useful for describing the relationships among compounds on the basis of perceived odorant similarity and dissimilarity. Odor databases are also useful for characterizing odor descriptor space by identifying groups of terms on the basis of their similar and dissimilar meanings; such groupings provide information about how people use different words to characterize odors. When semantic methods are used, two or more descriptors are considered to be similar if they are often applied together to describe a given smell; the opposite applies to dissimilar attributes. When numeric methods are used, two descriptors are considered to be similar if they present a significant positive correlation; they are considered dissimilar if the correlation is negative.

When people are asked to assess the dissimilarity between two odorants on a numeric scale (e.g., 0 = *identical*, 10 = *completely different*), rather similar results are expected among the assessors. By contrast, if we ask a panel to rate the woody character of a given odorant, unless a reference material is assigned for this descriptor, it is more difficult to obtain a consensus because of different preconceptions each individual has about the woody odor character. There is no general agreement

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about which materials should be chosen as references for the odor descriptors used in perfumery (Brud, 1986). Therefore, it seems easier to achieve a consensus in the description of odorant object space. This issue is relevant to perfumers, because part of their work is to determine which odorants should be chosen to develop a successful fragrance.

Despite the problems arising in the characterization of odor descriptor space, the development of standard low-dimensional perceptual maps of odor descriptors is of broad interest in perfumery for several reasons. Such maps (1) clarify consumer preference (Nute, Macfie, & Greenhoff, 1988), (2) aid in the description of complex mixtures of odorants, (3) enable training of sensory panels, (4) provide certain standards of communication among perfumers, (5) assist in perfume classification (J. S. Jellinek, 1992), and (6) allow better communication among perfume retailers and customers. Actually, with such maps the description of scents becomes easier, because the maps reflect the similarities and dissimilarities among odor categories.

Not all of the terms commonly used to describe a given odor are independent. For example, if a certain substance smells fruity, it is expected that different descriptors, such as *apricot*, *cherry*, *peach*, *pineapple*, *banana*, or *apple*, may be applied to describe the odor character. Because these fruity descriptors share certain similarities, they can be considered an independent odor class. Such similarities among fruity descriptors have been reported in the analysis of a semantic odor database (Zarzo & Stanton, 2006). From a multivariate standpoint, a class of semantically related attributes can also be regarded as an underlying semantic dimension in the odor descriptor space.

Semantic dimensions are objective constructs, in that they account for odor descriptors that evoke the smell source (e.g., all fruity descriptors recall the scent of one or more fruits). In some cases, underlying dimensions might involve odor descriptors that are semantically very different. A recent study of the Dravnieks database has found that the most salient dimension of odor descriptor space is related to hedonic aspects (*pleasantness*) (Zarzo, 2008a). Thus, there is a significant positive correlation among the most pleasant odor descriptors, which are negatively correlated with the unpleasant attributes. Similarly, studies have reported that if a wide range of odorants is assessed, pleasantness is the most salient dimension in descriptions of odorant object space (e.g., Coxon, Gregson, & Paddick, 1978; Davis, 1979; Schiffman, 1974). Pleasantness is not a semantic dimension, nor is it a dimension of odor character, because it reflects a similarity among descriptors that are semantically very different (i.e., they evoke different things) yet share a pleasant quality and that have clearly different odor characters (e.g., floral, fruity, vanilla).

Odor impressions are sensory experiences, and sometimes we may describe scents by using words associated with sensory perceptions, such as *sweet*, *bitter*, and *soft*. These are subjective descriptors, because they do not clearly evoke a well-defined odor source. Other subjective terms, such as *calming*, *exciting*, and *exhilarating*, are descriptions of odor effects (i.e., physiological and psychological reactions) that may be induced by different senses, including olfaction. Conversely, odors may calm, excite, or exhilarate, but they cannot exert floral, green, fruity, or woody effects on us. Given this distinction between odor sensations and odor effects, it is necessary to define another concept: *Dimensions* of odor effects are the underlying constructs that comprise odor descriptors that produce a similar effect (e.g., *citrus*, *green*, and *watery* refer to fresh odors, as discussed below, and hence *refreshing* could be considered to be a dimension of *odor effect*).

Mapping Perfumery Odor Descriptors: The Odor Effects Diagram

As a result of his long experience as a perfumer, and also on the basis of empirical evidence, P. Jellinek (1951) developed an olfactory representation that he named the *odor effects diagram*, which displays contrasting odor effects on opposite corners of a square. This representation relies on the idea that the effects of fragrances and their constituents may be described according to two basic polarities: *erogenous* versus *antierogenous* (*refreshing*) and *narcotic* versus *stimulating*. For purposes of clarity, P. Jellinek (1951) inserted the most common descriptors into the odor effects diagram in order to indicate their specific effects. This schematic arrangement is referred to here as Jellinek's *odor map*. The fourth edition of the original work (P. Jellinek, 1997), available in English, also updates and thoroughly discusses the odor effects diagram (J. S. Jellinek, 1997).

Experimental studies have attempted to verify the effects of odors on the human organism (for a review, see J. S. Jellinek, 1994). Although the erogenous, stimulating, or narcotic effects of individual perfume materials have yet to be proven scientifically, Jellinek's odor map has received remarkable confirmation in some investigations on perfumes. Tisserand (1988) reviewed the use of essential oils as psychotherapeutic agents and found that the odor effects diagram was consistent with his own insights regarding the effects of odors on emotional states. In another study (Thiboud, 1991), a two-dimensional projection of a similarity matrix developed from interviews with consumers in the United States, England, Spain, Brazil, and Japan relating to defined perfume bases and to verbal descriptions also exhibited striking similarities with Jellinek's odor map.

One consumer study used 10 commercial perfumes and obtained free descriptors from female perfume users. A multidimensional scaling of the resulting data found that the two dimensions along which the perfumes were most clearly distinguished were heavy/light and floral/nonfloral (J. S. Jellinek, 1990, 1992). Another consumer study, again with 10 popular fragrances, resulted in a projection in which the dimensions sensual/cool and sensitive/passionate clearly emerged (J. S. Jellinek, du Bosque, Gschwind, Schubert, & Scharf, 1992). In both studies, the results were consistent with the basic dimensions of the odor effects diagram.

Additional studies reviewed by J. S. Jellinek (1992, 1997) support the idea that the odor effects diagram is an adequate representation of the psychological impressions

created by men's and women's commercial fragrances as well as scents used in cosmetics, toiletries, household products, and even the natural scents found in the plant and animal kingdoms. Thus, apart from the advantages of mapping perfumery odor descriptors mentioned above, Jellinek's odor map also facilitates the perfumers' work, in both the creation and sensory evaluation of fragrances. Because Jellinek's odor representation was derived basically from the practical experience of a single author who did not claim absolute exactitude, his map requires further validation and interpretation.

Other Representations of Olfactory Perception Space

With more than 3,500 perfumes launched since the year 2000, shopping for a new fragrance can be confusing and frustrating. The perfume-using population needs a perfume classification system based on the way perfumes smell. Perfumery companies have developed different schemes for classifying commercial fragrances: These include the H&R Genealogy, Analogies of Givaudan (both reproduced by Thiboud, 1991), the Drom fragrance circle (see Brud, 1986), the hexagon of fragrance families (see J. S. Jellinek, 1990), and some others mentioned by J. S. Jellinek (1992). Edwards (2008) has classified more than 5,700 commercial fragrances into 14 categories displayed around a central hub of a sensory map called the *Fragrance Wheel*. Another sensory wheel of odor descriptors is the Discodor (Harder, 1979). Additional sensory maps of perfume materials have been proposed by firms such as Firmenich, PPF, and Aftelier (2006). However, in most cases, the details of how these odor representations have been developed remain confidential.

Few comprehensive semantic odor-profile databases have been published (Arctander, 1969; Burdock, 2004; Sigma–Aldrich, 2003). Different researchers have numerically coded the semantic descriptions contained in these databases and have analyzed them with multivariate statistical methods (Abe, Kanaya, Komukai, Takahashi, & Sasaki, 1990; Chastrette, de Saint Laumer, & Sauvegrain, 1991; Chastrette, Elmouaffek, & Sauvegrain, 1988; Jaubert, Tapiero, & Doré, 1995; Madany-Mamlouk, Chee-Ruiter, Hofmann, & Bower, 2003; Zarzo & Stanton, 2006). The results led to the classification of descriptors into 10 to 32 clusters, confirming the belief that olfactory perception space is high-dimensional. Callegari, Rouault, and Laffort (1997) compared the information of different odor databases reported in the literature and determined that 25 well-chosen descriptors seemed sufficient to faithfully represent the perceptual olfactory space. Similarly, the Flavornet database (www.flavornet.org) classifies odor descriptors into 25 categories. Another outcome of some of these studies (Abe et al., 1990; Chastrette et al., 1991; Jaubert et al., 1995; Madany-Mamlouk et al., 2003) is the development of two-dimensional representations of odor descriptor space. However, none of them provides a meaningful interpretation for the two dimensions that make up the odor map. Odor profile databases contain useful information for further discussion of the various odor maps reported in the literature, but this issue has not received much attention yet.

Any attempt to reach a consensus in mapping perfumery odor descriptors should start with a detailed study of the odor maps reported in the literature. For this purpose, we analyzed two odor databases of perfume materials with principal components analysis (PCA). In the present article, we discuss the resulting low-dimensional representations of odor descriptor space and compare them with both Jellinek's odor map and the Fragrance Wheel.

METHOD

The Boelens–Haring Database of Numeric Odor Profiles

The database obtained by Boelens and Haring (1981) contains 309 compounds assessed by a panel of six perfumers who rated the compounds' similarities to 30 reference materials. Each odor reference was selected to represent the maximum odorous intensity known for a specific odor aspect. The similarities, referred to as *odor aspect strengths*, were quantified on a 10-point scale, where 0 = *odor aspects not found to be present when smelling a compound*, 1 = *minimum noticeable level*, and 9 = *undiluted reference substance*. The final odor profile of each compound was obtained after averaging the ratings and generating a consensus among the panelists.

Although the panelists who participated in Boelens and Haring's (1981) study disagreed significantly on the odor profile of certain odorants, on the whole they arrived at very comparable profiles for a given compound. We arranged odor profiles from the original publication (Boelens & Haring, 1981) in a matrix (referred to here as the *B–H database*) with 309 chemicals (in rows) × 30 variables (in columns). The matrix elements, x_{ij}, represent the similarity of the chemical i compared with the odor reference j, according to the panel. These variables, which we refer to as *odor aspect attributes* or simply *odor descriptors*, are listed in Table 1.

Prior to conducting the statistical analysis of this database, we checked the odor descriptions of the materials in sources such as Brechbill (2007), Green (1999), Müller (1992), Poucher (1974), and Sigma–Aldrich (2003). As a preliminary study, we calculated the correlation coefficient for all possible pairs of descriptors and focused the attention on the 48 highest values. We checked whether a high positive correlation between two descriptors could be partly explained by certain odor similarities of their corresponding reference materials (see the Results and Discussion section for details).

Next, we conducted a PCA using SIMCA-P 10.0 software (www.umetrics.com). Principal components are directions of maximum data variance obtained as linear combinations of the original variables. The projections of observations (odorants, in this case) over these directions are called *scores*. The contributions of the variables in the formation of a given component are called *loadings*, $p[1]$ being the loadings in the formation of the first principal component (PC1); $p[2]$, the loadings of PC2; and so on. A

Table 1
Odor Description of the 30 Reference Materials in the B–H Database

Attribute	Reference Material	Odor Description
Aldehyde	aldehyde C-10	[a]Powerful, somewhat sweet, citrus peel-like odor with slightly rancid–fatty notes.
Animal	civet absolute	[a]Very powerful, somewhat fecal, animalic odor.
Anisic	fennel oil	[b]Sweet, delicate aroma resembling aniseed.
Aromatic	vanillin	[d]Sweet, vanilla, chocolate, balsamic.
Balsamic	olibanum resinoid	[a]Balsamic, spicy, slightly lemon-like odor that displays typical incense notes and is somewhat coniferous and resinous. [c]Rich, deep, warm, balsamic, sweet with incense-like overtones.
Buttery	diacetyl	[d]Powerful, buttery on high dilution.
Citrusy	lemon oil	[a]A very typical, lively, refreshing odor. [h]Citrus.
Coniferous	fir needle oil	[a]Fresh, powerful pine–forest odor with spicy, fatty undertones.
Dusty	patchouli oil	[a]Very intense, woody, sweet-balsamic odor with spicy and woody–earthy undertones. [h]Earthy–rich.
Earthy	mousse de chêne resinoid[i]	[a]Generally earthy, mossy, spicy, woody odor with slight phenolic and leather-like notes.
Erogenic	mixture: + ambergris	[a]Exhibits different nuances such as woody, dry balsamic, somewhat tobacco-like notes and also has an erogenic note. [h]Animalic–rich.
	+ costus oil	[h]Animalic–rich.
Fatty	undecylenic alcohol (10-undecen-1-ol)	[f]A pleasant soapy, waxy, floral, rose aroma. Commonly used in soaps and detergents for a fresh, rosy nuance. [g]Fresh, citrus, floral, waxy, ozone, clean.
Floral	jasmine absolute	[a]Powerful, honey-like, sweet, floral odor with fruity–herbaceous undertones.
Fresh	bergamot oil	[a]Has a fresh, clear, lively odor, somewhat fruity and sweet, that displays great originality. [h]Citrus.
Fruity	hexadecanal	[b]Powerful odor recalling strawberries.
Green	methyl heptin carbonate (methyl octyonate)	[b]Develops a floral violet fragrance in dilution. Commonly called "artificial violet green." Imparts a fresh leafy effect.
Honey	ethyl phenylacetate	[b]Sweet honey-like aroma, suggestive of musk.
Lavender	lavender oil	[a]Dry–fresh, sweet, balsamic, herbaceous odor with floral, woody undertones.
Medicinal	methyl salicylate	[a]Pungent–sweet, rather musty odor with green, medicinal undertones. Reminiscent of wintergreen oil.
Metallic	bay oil	[a]Very powerful, spicy, sweet odor with a distinct clove note. [b]Imparts freshness when used in soap perfumes.
Minty	peppermint oil	[a]Powerful, minty, fresh, grass-like odor with sweet, balsamic undertones.
Powdery	mixture: + musk ketone	[a]Warm, sweet, erogenous musky odor.
	+ coumarin	[a]Sweet, herbaceous–warm, somewhat spicy odor that, when diluted, is reminiscent of freshly cut hay.
Smoky	cade oil	[e]Intense tar-like, smoky, phenolic odor. [b]Obtained by destructive distillation of woods.
Sourish	styrallyl acetate	[a]Very intense, floral–green, somewhat bitter odor, reminiscent of gardenia. [d]Floral (gardenia), green, fruity (pineapple, apricot, plum, apple).
Spicy	eugenol	[a]Warm–spicy, medicinal, rather dry and almost sharp odor reminiscent of cloves. [e]Powerful, warm, spicy, balsamic.
Sweet	heliotropin (piperonal)	[a]Sweet, very warm, floral–narcotic odor somewhat reminiscent of almonds. [b]Delightful odor of cherry pie.
Tart (dry)	galbanum resinoid	[a]Spicy–green, leaf-like odor with woody, pine-needle-like and balsamic undertones.
Vegetable	clary sage oil	[c]Herbaceous, spicy, hay-like. [h]Green.
Watery	cyclamen aldehyde	[a]Very pleasant, floral–green odor with a watermelon-like note. [g]Floral, fresh, rhubarb, musty, green.
Woody	cedarwood oil	[a]Harmonious, soft, woody odor.

[a]Odor description according to Müller (1992). [b]Odor description according to Poucher (1974). [c]Odor description according to Green (1999). [d]Odor description according to Sigma–Aldrich (2003). [e]Odor description according to Brechbill (2007). [f]Odor description: www.bedoukian.com/products. [g]Odor description: www.thegoodscentscompany.com. [h]Classification of the perfume material according to Aftelier (2006). [i]French name for oakmoss (Aftel, 2001).

scatterplot of the loadings corresponding to two different components is referred to as a *loading plot*. The loading plot corresponding to PC1 and PC2 (i.e., $p[2]$ vs. $p[1]$), referred to here as the *PC1/PC2 plot*, usually provides the most relevant information from the database.

The loading plots corresponding to the relevant components were inspected in order to interpret the similarities between attributes, which we discuss according to the odor description of the reference materials as well as the classification of odor descriptors proposed by two reported studies (Abe et al., 1990; Jeltema & Southwick, 1986). The PC1/PC2 plot was compared with Jellinek's odor map. Attempting to interpret PC1 and PC2 as salient dimensions in the perception of perfumery odors, we discuss the results, taking into account the psychological aspects involved in cosmetic odors that were studied extensively by P. Jellinek (1997) and by other authors. For the interpretation of PC2, we also calculated the frequency of occurrence of attributes in the odor description of the fragrances contained in the H&R Fragrance Guide (Glöss, 1991).

Thiboud's Database of Semantic Odor Profiles

The second odor database analyzed here was reported by Thiboud (1991). This database contains semantic odor profiles of 119 perfume materials: 44 natural odorants and 75 synthetic chemicals. Each material is labeled with a set of 3 or 4 main odor descriptors and with a number of secondary attributes, ranging from 0 to 14 (with an average of 6.6). The database comprises a total of 85 odor descriptors. The one encountered most frequently is *fresh*, which is applied as a primary or secondary attribute to 53.8% of the odorant materials.

In a previous study (Zarzo & Stanton, 2006), we numerically coded a semantic odor database, which we an-

Table 2
Forty-Eight Pairs of Odor Aspect Attributes With Highest Correlation

r	Attributes	Common Note	*r*	Attributes	Common Note
.638	aromatic–sweet	sweet	.394	balsamic–aromatic	balsamic
.628	tart (dry)–green	green, leafy	.391	woody–earthy	woody
.622	woody–dusty	woody	.390	balsamic–powdery	spicy
.609	earthy–dusty	earthy, woody	.380	smoky–spicy	phenolic
.586	vegetable–tart	spicy, green	.377	fatty–watery	floral
.584	sourish–fresh	fruity	.375	anisic–sweet	sweet
.571	earthy–vegetable	spicy	.373	balsamic–woody	
.565	earthy–tart (dry)	spicy, woody	.371	watery–fresh	fresh
.562	aldehyde–fatty	fatty	.363	dusty–spicy	spicy
.511	sourish–green	floral–green	.357	metallic–tart (dry)	spicy
.495	powdery–erogenic	erogenous	.350	vegetable–sourish	green
.495	dusty–powdery	spicy	.344	balsamic–dusty	balsamic, spicy
.482	aldehyde–watery		.341	smoky–medicinal	phenolic
.466	smoky–dusty	woody	.338	balsamic–sweet	sweet
.464	erogenic–animal	animalic	.330	metallic–watery	fresh
.458	vegetable–green	green	.320	balsamic–spicy	spicy
.454	smoky–earthy	woody	.316	minty–fresh	fresh
.450	lavender–fresh	fresh	.312	lavender–coniferous	fresh
.440	powdery–sweet	sweet, warm	.312	minty–coniferous	fresh
.433	green–fresh	fresh	.309	minty–medicinal	sweet
.429	tart–sourish	green	.307	woody–powdery	
.428	fruity–sourish	fruity	.302	fruity–fresh	fruity
.427	citrusy–fresh	citrus	.297	watery–green	floral–green
.427	spicy–aromatic	balsamic	.295	woody–smoky	woody

Note—Common Note = odor note that is supposedly shared in common by both attributes, according to the comparison of odor description for the reference materials (Table 1), as well as from additional sources discussed in the text.

alyzed with PCA. We found that descriptors with fewer than five occurrences did not provide relevant information, and those were discarded. In the present study, we discarded attributes (15 in total) with three or fewer occurrences. Additionally, *powerful*, *weak*, and *strong* were disregarded, because they refer to odor intensity. *Harsh* and *rigorous* were considered synonymous and were combined into a single new descriptor, *harsh*. These adjustments left 66 descriptors for the subsequent multivariate analysis.

The semantic profile of a given odorant was numerically coded by assigning a value of 1 to the descriptors that were applied to describe the primary or secondary odor character of that particular odorant, and 0 otherwise. This procedure yielded an array of 119 odorants × 66 dichotomic variables, which we called a *dichotomic matrix*. A second array was created by assigning 1 to the descriptors applied to describe the main odor character of a given odorant, 0.5 to the secondary descriptors, and 0 to the rest. In this case, the 66 variables contain three possible values, and therefore the array was called a *trichotomic matrix*. Next, a PCA was conducted with each matrix. The relevant loading plots were compared with the PC1/PC2 plot from the B–H database, as well as with Jellinek's odor map, in order to find coincidences and discrepancies.

Comparison Between the Fragrance Wheel and the Odor Effects Diagram

The Fragrance Wheel displays perfume categories around a central hub, except for *aromatic*/*fougère*, which is at the center of the odor wheel (Edwards, 2008). This odor representation was conveniently rotated in order to achieve the best possible coincidence with the odor effects diagram. Taking into account that the narcotic/stimulating dimension of this diagram can be interpreted as feminine versus masculine (P. Jellinek, 1997), we checked the frequency of men's and women's fragrances in each odor category. The results provide clues about how to improve the Fragrance Wheel so that it can better describe the perceptual space of fragrances.

RESULTS AND DISCUSSION

B–H Database

Identification of the highest correlation coefficients. The linear correlation coefficient (r) was calculated for all 435 possible pairs of attributes. The correlation was statistically significant ($p < .001$) in 206 cases. Obviously, this number is unmanageably large for discussing the similarities among descriptors, and so we focused our attention subsequently on only the 48 pairs with highest correlation (Table 2). This information was used to interpret the PCA loading plots.

The highest correlation coefficient ($r = .64$) corresponds to *aromatic* and *sweet*. This similarity is probably caused by a common sweet smell shared by vanillin and heliotropin, which were selected as reference materials for these descriptors (Table 1). Actually, both odorants were regarded by Harper (1975) to be standards for *sweet*. The extract of the vanilla bean is the best-known example of a sweet-smelling natural product (Müller, 1992).

Table 3
Most Similar and Dissimilar Odor Aspect Attributes in the B–H Database

Attribute[a]	$\bar{x}_j$[b]	Most Similar[c]	r_{max}	Most Dissimilar[d]	r_{min}
Fresh	2.1	sourish	.58	powdery	−.58
Sourish	1.6	fresh	.58	powdery	−.44
Citrusy	0.4	fresh	.43	sweet	−.26
Tart (dry)	1.4	green	.63	sweet	−.44
Green	1.7	tart (dry)	.63	sweet	−.41
Vegetable	1.8	tart (dry)	.59	floral	−.27
Metallic	1.1	tart (dry)	.36	sweet	−.28
Watery	1.7	aldehyde	.48	aromatic	−.34
Fatty	0.6	aldehyde	.56	aromatic	−.26
Aldehyde	0.6	fatty	.56	sweet	−.36
Fruity	1.9	sourish	.43	dusty	−.39
Minty	0.3	fresh	.32	floral	−.21
Lavender	0.3	fresh	.45	sweet	−.19
Coniferous	0.3	lavender	.31	floral	−.35
Sweet	2.2	aromatic	.64	tart (dry)	−.44
Aromatic	1.0	sweet	.64	watery	−.34
Honey	0.3	aromatic	.27	fresh	−.13
Anisic	0.3	sweet	.37	watery	−.15
Spicy	0.8	aromatic	.43	watery	−.28
Balsamic	0.4	powdery	.39	fresh	−.37
Powdery	1.5	erogenic	.49	fresh	−.58
Erogenic	0.4	powdery	.49	sourish	−.25
Animal	0.5	erogenic	.46	fresh	−.29
Earthy	1.1	dusty	.61	fruity	−.34
Dusty	1.3	woody	.62	fruity	−.39
Woody	1.0	dusty	.62	fruity	−.22
Smoky	0.2	dusty	.47	fruity	−.25
Medicinal	0.6	smoky	.34	fruity	−.21
Buttery	0.5	fruity	.19	dusty	−.18
Floral	3.1	sweet	.28	conifer	−.35

[a]Odor aspect attributes, sorted properly in the table to provide an easier interpretation. [b]Average value for the 309 compounds. [c]Most similar attribute (highest positive correlation coefficient). [d]Most dissimilar attribute (highest negative correlation coefficient).

Odor descriptions were also checked for the remaining 47 attribute pairs with highest correlation, and some shared notes were found in most cases (Table 2). The correlation between *fresh* and *citrusy* ($r = .43$) is rather obvious because the reference materials of both descriptors are obtained from the peel of citrus fruits, and different authors have classified these materials as *citrus* (Aftelier, 2006; Harper, 1975). *Vegetable* and *tart (dry)* are also correlated ($r = .59$), and the references assigned to both attributes were classified as *green* (Aftelier, 2006). Patchouli oil was the selected reference for *dusty*, but Aftelier classifies it as *earthy*, which explains the strong correlation observed between *dusty* and *earthy* ($r = .61$).

Next, the highest positive and negative correlation coefficients were identified for each attribute (Table 3). An examination of the results showed that most of the first 14 attributes in Table 3 were similar to *fresh* or to related notes (*sourish*, *tart*, *aldehyde*) and were dissimilar to *sweet*, *aromatic*, or *powdery*. Curiously, the opposite occurred for most of the remaining attributes. We examined this observation in more detail as part of the subsequent multivariate analysis.

PCA. If PCA is applied directly to a given matrix with no data pretreatment, PC1 provides information about the mean profile of all observations and allows for the identification of the variables with the highest averages. If a PCA is conducted with centered data (subtracting the mean odor profile so that all centered variables have a null average), the subsequent principal components are influenced by the variables with highest variances. Because all variables in the present study were measured using the same numeric scale (0–9), the highest variance corresponds in general with the highest average. PCA applied to the mean-centered B–H database yielded a PC1/PC2 plot (Figure 1) in which all variables outside of the central cluster have an average ≥1 (average values shown in parentheses), with the exception of *metallic*. This loading plot provides information about the general data variability, but here the main interest is to study the correlation structures among variables. It is therefore more appropriate to use the autoscaling pretreatment (i.e., variables mean centered and scaled to unit variance) in order to prevent PCs from being influenced by the variables with the highest variance. If this pretreatment is used, the PC1/PC2 plot undergoes a dramatic change (Figure 2).

One approach commonly used in PCA that was also adopted in another reported analysis of this database (Ennis, Boelens, Haring, & Bowman, 1982) is to focus on PCs with an eigenvalue of >1. This criterion is satisfied by PC1 and by further components up to PC9 (Table 4), so it seemed reasonable to study the loading plots for these components. Another approach is based on the amount of variance explained by cross-validation (Q^2). PCA following the autoscaling pretreatment option indicated that PC1 and PC2 are the only components that satisfy the cross-validation criterion, because their Q^2 value is higher than the threshold considered by the software SIMCA-P 10.0. Nonetheless, the Q^2 values of PC3, PC4, and PC6 are close to the threshold (Table 4). PC1 and PC2 account for 32% of the total data variance, and hence the PC1/PC2 plot (Figure 2) may be expected to provide the most relevant information.

Twelve odor descriptors in the B–H database have a score of 0 for more than 75% of the odorants. These descriptors basically correspond to the attributes in Table 3 with the lowest average value. To determine the effect of these descriptors in the resulting loading plot, these 12 variables were discarded, and a new PCA was conducted with the autoscaling pretreatment. The resulting PC1/PC2 plot was very similar to Figure 2, although it appeared slightly rotated. Another PCA was carried out after centering the data, and the plot was nearly the same as that in Figure 1. Hence, the descriptors rated with a low frequency did not introduce noise in the results.

In an attempt to ease the interpretation of similarities between descriptors, in Figure 2, we highlight the pairs of variables with highest correlation shown in Table 2. The results reveal that very few variables with $p[1] < 0$ are strongly associated with those characterized by $p[1] > 0$. This categorization of attributes according to the $p[1]$ loadings is also reflected by checking the most similar and most dissimilar descriptors for each attribute (Table 3). Actually, for all attributes with $p[1] > 0$, the most similar descriptor also presents a positive $p[1]$, but it presents a negative $p[1]$ for the most dissimilar. Thus, PC1 provides a gross classification of odor descriptors

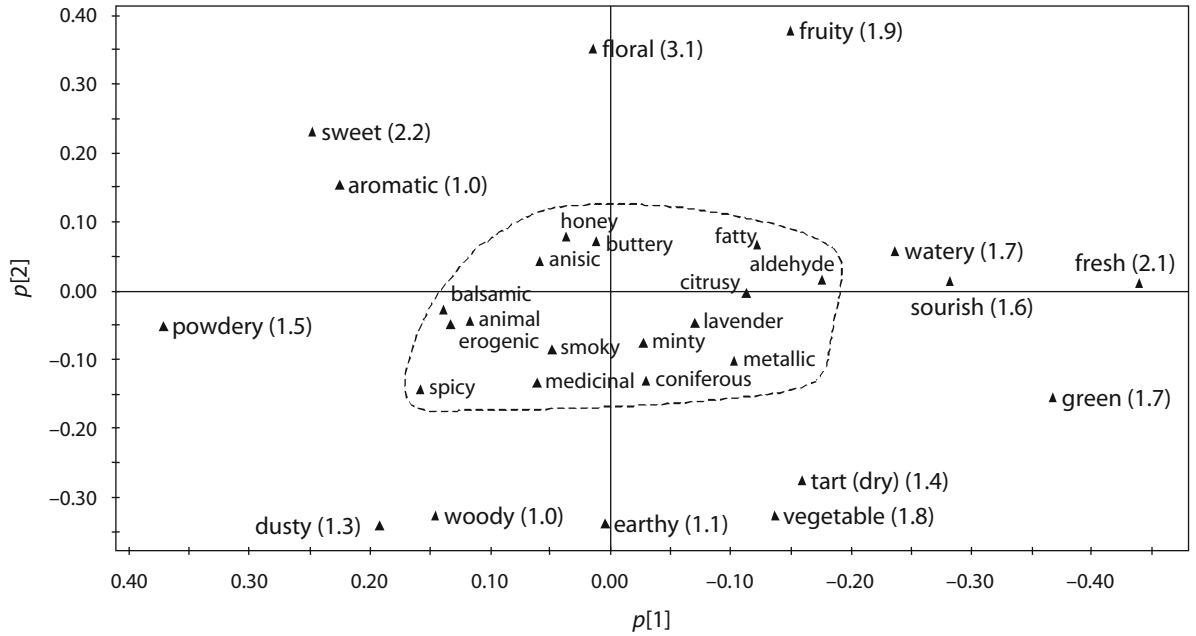

Figure 1. Loading plot for the first and second principal components (PC1/PC2) from the PCA conducted with the B–H database after centering the variables. Numbers in brackets correspond to the average value of each descriptor according to Table 3.

according to a certain underlying dimension of odor perception.

Most odor attributes of the B–H database are included in the long list of descriptors classified by Abe et al. (1990) and Jeltema and Southwick (1986) shown in Table 5. Although a reasonable agreement occurs in the classification of many of these descriptors, some discrepancies are apparent (e.g., *lavender*, *fatty*, or *metallic*); these are discussed in detail below. Jeltema and Southwick analyzed a database of 415 odorants assessed by a panel of about 20 individuals according to the applicability of 146 odor descriptors. A factorial analysis of this database resulted in the classification of these descriptors into 17 groups. Abe et al. selected 126 odor descriptors for 1,573 com-

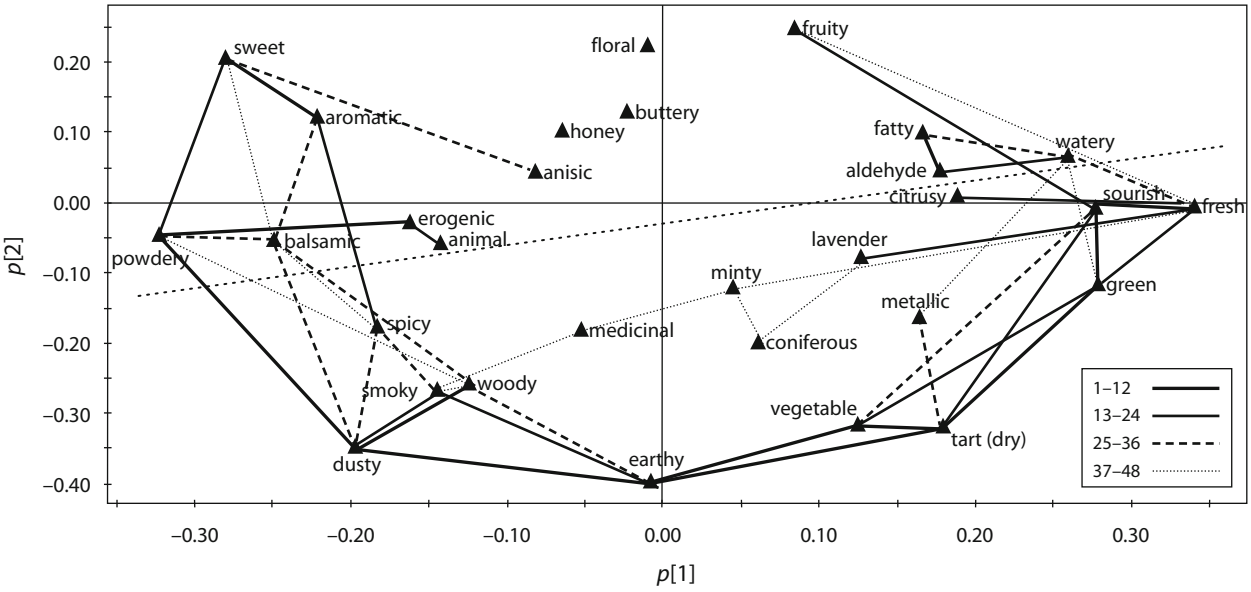

Figure 2. Loading plot for PC1/PC2 from the PCA conducted with the B–H database. Variables were autoscaled prior to the analysis. The 48 pairs of odor descriptors with highest correlation coefficient indicated in Table 2 are highlighted: Thicker solid lines correspond to the 12 highest values, thinner solid ones indicate the next 12 highest values, and so on, according to the legend shown in the figure. Descriptors above the dotted line are more frequently encountered in feminine than in masculine fragrances (Tables 6 and 7).

Table 4
Summary Overview of Two PCA Models for 10 PCs With Autoscaling Pretreatment

	PCA of the B–H Database					PCA of Thiboud's Database				
PC	R^2_x	R^2_{cum}	Eigenvalue	Q^2	Q^2_{limit}	R^2_x	R^2_{cum}	Eigenvalue	Q^2	Q^2_{limit}
1	.175	.175	5.25	.102	.035	.105	.105	6.94	.048	.023
2	.142	.317	4.26	.106	.036	.090	.195	5.92	.046	.023
3	.084	.401	2.53	.030	.038	.056	.251	3.70	.002	.024
4	.066	.467	1.98	.011	.039	.050	.301	3.27	−.001	.024
5	.058	.525	1.73	−.030	.040	.044	.344	2.90	−.011	.024
6	.054	.579	1.63	.020	.042	.038	.383	2.51	−.023	.025
7	.044	.623	1.32	−.035	.043	.036	.418	2.37	−.022	.025
8	.036	.659	1.07	−.066	.045	.035	.453	2.30	−.019	.025
9	.034	.693	1.02	−.050	.047	.031	.484	2.06	−.027	.026
10	.032	.724	0.94	−.055	.049	.027	.512	1.80	−.037	.026

Note— R^2_x, variance explained; R^2_{cum}, cumulated values; Q^2, variance explained by cross-validation; Q^2_{limit}, threshold value for Q^2 to satisfy the cross-validation criterion.

pounds from Arctander's (1969) database and applied cluster analysis, which allowed classification of these descriptors into 19 clusters. Arctander's database was compiled in the context of perfumery, and most odors were characterized by only one person (S. Arctander), resulting in an arguable degree of personal subjectivity. Maybe for this reason, a recent study (Pintore et al., 2006) has found significant differences between Arctander's database and another commercial database of semantic odor profiles (BACIS, 2001).

The descriptors *anisic*, *buttery*, and *honey* are closest to the center of the loading plot in Figure 2, revealing a low correlation with the rest of the variables. Because of this, these three descriptors may be expected to form orthogonal directions of variability. Actually, these attributes present the highest loadings in PCs 7, 9, and 10 (figures not shown). The r_{max} and $|r_{min}|$ of these descriptors are among the lowest in Table 3, confirming their low correlations with the rest of the variables. Consistent with these results, *anise* was proposed as an independent odor

Table 5
Classification of Odor Attributes Contained in the B–H Database

B–H Odor	Classification According to Abe et al. (1990)		Classification of Jeltema and Southwick (1986)		
Attribute[a]	CN[b]	Subcluster and Individual Descriptors[c]	Dravnieks Descriptor[d]	FN[e]	Factor Name[f]
Balsamic	1	Balsamic (amber, oriental)			
Spicy	1	Spicy (cinnamic)	Spicy	13	spicy
Aromatic	1	vanillin: intermediate of Spicy and Balsamic	Vanilla	6–14	intermediate brown–almond
Floral	2	Floral (hyacinth, heliotrope, narcissus, lily, mimosa, lilac . . .)	Floral	7	floral
Anisic	3	Anise (fennel)	Anise	17	caraway, anise
Vegetable	4	Herbaceous (tobacco, hay, tea, lavender, clary–sage . . .)	Fresh green vegetable	4	green
Lavender	4	individual descriptor within Herbaceous	Lavender	7	floral
Fruity	6	Fruity (apple, pineapple, banana, jasmine, apricot, plum . . .)	Non-citrus fruit	3	non-citrus fruit
Buttery	7	[?] (buttery, creamy, berry)	Buttery	6	brown
Citrusy	9	Citrusy (lemony)	Citrus	10	citrus
Fresh	9	[?] (bergamot)			
Fatty	11	Fatty (rancid)	Oily, fatty	1	animal, foul
Green	12	Green (leafy, vegetable, metallic, violet–leaf, cucumber . . .)	Green	4	green
Metallic	12	individual descriptor within Green	Metallic	2	solvent
Animal	13	Animal (civet)	Animal	1	animal, foul
Honey	13	Honey (honey)	Honey	6	brown
Aldehyde	14	[?] (aldehyde)	Alcoholic	2	solvent
Woody	15	Woody (peppery, sap, bark)	Woody	12	woody
Minty	15	Minty (minty)	Minty	8	cool, minty
Coniferous	15	[?] (orrisy, pine)	Turpentine	2	solvent
Earthy	16	Earthy (mossy, root, walnut)	Musty, earthy, moldy	4	green
Medicinal	17	Medicinal (phenolic)	Medicinal	2–8	intermedite solvent–minty
Smoky	17	[?] (tar, leather, smoky)	Burnt, smoky	5–9	intermediate nutty–burnt
Sourish			Sour, vinegar	1	animal, foul
Sweet			Sweet	3	non-citrus fruit

[a]Some descriptors with an uncertain classification were omitted. [b]Cluster number. Descriptors grouped under the same cluster are supposed to account for similar odors. [c]Most clusters proposed by Abe et al. (1990) are divided in up to four subclusters, and each one comprises a set of different individual odor descriptors (indicated within parentheses). [d]Dravnieks descriptor that is supposed to be most similar to each attribute in the B–H database. [e]Factor number. Descriptors grouped under the same factor are supposed to account for similar odors. [f]Intermediate indicates classification in two categories.

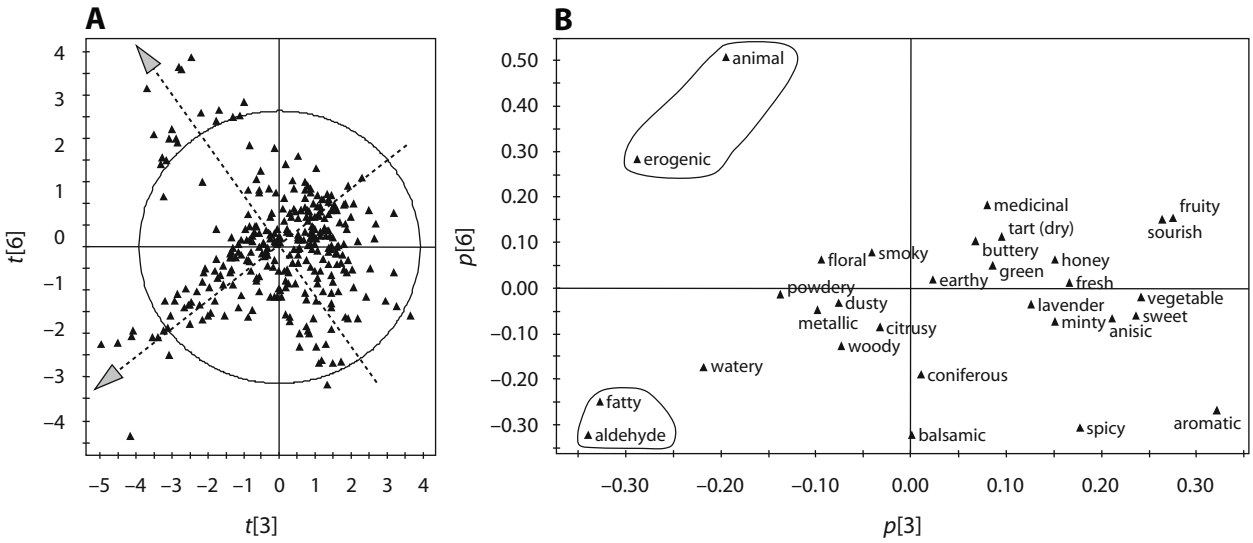

Figure 3. (A) Score plot (*t*[6] vs. *t*[3]) and (B) loading plot (*p*[6] vs. *p*[3]) corresponding to PC3/PC6 from the PCA conducted with the B–H database. Variables were autoscaled prior to the analysis.

by several authors (e.g., Jennings-White, 1984; Rimmel, 1895), and this criterion has been corroborated by the statistical analyses of odor profile databases (Table 5). In the case of *buttery*, various authors have regarded it as a rather independent descriptor (e.g., Abe et al., 1990; Zarzo & Stanton, 2006). In contrast, Jeltema and Southwick (1986) classified it as *brown* (a category that groups balsamic-related odors), but the correlation *buttery–balsamic* is not statistically significant ($p = .73$) in the B–H database.

Honey scents are described as *sweet*, *heavy*, and *syrupy*, with a *waxy* background (Thiboud, 1991). The same criterion was used in the Sigma–Aldrich (2003) catalog of flavors and fragrances, because *honey*, *sweet*, *vanilla*, and *caramel* (i.e., syrupy odors) are classified as *balsamic*. Similarly, Jeltema and Southwick (1986) regarded *honey* as a *brown* descriptor (Table 5). Consistent with these similarities, *honey* yields the highest correlation with *sweet* and *aromatic* (i.e., *vanillin-like*) in the B–H database. By contrast, *honey* and *animal* were classified by Abe et al. (1990) in the same cluster (Table 5), but the correlation between both descriptors is not statistically significant ($p = .54$).

Interpretation of PC3 and further principal components. Attempting to further understand the similarities between descriptors, we inspected different loading plots for PC_i/PC_j (i, j from 3 to 10). The score plot for PC3/PC6 (Figure 3, left) shows two rotated directions of variability, and the corresponding loading plot (Figure 3, right) clearly reveals the variables responsible for those directions. One of them is determined by *animal* and *erogenic*, suggesting that these descriptors are similar. Actually, the reference materials for both attributes were classified by Aftelier (2006) as *animalic–rich*. The score plot also suggests that fewer than 30 odorants in the B–H database account for this *animal–erogenic* dimension. Because of this low number of occurrences, the resulting average value of the two descriptors is low (Table 3). Although a zero score was used often, the similarity between both attributes is reflected clearly in Figure 3, and it is consistent with the criterion of perfumers, as commented on below. Moreover, the correlation coefficient between them is the 15th highest value among all possible descriptor pairs (Table 2). The same discussion applies to other descriptors in the B–H database rated with a low frequency.

Another direction of variability is determined by *aldehyde* and *fatty* (Figure 3). Both attributes are correlated ($r = .56$), probably because decanal (the reference for *aldehyde* in the B–H database) displays a *fatty* note (Table 1). The similarity between both descriptors is also deduced from a poll of 120 perfumers (Brud, 1986), 18% of whom chose different aldehydes as reference materials for *fatty*. *Watery* appears in Figure 3 very close to *fatty* and *aldehyde*. The similarity among these descriptors was also reported by Müller (1992), who described the odor effect produced by short-chain aliphatic aldehydes as "fatty," "watery," and "tallowy," or even "snuffed candle."

Fatty is usually used to describe smells that suggest oil, lard, or wax (Müller, 1992). In a study of Arctander's (1969) database, a cluster was formed with *fatty*, *oily*, and *waxy* (Chastrette et al., 1988). In the context of perfumery, a given odor may be described as *fatty* if it presents a certain *oily*, *waxy*, or *rancid* note, although other aspects, such as *floral* or *green*, might predominate.

Medicinal is the descriptor with highest contribution in PC5. It yields the highest correlation with *smoky* and *minty* (Table 2). Thus, it appears in Figure 2 in the middle of both descriptors, and close to *minty* in Figure 4. Abe et al. (1990) also regarded *medicinal* and *smoky* as similar. The similarity between *medicinal* and *minty* was also reported by Jeltema and Southwick (1986) (Table 5). Taking into account that *phenolic* and *medicinal* are related descriptors (Abe et al., 1990; Chastrette et al., 1988), the correlation *medicinal–smoky* can be explained by the

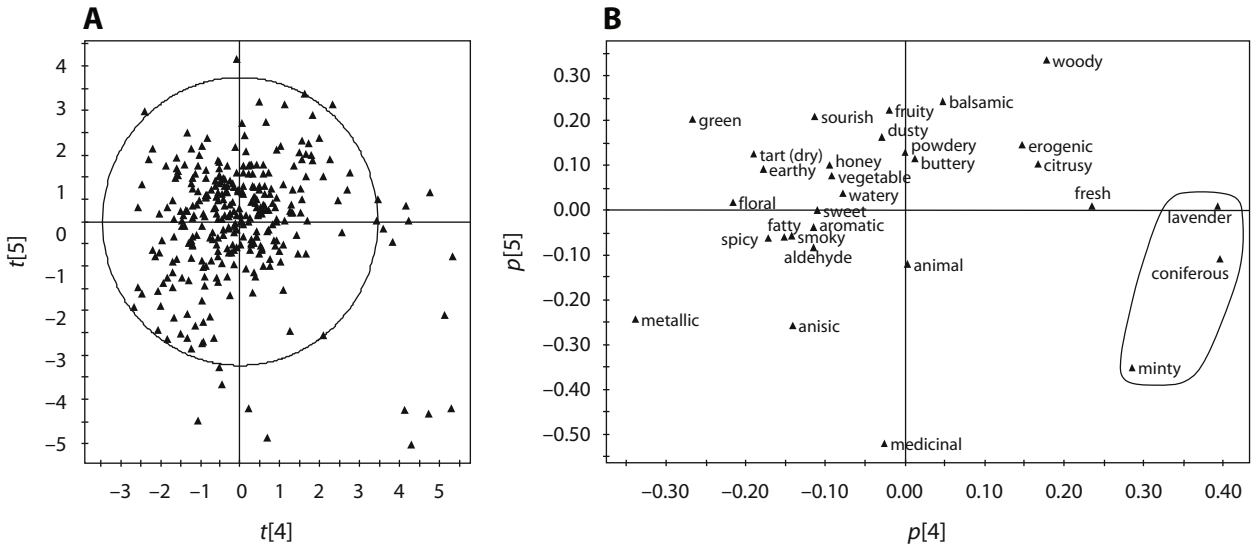

Figure 4. (A) Score plot (*t*[5] vs. *t*[4]) and (B) loading plot (*p*[5] vs. *p*[4]) corresponding to PC4/PC5 from the PCA conducted with the B–H database. Variables were autoscaled prior to the analysis.

phenolic note that is present in the reference material for *smoky* (Table 1). Klein (1947) also regarded *phenolic* and *burnt* as related descriptors.

Minty, *coniferous*, and *lavender* present the highest loadings in PC4 (Figure 4) and appear close to each other in Figure 2. This common pattern is probably due to a *camphoraceous* note shared by the reference materials of these descriptors. Actually, according to Müller (1992), camphor-like notes are present in lavandin, rosemary, and conifer oils, among others. In a reported study of Arctander's database, *minty*, *camphoraceous*, and *pine* were grouped in the same cluster (Abe et al., 1990). Other works have also reported a similarity between *camphor* and *minty* (Chastrette et al., 1988), between *camphoraceous* and *piney* (Chastrette et al., 1991), and between *camphoraceous* and *lavender* (Calkin & J. S. Jellinek, 1994).

Effect of the selected references on the similarities between descriptors. Brud (1986) asked 120 perfumers to indicate perfume raw materials that they would choose as representative for different odor descriptors. We compared the results of this survey with the references selected by Boelens and Haring (1981). Cedarwood oil and civet absolute were the preferred materials for *woody* and *animal*, respectively. The same criteria were used in the B–H database. Jasmine absolute was the second material most frequently chosen for *floral*, and eugenol was also the second choice for *spicy*. However, only 2% of respondents selected olibanum resinoid as a standard for *balsamic*, and the same percentage resulted in the case of methyl heptin carbonate as a reference for *green*. None of the perfumers who took the survey chose undecylenic alcohol or hexadecanal as a standard for *fatty* or *fruity*, respectively. Nonetheless, methyl heptin carbonate was one of the six consensus materials chosen by a group of experts as a reference for *green*, and hexadecanal was one of the standards proposed for *fruity* (Harper, 1975).

Galbanum resinoid and patchouli oil were the materials most frequently selected for *green* and *earthy*, respectively (Brud, 1986). By contrast, Boelens and Haring (1981) assigned these materials to *tart (dry)* and *dusty*, respectively (Table 1). Therefore, if they had been used in the original study according to the preferred selection of Brud's survey, *green* would appear instead of *tart (dry)* in the loading plots, and *earthy* would appear instead of *dusty*.

Metallic notes are reminiscent of the flavor caused by metal ions, such as iron or copper, in solution. Some perfumes also contain metallic nuances, and several studies have found a similarity between *metallic* and *geranium* (Abe et al., 1990; Chastrette et al., 1988). Bay oil was the reference material for *metallic*. It smells *spicy–fresh* (Table 1), and the metallic character is probably a minor note. This observation suggests that perfumers might select a material as a reference for a particular aspect, although this odor character is not the dominating note. Most likely, naive participants will not describe the odor of bay oil as "metallic," a term that they would apply to smells with a strong metallic character. This reason might explain why *metallic* was classified by Jeltema and Southwick (1986) as falling within the solvent cluster along with descriptors such as *paint*, *chemical*, and *alcoholic*.

Interpretation of PC2. Perfumes with floral accents are generally considered to be especially feminine (Müller, 1992). Actually, 60% of the feminine fragrances in the H&R Fragrance Guide (Glöss, 1991) appear under the floral category, but only 8% of masculine fragrances are listed under a floral subcategory of *fougère* or *citrus*. J. S. Jellinek (1992) developed a two-dimensional mapping of commercial perfumes, and one of the dimensions was *floral (romantic)* versus *not floral*. *Floral* is one of the variables with highest *p*[2], which might indicate that PC2 discriminates odor descriptors that are more characteristic of women's versus men's fragrances. This hypothesis, pro-

Table 6
Frequency of Occurrence of Odor Character Descriptors Used by the H&R Fragrance Guide (Glöss, 1991) to Describe the Top, Middle, and Base Note of 820 Commercial Perfumes

Feminine Descriptors (%F > %M)							Masculine Descriptors (%M > %F)						
	Top Note		Middle Note		Base Note			Top Note		Middle Note		Base Note	
Descriptor	%F	%M	%F	%M	%F	%M	Descriptor	%F	%M	%F	%M	%F	%M
Floral	18.5	0.5	96.0	67.0	10.4	0.0	Spicy	12.4	29.2	12.1	51.5	0.0	0.3
Fruity	32.5	1.1	4.6	0.8	0.7	0.0	Fresh	52.1	92.6	2.9	13.6	0.2	1.9
Sweet	0.0	0.0	10.2	1.1	23.8	13.4	Herbaceous	2.0	42.5	0.2	1.6	0.0	0.5
Green	34.2	23.2	5.3	3.0	0.2	0.0	Woody	0.0	0.8	5.5	38.4	34.2	40.9
Exotic	0.0	0.0	11.5	0.0	0.2	0.0	Leathery	0.0	0.0	0.2	0.0	2.4	25.3
Elegant	0.0	0.0	10.6	0.0	0.2	0.0	Resinous	0.2	0.0	0.9	13.4	0.0	1.6
Light	0.7	0.0	3.3	0.0	0.0	0.0	Dry	3.1	1.4	2.9	13.6	0.0	0.0
Cool	1.1	0.0	4.2	1.9	0.0	0.0	Lavendaceous	0.2	0.8	0.0	0.8	0.0	0.0
Mild	0.0	0.0	0.2	0.0	4.2	1.4	Tobacco	0.0	0.0	0.0	0.3	0.0	0.5
Delicate	0.2	0.0	2.4	0.0	0.0	0.0							
Sultry	0.0	0.0	0.9	0.0	0.2	0.0							

Note—A given descriptor is classified as feminine if the percentage of feminine fragrances with the top, middle, or base note labeled with that descriptor (%F) is higher than the percentage in the case of masculine fragrances (%M).

posed by Zarzo (2008b) in a previous study of the B–H database, was further investigated here using the H&R guide. It contains the semantic odor description of 820 commercial perfumes (367 men's and 453 women's) according to top, middle, and base notes. For each descriptor in the guide, we counted the number of times that it was applied to describe feminine fragrances. The relative frequency of occurrence was obtained by dividing these values by the total number of feminine fragrances. The same procedure was applied with masculine fragrances (Table 6). Some additional descriptors with a lower frequency of occurrence that are used in only one of the phases (top, middle, or base notes) are listed in Table 7.

Most of the 30 descriptors in the B–H database have a direct correspondence with the terms used by the H&R guide. Perfumers use *resinous* to describe the odors of gums exuded from trees, particularly pines and other evergreens that present a somewhat harsh piney note from the turpentine oil usually present (Thiboud, 1991). The reference material for *coniferous* smells piney (Table 1), and hence it can be matched with *resinous*. *Herbaceous* refers to a fragrance that is natural, hay-like, and reminiscent of herbs that are used as food or medicine. Some examples are chamomile, lavender, rosemary, and sage (in particular, clary sage) (Müller, 1992). Taking into account that clary sage oil was the reference for *vegetable*, this descriptor was considered equivalent to *herbaceous*. *Smoky* is not included in the H&R guide, but it could be matched with *leathery*, given that *smoky* notes are used mainly in masculine perfumes to create natural leather effects (Müller, 1992). The similarity between *smoky* and *leathery* was also reported by Abe et al. (1990) (see Table 5).

As shown in Tables 6 and 7, the descriptors that were applied more often to feminine rather than masculine fragrances were classified as *feminine*. If the opposite applied, the attribute was classified as *masculine*. Despite the low frequency of occurrence of *lavendaceous* (Table 6), this descriptor was classified as masculine because lavender oil is used especially in masculine notes (Müller, 1992). *Erogenic* was not included in the H&R guide, but it was regarded as feminine, because erogenous components are to be avoided in men's fragrances (J. S. Jellinek, 1997). Given the similarity between *erogenic* and *animal* (Table 2, Figure 3), and taking into account that the latter is seldom used in the H&R guide, both descriptors were classified as feminine. This criterion is consistent with the classification of *sensual* and *warm* as feminine descriptors (Table 7). Actually, *sensual* refers to perfumes that have an erotically stimulating effect and that are usu-

Table 7
Frequency of Occurrence of Odor Character Descriptors Used by the H&R Fragrance Guide (Glöss, 1991) That Are Only Applied to Describe the Top, Middle, or Base Note

Feminine Descriptors (%F > %M)						Masculine (%M > %F)		
Descriptor[a]	%F[b]	%M[c]	Descriptor[a]	%F[b]	%M[c]	Descriptor[a]	%F[b]	%M[c]
T_aldehydic	29.4	1.9	M_precious	4.2	0.0	B_mossy	15.9	49.0
B_powdery	53.2	36.8	M_classic	4.0	0.0	T_citrusy	3.5	11.2
B_sensual	15.5	0.0	M_narcotic	0.9	0.0	B_ambery	13.7	20.4
B_warm	21.6	10.6	B_oriental	0.7	0.0	B_musky	0.7	1.9
B_balsamic	13.9	3.5	M_honey	0.2	0.0	M_ozonic	0.0	0.5
B_feminine	6.2	0.0	M_watery	0.2	0.0	M_algoid	0.0	0.3
M_radiant	4.2	0.0	B_animalic	0.4	0.3	B_earthy	0.0	0.3

[a]The prefix "T_," "M_," or "B_" indicates that the descriptor is only applied to top, middle, or base notes, respectively. An additional 15 descriptors with very low frequencies of occurrence are not listed. [b]Percentage of feminine fragrances labeled with a given descriptor. [c]Percentage of masculine fragrances labeled with a given descriptor.

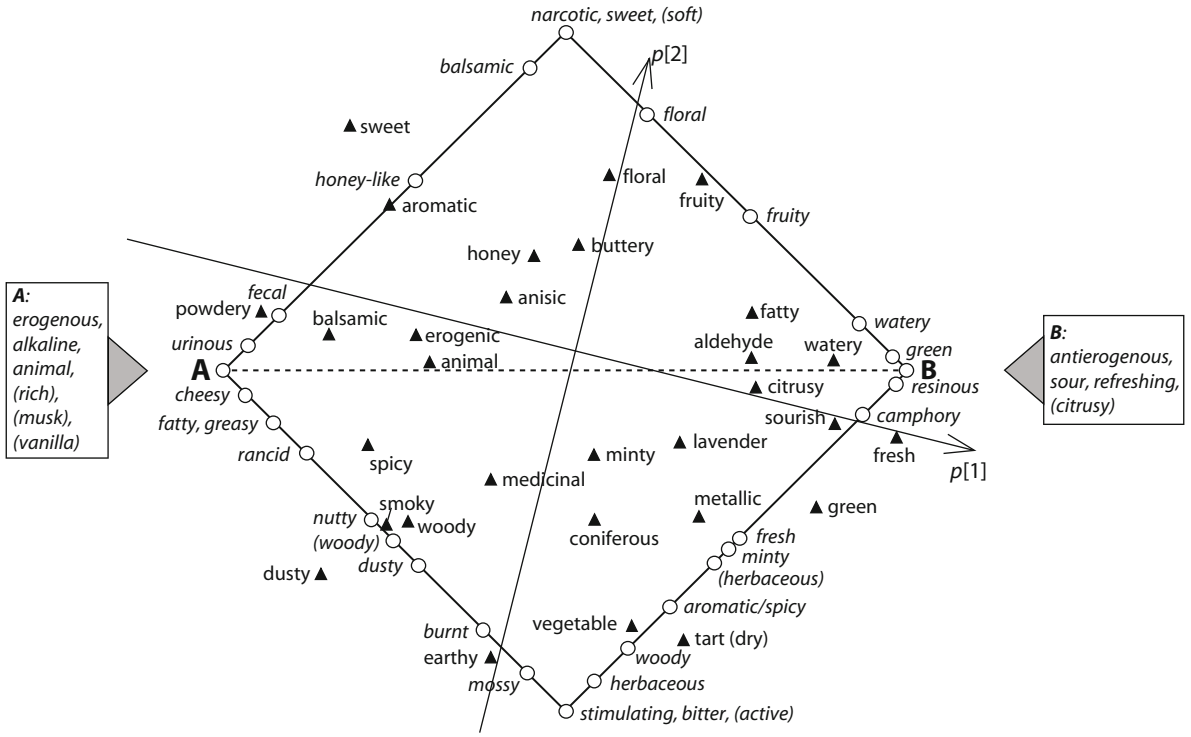

Figure 5. Rotated loading plot for PC1/PC2 from the PCA conducted with the B–H database. The dashed line corresponds to the dotted line indicated in Figure 2. The odor effects diagram (P. Jellinek, 1951, 1997) is also indicated for comparison purposes (odor descriptors in italics). Descriptors within parentheses correspond to the simplified diagram proposed by Calkin & J. S. Jellinek (1994).

ally characterized by an accentuated portion of animalic components and exotic blossom notes (Müller, 1992). *Warm* perfumes also contain a high portion of animalic ingredients (Müller, 1992).

A dotted line was drawn in the PC1/PC2 plot (Figure 2). Interestingly, all descriptors classified as feminine appear above the line, and the opposite applies to masculine descriptors. The only exception is *green*, a general term used in perfumery for the odors reminiscent of freshly cut grass, leaves, stems, and so on (Müller, 1992). However, some authors distinguish *green* from *grassy* (Thiboud, 1991). The former refers to freshly cut leaves such as violet leaf absolute, which displays floral notes of violets. *Grassy* is used for a specific type of *green* note, freshly cut grass, which suggests dry accents (Thiboud, 1991). Taking into account that dry notes are used mainly in masculine perfumes (Müller, 1992), the position of *green* below the dotted line suggests that it can be interpreted as *grassy*.

Comparison of results with P. Jellinek's odor map. Figure 2 was rotated clockwise until the dotted line became horizontal. Jellinek's odor map was rotated 90º clockwise, and, next, both plots were overlaid (Figure 5). The position of descriptors on the odor effects diagram (empty circles) corresponds to the original diagram as it was published in the first edition (P. Jellinek, 1951). A strikingly similar position is observed between descriptors in the B–H database and the corresponding terms in Jellinek's odor map, except in some cases that are discussed in detail.

Burnt and *smoky* are semantically related descriptors, and they appear close to each other in Figure 5. Birch tar oil was the reference selected by P. Jellinek (1997) for *burnt*, and cade oil was assigned to *smoky* in the B–H database. Both materials smell tar-like, smoky, and phenolic (Brechbill, 2007). The proximity between *lavender* and *camphory* is also appealing because lavender scents present a *camphoraceous* note (Calkin & J. S. Jellinek, 1994). *Coniferous* can be matched with *resinous* as mentioned above. The latter appears very close to *refreshing*, but, according to our results, it seems more appropriate to place *resinous* closer to *coniferous*.

Earthy notes give the impression of such things as freshly turned earth, forest soil, mold, moss, must, roots, yeast, and mushrooms. In perfumery, earthy essences are derived from a variety of mosses such as oakmoss, treemoss, and lichens. Oakmoss was the selected reference for *earthy* in the B–H database and, hence, it can be matched with *mossy*. The similarity of both descriptors is reflected in Figure 5.

Nutty was included in a later version of the odor effects diagram (see J. S. Jellinek, 1992). This descriptor is not far from *woody*, *spicy*, and *earthy* in Figure 5. Consistent with this result, Klein (1947) grouped *nut-like* and *woody* odors within the same cluster, whereas Abe et al. (1990) classified *walnut* (a nutty odor) as *earthy*. Moreover, nutty descriptors appeared close to *spicy*, *cinnamon*, and *earthy* in a reported analysis of semantic odor profiles (Zarzo & Stanton, 2006).

If the correspondence between *vegetable* and *herbaceous* is taken into account, the proximity of both descriptors is intuitively appealing. The position of *green* in the PC1/PC2 plot is consistent with the relative position of this descriptor in the odor map reported by Thiboud (1991). Phenyl acetaldehyde dimethyl acetal was regarded by P. Jellinek (1997) as a reference for *green*. This odorant is contained in the B–H database, and the floral score is 6 (on a 0–9 scale). By contrast, methyl heptin carbonate (the reference selected in the B–H database) was given a floral score of 3. The different floral character of both references would explain why the position of *green* in the PC1/PC2 plot is not coincident with P. Jellinek's criterion.

Peru balsam is often regarded as a standard for *balsamic* (Brud, 1986), and this criterion was adopted by P. Jellinek (1997). This material smells balsamic, sweet, and reminiscent of vanilla (Brechbill, 2007; Rimmel, 1895). Olibanum resinoid, the reference selected by Boelens and Haring (1981), does not smell so sweet (Table 1), and it is probably for this reason that P. Jellinek (1997) located *balsamic* close to the sweet corner of the odor effects diagram, but it appears more distant in the PC1/PC2 plot.

Eugenol was chosen by Boelens and Haring (1981) as a standard for *spicy*, whereas safrole was assigned to *aromatic*/*spicy* (P. Jellinek, 1951). Zwaardemaker (1925) classified eugenol as *aromatic*/*spicy*, but safrole was regarded as *aromatic*/*aniseed*. Thus, *aromatic*/*spicy* in Figure 5 should be matched with *anisic* instead of with *spicy*. This interpretation would explain the discordant position between *aromatic*/*spicy* and *spicy*. Although spices and some herbs are used as culinary condiments, spicy odors are basically perceived as warming or hot in character, as opposed to the neutral or cool effects of herbal notes. Taking into account that PC1 can be interpreted as a warm/cool dimension, as discussed below, the position of *spicy* derived from the B–H database seems appropriate.

Eugenol and safrole are contained in the B–H database, and their odor profile is significantly different. In the case of safrole, the highest scores assigned by the panel correspond to *anisic* (7), *vegetable* (5), and *spicy* (4). The vegetable character of safrole supports the position of *aromatic*/*spicy* close to *herbaceous* in the odor effects diagram. Interestingly, Aftelier (2006) classified fennel oil (the reference for *anisic*) as *herbal–anisic*. But this similarity is not reflected in the B–H database, because the correlation between *anisic* and *vegetable* is very low ($r = .12$). *Anisic* appears close to the center of the PC1/PC2 plot because it yields a low correlation with the rest of the variables. It is unclear where this descriptor fits best on the odor effects diagram.

The position of *fatty* is also discordant, probably because of the different odor character of the reference materials. *Fatty, greasy* appears near the erogenous corner of the diagram because nonyl alcohol (the reference of this descriptor assigned by P. Jellinek, 1997) was regarded as *erogenous* in a sensory experiment that assessed the erotic power of about 200 perfume materials (P. Jellinek, 1997). This similarity between *fatty* and *erogenous* was also reported by different authors. According to Müller (1992), *fatty* notes are reminiscent of the smell of human skin in small doses, and hence they can contribute to the erotic effect of a perfume. Jeltema and Southwick (1986) classified *oily, fatty* as *animal–foul* (Table 5). *Fatty* and *rancid* are related descriptors, as shown in the diagram, because rancid odors are caused by the oxidation of fats.

Undecylenic alcohol was the selected reference for *fatty* in the B–H database. The position of this descriptor in the loading plot reveals that this odorant smells fresh, which is actually the case (Table 1). Interestingly, P. Jellinek (1997) regarded this odorant as *antierogenous*. Brud (1986) reported that 1-decanol and 1-dodecanol were the odorants most frequently chosen among perfumers as standards for *fatty*. The latter was perceived as *erogenous*, and the former was somewhat intermediate of *erogenous* and *antierogenous* (P. Jellinek, 1997). Therefore, the position of *fatty* in the odor effects diagram strongly depends on the selected reference. This observation highlights the need to achieve a consensus in assigning reference materials to odor descriptors as a prerequisite for developing standard maps of odor descriptors.

The narcotic dimension of odor effect: A discussion. According to P. Jellinek (1997), narcotic odorous materials have certain female characteristics, whereas the stimulating materials present certain male characteristics. Thus, the underlying dimension in odor descriptor space based on the polarity *feminine*/*masculine* that was found in our study is consistent with the *narcotic*/*stimulating* dimension of odor effects. Similarly, Thiboud (1991) obtained a two-dimensional odor map, and the pair of contrasting descriptors *men–husbands* versus *young wives–mothers* was the polarity that better explained one of the dimensions. Describing scents as feminine versus masculine is probably more intuitive than is narcotic versus stimulating, given that the narcotic or stimulating effect of the individual perfume materials has yet to be proven scientifically. *Narcotic* is used in perfumery to describe the sweet, mellow, floral–balsamic fragrance of certain flowers said to be intoxicating (e.g., narcissus, tuberose, or ylang ylang). Consistent with this criterion, the position of *narcotic* on the odor effects diagram is somewhat intermediate of *floral* and *balsamic*.

P. Jellinek (1997) associated *sweet* and *bitter* with narcotic and stimulating effects, respectively. *Sweet* is a term common to tastes and flavors that has two applications in perfumery: (1) It can describe a rich fragrance with the ambrosial characteristics of a sweet taste (e.g., balsamic scents). (2) It can also refer to the perfumer's changes in a fragrance that make the odor smoother or softer when it is too dry, leafy, or bitter (Thiboud, 1991). Taking into account that *smooth*, *soft*, and *feminine* are similar descriptors, as described below, the second meaning supports the correspondence between *sweet* and *narcotic* proposed by P. Jellinek (1997). However, the analysis of the B–H database suggests that s*weet* is better mapped somewhere between the position of *narcotic* and *erogenous*. A similar result was observed in the odor map reported by Thiboud. Boelens and Haring (1981) assigned *sweet* to heliotropin, which smells very warm and floral–narcotic (Table 1). As-

suming that *warm* and *erogenous* are related descriptors, as discussed below, it is intuitively appealing that the position of *sweet* in the PC1/PC2 plot is somewhat intermediate between *erogenous* and *narcotic* (Figure 5).

Bitter is one of the four basic taste sensations identified by human taste buds. Although perfumers do not largely agree on what is or what is not a bitter smell (Thiboud, 1991), this attribute is often applied to perfume odors that have a metallic green quality, without sweetness. Consistent with this criterion, P. Jellinek (1997) regarded *bitter* and *sweet* as opposite descriptors. But the polarity *sweet*/*bitter* is probably better interpreted as *sweet*/*dry*, because *dry* usually refers to the absence of sweetness in a fragrance (Aftel, 2001; Thiboud, 1991). The descriptor most dissimilar to *sweet* in the B–H database is *tart (dry)*, and both variables appear at opposite positions in the PC1/PC2 plot. P. Jellinek (1997) postulated that *sweet*/*bitter* could be matched with the *narcotic*/*stimulating* dimension. But the analysis of the B–H database does not support this hypothesis, because the *sweet*/*dry* polarity clearly departs from the vertical axis in Figure 5.

The associations *sweet–feminine* and *dry–masculine* are well known in perfumery. Masculine fragrances are generally less floral than feminine perfumes and contain dry notes of leather, tobacco, herbs, spices, mosses, and woods. Bitter accents are also characteristic of men's fragrances (Müller, 1992). Conversely, most feminine fragrances smell floral, and this descriptor yields the highest correlation with *sweet* in the B–H database (Table 3). Nonetheless, *floral* and *sweet* account for independent dimensions of odor character. Actually, the reference selected by P. Jellinek (1997) for *floral* (hydroxycitronellal) is contained in the B–H database, and the sweet score of this odorant is rather low (2 on a 0–9 scale).

The sweet smell of certain odors seems to be caused by associative learning due to the co-occurrence of such odors and tastes (Stevenson, Prescott, & Boakes, 1995). A similar interpretation applies for perfumes. Kirk-Smith and Booth (1987) suggested that a fragrant scent can acquire subtle meaning through learned associations if it is experienced in a meaningful situation. The perceived odor may evoke recognition of the source as well as any thing, place, persons, or effect that might be associated with it. The same reasoning would suggest that the relationship between sweet and feminine odors might be the result of a stable cross-modal association developed in the first months of our life between the taste of food while breastfeeding (milk clearly tastes sweet) and the odor of the food source (feminine smell). This hypothesis is mere speculation, but it deserves to be investigated further.

Interpretation of PC1. *Fresh* was long ago proposed as an independent category of odors (Bain, 1855). Similarly, it is one of the five standard families of perfumes proposed by Edwards (2006), which is subdivided into three categories: *citrus*, *green*, and *water*. Different authors suggest that *fresh*, in relation to the effect of a fragrance, is a perception not easy to define (Calkin & J. S. Jellinek, 1994; Müller, 1992; Thiboud, 1991). Some experts maintain that *fresh* is an effect introduced into a fragrance by the use of citrus oils or certain aldehydes. Other perfumers use *fresh* when referring to the *green* note of recently cut leaves. A fresh fragrance is usually considered invigorating, nature inspired, or reminiscent of the outdoors and is typified by green, citrus notes (Thiboud, 1991). Interestingly, *fresh* is the descriptor with the highest loading in PC1, and it is located close to *watery*, *citrusy*, *aldehydic*, and *green* in the PC1/PC2 plot (Figure 2). Thus, PC1 can be interpreted as a dimension of freshness. In order to better understand the psychological aspects associated with this dimension, it is of interest to discuss our results in relation to the work of P. Jellinek (1997).

Interpretation of PC1 as erogenous versus antierogenous. The position of *fresh* and related descriptors in the PC1/PC2 plot has a direct correspondence with the odor effects diagram (Figure 5). Hence, PC1 could be interpreted as the *erogenous*/*antierogenous* dimension of odor effects. P. Jellinek (1997) regarded *refreshing* and *fresh* as different odor descriptors. The former was associated with *antierogenous*, *sour*, and *citrusy*, as well as with the perfume type *Eau de Cologne*, with the citrus note emphasized. By contrast, *fresh* was basically associated with *green–herbaceous* odors, which were supposed to produce antierogenous and stimulating effects. Methyl heptin carbonate (the selected reference for *green* in the B–H database) was classified as *fresh* (i.e., refreshing–stimulating) by P. Jellinek (1997). The position of *green* in the loading plot, somewhat intermediate of *antierogenous* and *stimulating* (Figure 5), is consistent with this criterion. Masculine fragrances often contain a high percentage of fresh ingredients (Müller, 1992). The classification of *fresh* and *citrusy* as masculine (Table 6) is consistent with the position of both terms below the dashed line in Figure 5.

The association between *sour* and *refreshing* proposed by P. Jellinek (1997) was also reported by a sensory study conducted with 50 participants who were asked to rate 11 odorant materials on a numeric scale according to 30 sense-descriptive adjectives. A factor analysis of the resulting data led to three relevant factors. One of them, interpreted as *clarity*, was basically determined by the terms *cool*, *clear*, and *sour* (Higuchi, Shoji, & Hatayama, 2004). Taking into account that *clarity* refers to fresh scents (Tisserand, 1988), this factor corresponds to the dimension of *freshness*.

The correspondence between *sour* and *citrusy* (Calkin & J. S. Jellinek, 1994) is based on a cross-modal association between taste and smell. Lemon tastes sour and, hence, lemon oil (a characteristic citrus scent) was regarded as a reference for *sour* (P. Jellinek, 1997). In the context of perfumery, *fruity* refers to the sweet-sour odors of natural fruits excluding citrus. Consistent with this description, the position of *fruity* in Figure 5 is intermediate between *sweet* and *sour*. Excesses of fruitiness are to be avoided in perfumes, because they would suggest food flavors rather than cosmetic products (Müller, 1992).

P. Jellinek (1997) probably located *alkaline* and *sour* at opposite corners of the diagram because they are semantically opposite terms. But the similarity *alkaline–erogenous* is arguable. By contrast, the association *animal–erogenous*

(Figure 5) seems more appropriate because animalic materials (i.e., natural or synthetic odorants smelling like extracts from animal origin) are often used in perfumes to add an erotic tone (P. Jellinek, 1997; Moran, 2000; Müller, 1992). The best-known products of the animal kingdom in the perfume industry are civet, musk, castoreum, and ambergris. They often smell unpleasant, obtrusive, and fecal in concentrated form. Correctly diluted, however, they are an irreplaceable ingredient in many perfumes, providing warmth and a sensual feel (Müller, 1992). It is therefore not surprising to find *fecal* close to the erogenous corner of the odor effects diagram (Figure 5). Similarly, Jeltema and Southwick (1986) classified *fecal*, *urine*, and *sweaty* in a cluster referred to as *animal–foul* (Table 5).

Assuming that *erogenous*/*antierogenous* is a salient dimension of odor descriptor space, and taking into account the observed similarity between *animal* and *erogenic* (r = .46), both descriptors were expected to be the ones most dissimilar to *fresh* (i.e., those located at the opposite position in the PC1/PC2 plot) among the 30 descriptors of the B–H database. But this is not the case (Figure 2), given that *animal* and *erogenic* define an independent dimension, somewhat intermediate to PC3 and PC6 (Figure 3), which is orthogonal to PC1 (i.e., the dimension of freshness). Nonetheless, *powdery* is the descriptor most dissimilar to *fresh* (Table 3), and it presents a similarity with *erogenic* (r = .49) because of certain erogenous and musky notes of the reference material (Table 1). Chastrette et al. (1991) grouped *powdery*, *musky*, and *animal* in the same cluster. The polarity *erogenous*/*refreshing* does not provide a good enough interpretation for PC1, and other complementary interpretations are discussed here.

Calkin and J. S. Jellinek (1994) also realized that *animal* is probably not the descriptor most dissimilar to *fresh*, and these authors proposed the term *rich*. The same criterion is applied by Edwards (2008), who considers *fresh* and *rich* to be opposite descriptors of fragrances, and who classifies as *rich* those fragrances in the family that produce the deeper impression. *Rich* and *deep* are similar terms in perfumery (Thiboud, 1991).

According to P. Jellinek (1997), women emphasize their feminine gender least when at work and most in their social life. This hypothesis explains why women prefer fresh fragrances (i.e., antierogenous) for informal daytime wear, whereas sensual perfumes are preferred for evening wear. This dimension of daytime versus evening in fragrance preference was reflected in a reported study conducted with 10 commercial perfumes that were rated according to different attributes (J. S. Jellinek, 1992). The preference of antierogenous scents for daytime is also reflected in the two-dimensional odor map reported by Thiboud (1991), showing that *morning* and *fresh* are mapped close to each other, whereas *evening* and *night* appear at opposite positions of this odor map.

Interpretation of PC1 as heavy versus light. *Light* odors correspond to materials that have low boiling points and that tend to disperse quickly into the air because of their high volatility. The opposite applies to *heavy* odors that are often described as *rich*. The parameter that measures the lasting property of an odorant is called *substantivity*, and it is partly dependent on the degree of volatility. Perfume is a complex mixture of substances of different volatilities. *Heavy* perfumes are those in which the least volatile ingredients, such as mosses and animal scents, dominate (Thiboud, 1991). Conversely, light fragrances are those perceived as nonsweet with a fresh note that is predominant and that is often associated with citrus, greens, aldehydes, and delicate floral notes (Green, 1999; Moran, 2000). According to Tables 6 and 7, *fresh*, *green*, and *aldehydic* are frequently encountered at the top note of a fragrance (i.e., light odors), and these descriptors appear in Figure 2 with $p[1] > 0$. Conversely, *powdery*, *sweet*, and *balsamic* generally correspond to base notes (i.e., heavy odors), and they are characterized by $p[1] < 0$. Therefore, PC1 could also be interpreted as a *heavy*/*light* dimension. Given the association *fresh–light–volatile*, Edwards (2008) defines *fresh* as the most effervescent fragrances.

Different studies have also reported that *heavy*/*light* is a salient dimension in the perceptual space of cosmetic scents. A sensory study conducted with 90 German women (J. S. Jellinek, 1980) revealed that the dimension *heavy*/*light* discriminated most strongly among the six perfumes used in that study. J. S. Jellinek (1992) developed a two-dimensional map of fragrances based on the dimensions *heavy*/*light* and *floral*/*nonfloral*, which are not difficult concepts for consumers to understand. With the help of a pilot study, this author found that the scale *warm*/*cool* was readily understood by German female perfume users. Taking into account that these descriptors are more neutral, in terms of value judgment and of the relationship to odor intensity, J. S. Jellinek (1992) used *warm*/*cool* in place of *heavy*/*light* in the map of fragrances. This criterion seems appropriate, because *heavy* has many meanings in perfumery, and it is sometimes applied to describe intense odors (Thiboud, 1991). Moreover, *warm* and *cool* are semantically opposite concepts.

Interpretation of PC1 as warm versus cool. *Warm* perfumes are often described as rich and deep (Thiboud, 1991), and they have a high proportion of animalic ingredients (Müller, 1992). Harper (1975) selected costus and amber (i.e., two animalic materials) as standards for *warm*. Hence, *warm* and *erogenous* are related descriptors. The reference materials for *powdery*, *sweet*, and *balsamic* in the B–H database are described as warm (Table 1). These are the attributes with the most negative loadings in PC1, whereas *fresh* is the descriptor with highest $p[1]$ (Figure 2). Thus, PC1 can also be regarded as a *warm*/*fresh* dimension. A similar interpretation is deduced from a reported analysis of the language of French perfume advertising. It was found that *warm* and *sensual* were closely related descriptors, and the dimension *warm*/*fresh* was the most important axis of the semantic field of fragrances (Blumenthal, 1979). Another study shows the classification of 140 commercial perfumes according to the *warm*/*cool* dimension (J. S. Jellinek, 1990).

Fresh, *cool*, and *warm* are terms semantically associated with temperature. On one hand, a temperature similar to that of our body tends to be described as warm. On the other hand, the materials whose smell is reminiscent of the human body odor are erogenous (J. S. Jellinek, 1997).

This association might explain the similarity between *warm* and *erogenous*. Klein (1947) also suggests that the human flesh aura evokes animalic scents.

J. S. Jellinek (1992) reports the results of a sensory study conducted with 10 commercial perfumes that were rated according to different attributes. The dominant factor distinguished fresh fragrances, which were described as "summer," from sensual and passionate fragrances, which were associated with winter. These results are consistent with the hypothesis that *fresh* evokes a cooling temperature and hence *fresh* perfumes are preferred in summer. Conversely, *sensual* (i.e., *erogenous*) perfumes evoke warming temperatures and are good for cooler seasons. *Oriental* perfumes are reminiscent of fragrances from the Orient and contain sensual ingredients, often heavy blends of oriental balsamic resins, opulent flowers, sweet vanilla, and musks (Edwards, 2008). These ingredients evoke warmth, and hence oriental fragrances are mostly used as "winter" perfumes (Müller, 1992).

A *cool* scent often suggests a clean, fresh, outdoor quality, possibly with green, citrus-mint undertones (Thiboud, 1991). Harper (1975) selected menthol and camphor as references for *cool, cooling*. These odorants share a *minty–fresh* odor character. Minty odors produce a trigeminal effect that is perceived as cooling, which would explain the similarity between *fresh* and *minty* ($r = .32$). In the Dravnieks database, *minty* yields the highest correlation with *cool, cooling* ($r = .82$). This similarity suggests that *cool* should be preferentially applied to the perception of freshness associated with a trigeminal effect. Therefore, we suggest that PC1 is better interpreted as *warm*/*fresh* instead of *warm*/*cool*. Trigeminal nerve receptors are responsible for tactile, pressure, pain, and temperature sensations in the nasal cavity. A number of chemical trigeminal stimulants produce effects described as irritating, tingling, pungent, cooling (menthol), or hot (capsaicin). The interaction between the trigeminal and olfactory systems is an important determinant of odor sensations (Hummel & Livermore, 2002).

Interpretation of PC1 as watery versus powdery. The observed similarity between *fresh* and *watery* ($r = .37$) is intuitively appealing because water is refreshing. Moreover, fruits (citrus or noncitrus), vegetables, and plants are natural products with a high water content, and their respective odor descriptors appear in Figure 2 with $p[1] > 0$. Conversely, *spicy*, *woody*, *dusty*, and *smoky* evoke products with a low water content, and these descriptors present $p[1] < 0$. Therefore, PC1 could also be regarded as an underlying dimension that evokes presence versus absence of water. This interpretation is not surprising, given that water is so abundant in nature.

Powdery is the descriptor most dissimilar to *fresh* (Table 3), and it evokes lack of water. The term *powdery* is preferable to *dry*, because the latter is usually applied to describe the lack of sweetness in perfumery odors (Aftel, 2001; Thiboud, 1991). In the Dravnieks database, *dry–powdery* is a single descriptor, and it yields the highest correlation with *woody* and *musk*. Müller (1992) defines *powdery* as the fragrance effect produced by the interaction of long-lasting (i.e., heavy) mossy, woody, sweet elements. The position of *powdery*, somewhat intermediate among *earthy*, *woody*, and *sweet* in Figure 5, supports this definition. Moreover, *powdery* yields the highest correlation with *erogenic*, *dusty*, *sweet*, *balsamic*, and *woody*. A mixture of musk ketone and coumarin (a sweet–herbaceous odorant) was selected as a reference for *powdery* in the B–H database (Table 1), and Harper (1975) also selected both materials as standards for *powdery*. Consistent with this criterion, *powdery* is often defined as a sweet–dry, somewhat musky odor.

Brechbill (2007) classifies odorant materials into 19 categories, one of which is *fresh air, ozone*. *Fresh* is sometimes applied to the clean and invigorating scent of early morning air or perhaps an ozonic smell (Thiboud, 1991). This definition fits the description of the water family of fragrances proposed by Edwards (2008), which is characterized by marine and aquatic notes. According to this author, water notes capture the pure scent of a waterfall, the ozonic aroma of wet air after a thunderstorm, and the cool freshness of sea air; and they evoke the scent of soft sea breezes. *Green* and *citrus* also refer to fresh scents, and, interestingly, lemon odors associated with *green* notes may evoke *sea* (Thiboud, 1991). Thus, although water is odorless, *watery* is used to describe the scent of natural environments associated with water. Taking into account the alternation of seasons, some being drier than others, the ability of olfaction to recognize water-related seasonal odors from the environment may be related to chronobiological annual rhythms.

In summary, PC1 can be interpreted as a dimension of freshness that has a direct correspondence with the *erogenous*/*antierogenous* dimension of odor effect as well as other contrasting polarities such as *rich*/*fresh*, *heavy*/*light*, *warm*/*cool*, and *powdery*/*watery*. Further research is encouraged to provide a better understanding of the psychological aspects involved in this underlying dimension.

PCA of Thiboud's Database

A variety of the studies mentioned above have reported that, although the hedonic dimension is usually the most salient in the multivariate analysis of numeric odor profile databases, that dimension rarely shows up in the analysis of semantic odor databases. Thus, it might be argued that the latter are more suitable for studying the underlying dimensions of odor descriptor space. Thiboud's (1991) database contains useful information to further investigate this issue. It comprises 119 materials selected as representatives of the main odor classes in perfumery: *fresh*, *fruity*, *rosy*, *floral*, *balsamic*, *spicy*, *woody*, *agrestic*, *green*, and *citrus*. Hence, the analysis of this database is supposed to reflect the similarities and dissimilarities among these categories of fragrances.

We analyzed the dichotomic matrix with PCA using the autoscaling pretreatment. In this case, there are 21 PCs with an eigenvalue >1. This number is obviously too high, and hence another criterion is necessary to determine how many components provide the relevant information. Table 4 shows the Q^2 value up to PC10. PC1 and PC2 are the only components that satisfy the cross-validation criterion (i.e., $Q^2 > Q^2_{\text{limit}}$). Thus, the PC1/

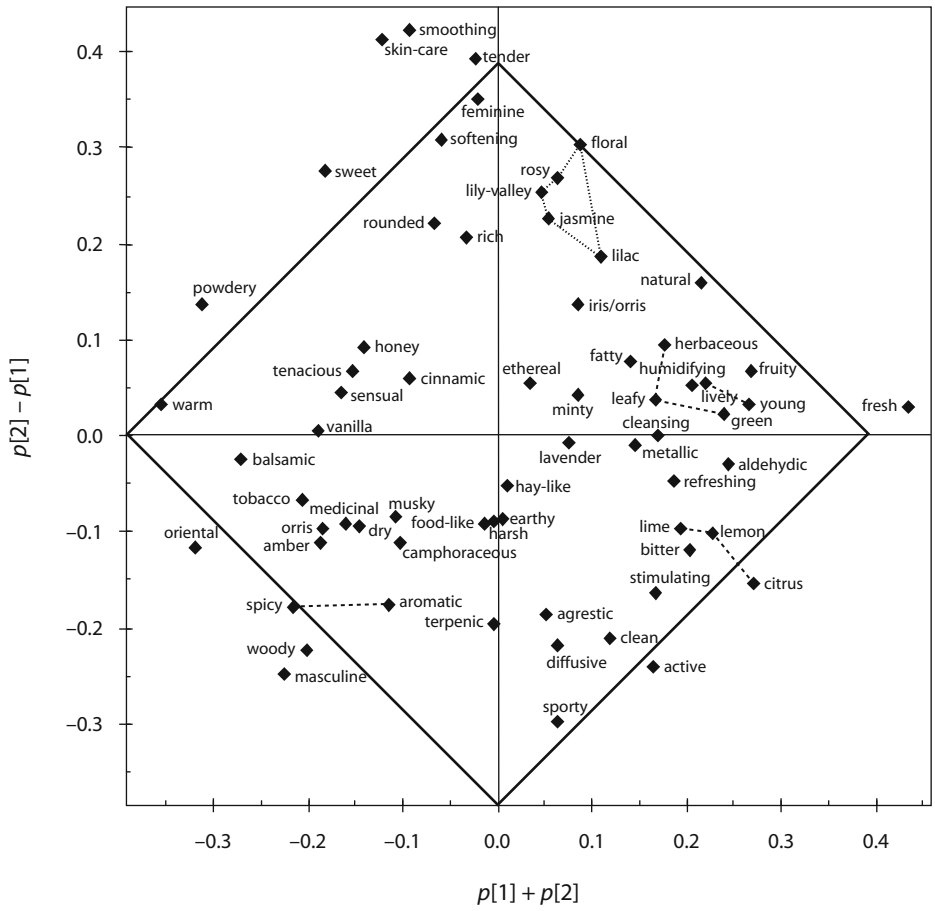

Figure 6. Rotated loading plot resulting from a PCA conducted with a dichotomic matrix of 66 odor descriptors. This matrix was obtained by coding numerically the semantic odor description of 119 perfume materials (Thiboud, 1991). Data were autoscaled prior to the PCA. In order to ease the comparison with Figure 5, $p[2] - p[1]$ is plotted against $p[1] + p[2]$, which corresponds to a 45º rotation of the loading plot for PC1/PC2. The square is intended to allow an easier comparison of this odor map with the position of descriptors in Jellinek's odor map (Figure 5). The dotted cluster groups floral descriptors. Dashed lines highlight similarities reflected by further components.

PC2 plot is expected to be a meaningful map of odor descriptors. Nonetheless, we also checked additional loading plots with different combinations of components up to PC5 and compared them with the PC1/PC2 plot in order to identify robust similarities among descriptors. PC1 and PC2 explain a similar amount of the data variance, given that their R^2_X and Q^2 values are similar. In such cases, the underlying dimensions are sometimes better interpreted by conveniently rotating the PC1/PC2 plot. We noticed that this plot was strikingly similar to Figure 5 after a 45º clockwise rotation. This rotation can be achieved by plotting $p[2] - p[1]$ versus $p[1] + p[2]$ (Figure 6).

We applied the same procedure to the trichotomic matrix: A PCA was conducted after the autoscaling pretreatment, and, next, the PC1/PC2 plot was rotated. The resulting odor map (figure not shown) was very similar to Figure 6. We found that the rotated loading plot obtained from the dichotomic matrix better resembled the two-dimensional map reported by Thiboud (1991); therefore, this plot is discussed in detail next.

Interpretation of the underlying dimensions according to the odor effects diagram. *Sensual* and *tenacious* (Figure 6) match approximately the position of *erogenic* in Figure 5. Taking into account that *tenacious* refers to odors with high substantivity (i.e., heavy), this result supports the interpretation of the *x*-axis as *erogenous*/*antierogenous* or *heavy*/*light*. The polarity *powdery*/*watery* is also reflected in Figure 6, because *powdery* and *humidifying* are located at opposite positions. Nevertheless, the *warm*/*fresh* interpretation seems to be the most appropriate given that *fresh* is the term with highest coordinate along the *x*-axis and, conversely, *warm* is located at the opposite extreme. *Rich* was expected to appear closer to *warm* and *sensual*, given the similarity among these descriptors mentioned above. However, *rich* is a rather subjective descriptor, and the results suggest that it was probably applied with a different meaning.

Young and *lively* can be regarded as similar descriptors, because they appear close to each other in Figure 6; moreover, both attributes have the highest loadings in PC3. According to P. Jellinek (1997), 20-year-old people prefer fresh scents. A similar criterion can be deduced from the plot on the basis of the position of *young*.

Feminine and *masculine* appear as opposite variables. Hence, the vertical axis of Figure 6 can clearly be interpreted as femininity versus masculinity, which corresponds to the *narcotic*/*stimulating* dimension of odor effects. Calkin and J. S. Jellinek (1994) associated this dimension with the polarity *soft* versus *active*. Interestingly, *softening* is mapped next to *feminine*; furthermore, *active* appears at the opposite extreme of the plot. It is intuitively appealing that *sporty* and *active* are next to each other, because sports involve physical activity.

The rose odor reflects softness, femininity, and sensitiveness (Thiboud, 1991). This odor quality of *rosy* is also reflected in Figure 6, because it appears near *softening* and *feminine*. *Smoothing* and *softening* have a similar meaning, and consequently they are plotted close together. *Skin-care* is mapped close to *feminine*, probably because of a psychological association given that women use skin-care products much more often than do men. The feminine characteristic of *tender* is rather obvious, because this adjective is applied primarily to women. In the context of perfumery, *rounded* and *harsh* are opposite concepts. The former suggests balance, smoothness, and harmony (Thiboud, 1991). Interestingly, the same relationships among *rounded*, *smoothing*, and *harsh* can be deduced from the plot as well.

The observed similarity between *soft* and *sweet* was also reported in a sensory study using 11 odorants that were assessed according to 30 adjectives. Three relevant factors were identified. One of them, interpreted as *softness*, was basically determined by *mild*, *soft*, and *sweet* (Higuchi et al., 2004). Given the association *soft–feminine–sweet* (Figure 6), and taking into account that *mild* is a feminine descriptor (Table 6), the factor of softness would correspond to the *narcotic*/*stimulating* dimension of odor effects.

Bitter usually refers to a dry perfume odor with a metallic green quality. Interestingly, the position of *bitter* in Figure 6 is similar to the position in Figure 5 of *metallic* and *green*, which are related descriptors (Table 5). The polarity *sweet*/*bitter* in Figure 6 does not match the odor effects diagram, but it corresponds approximately to *sweet*/*tart (dry)* in Figure 5.

Interpretation of results according to the odor classification of Zwaardemaker (1925). One of the early odor classification systems is based on nine categories: *ethereal*, *aromatic*, *fragrant* (i.e., *floral* and *balsamic*), *ambrosial*, *alliaceous*, *empyreumatic*, *caprylic*, *repulsive*, and *fetid* (Zwaardemaker, 1925). The hypothesis that *ethereal* is a rather independent category is also reflected in Figure 6, because this descriptor is the one closest to the center. A similar result was obtained by Zarzo and Stanton (2006), who found a similarity between *ethereal* and *chemical*.

Aromatic yields the highest correlation with *fragrant* in the Dravnieks database, but Zwaardemaker (1925) considered both terms as independent categories of odors. Regarding aromatic odors, this author proposed five subcategories: *camphoraceous*, *spicy*, *aniseed*, *citrus*, and *almond*. Interestingly, *camphoraceous* and *spicy* are close to *aromatic* in Figure 6, but the loading plot for PC4/PC5 (figure not shown) suggests that *aromatic* was applied in Thiboud's (1991) database primarily to describe spicy odors. The position of *spicy* in Figure 6 is nearly the same as in the PC1/PC2 plot from the B–H database (Figure 5). We suggest that the same criterion could be adopted in future versions of the odor effects diagram.

Benzaldehyde was selected as a standard for *aromatic* by Harper (1975), but Zwaardemaker (1925) classified it as *aromatic–almond*. Edwards (2008) associates *aromatic* with *fougère*, which refers to the combination of fresh herbaceous lavender notes on a mossy foundation (Müller, 1992). This criterion is not consistent with the subcategories of aromatic odors proposed by Zwaardemaker. The term *aromatic* was used in former times to describe the fragrance impression of sweet balsams (Müller, 1992). This criterion was probably adopted by Boelens and Haring (1981), because they selected vanillin as a reference for *aromatic*. By contrast, Zwaardemaker regarded vanillin as a *balsamic* odor. Given the subjectivity of *aromatic*, which is not always applied in perfumery with the same meaning, it seems convenient to disregard it in future studies of odor profiling.

Ambergris exhibits notes of *woody*, *dry balsamic*, and *tobacco-like* (Table 1). This odor description is consistent with the position of *amber* in Figure 6. Zwaardemaker (1925) classified musk and amber odors (i.e., those resembling ambergris) as *ambrosial*. Interestingly, *musky*, *amber*, and *dry* are close to each other, and these descriptors are perceived as primarily masculine (see Table 7).

Further discussion of the resulting map of odor descriptors. Figure 6 suggests that *balsamic*, *vanilla*, *honey*, and *cinnamic* are similar descriptors. Interestingly, these descriptors are classified as *balsamic* in the Sigma–Aldrich (2003) catalog. The position of *balsamic* is consistent in the two odor databases analyzed (Figures 5 and 6), but this descriptor appears on the odor effects diagram closer to *sweet*. This result further suggests that the position of some descriptors in Jellinek's odor map should be revised.

The positions of *fatty* and *aldehydic* are consistent with the PC1/PC2 plot from the B–H database. *Citrus*, *lemon*, and *lime* are close to each other in Figure 6 as well as in the loading plot for PC3/PC4 (not shown). This relationship is obvious, because limes and lemons are citrus fruits. The proximity between *citrus* and *stimulating* suggests a masculine character of citrus odors that is also reflected in Table 7.

Orris and *iris*/*orris* are located at opposite positions, although they are semantically related. Orris is a perfume material extracted from the rhizomes of the iris plant (*Iris pallida* and other species) that produces a violet-like and woody odor (Müller, 1992). Given that *iris*/*orris* appears close to *floral*, it seems that this descriptor referred to a violet-like odor character. By contrast, *orris* is close to

Table 8
Odor Categories That Comprise Edwards's Fragrance Wheel and Number of Fragrances (Women's, Men's, and Unisex) Listed Under Each Category (Edwards, 2008)

	Number of Fragrances			Column Percentages		
Category	Women	Men	Unisex	Women	Men	Unisex
Fruity	21	0	3	0.6	0.0	0.5
Green	33	15	29	1.0	0.9	5.3
Water (marine)	35	81	21	1.0	4.7	3.8
Floral	1,446	17	44	41.8	1.0	8.0
Soft floral	354	10	23	10.2	0.6	4.2
Floral oriental	533	1	6	15.4	0.1	1.1
Soft oriental	97	18	19	2.8	1.0	3.5
Oriental	145	15	31	4.2	0.9	5.6
Woody oriental	352	361	65	10.2	21.0	11.8
Woods	71	263	63	2.1	15.3	11.5
Mossy woods	175	70	15	5.1	4.1	2.7
Dry woods	47	156	43	1.4	9.1	7.8
Citrus	146	138	167	4.2	8.0	30.4
Aromatic (*fougère*)	8	572	21	0.2	33.3	3.8
Total	3,463	1,717	550	100.0	100.0	100.0

Note—Categories are sorted as they are arranged in the Fragrance Wheel.

woody, which might indicate that this attribute referred to a woody-like rather than to a floral odor.

The similarity of *leafy*, *green*, and *herbaceous* (Thiboud, 1991) is reflected in Figure 6 as well as in the loading plot for PC1/PC3 (not shown). The position of *green* is coincident with Jellinek's odor map (Figure 5), but that is not the case with *herbaceous*. This term is applied to describe a grassy-green, spicy, and somewhat medicinal odor (Thiboud, 1991), and hence the position of *herbaceous* in Figure 5 seems more appropriate. This descriptor was applied to 24 materials in Thiboud's database, which is a relatively high number and suggests that *herbaceous* was used with a different meaning.

Agrestic and *rustic* are semantically related concepts. Billot (1948) proposed a *rustic* category of smells that comprised *minty*, *camphoraceous*, *herbaceous*, *lavender*, *green*, *earthy*, and *vegetable* odors. Hence, *rustic* could be mapped in the PC1/PC2 plot (Figure 5) by averaging the coordinates of *minty*, *vegetable*, *lavender*, *green*, and *earthy*. Interestingly, the resulting position matches nearly exactly with *agrestic* in Figure 6.

Thiboud's (1991) database contains seven odorants described as *minty*, four as *lavender*, and five as *camphoraceous*. These descriptors share a camphor-like note, but this similarity is not reflected in Figure 6. Their position is not consistent with Figure 5, probably because of the low number of occurrences in the database. Nonetheless, most of the eight descriptors with just four occurrences (*cinnamic*, *rounded*, *ethereal*, *musky*, *leafy*, *lavender*, and *iris/orris*) seem to be mapped properly in Figure 6, as already discussed, suggesting that they provide relevant information. Thus, the criterion to discard descriptors with fewer than four occurrences seems appropriate.

Comparison of Results With Edward's Fragrance Wheel

One perfume category of the Fragrance Wheel is *aromatic/fougère*. However, given the subjectivity of *aromatic*, discussed above, it seems more appropriate to refer to this category as *fougère*. The Fragrance Wheel was properly rotated so that the *floral* and *woods* categories matched approximately the positions of *floral* and *woody*, respectively, in Figures 5 and 6. Taking into account that *dry* and *sweet* are opposite concepts in perfumery, *dry woods* should appear close to the *stimulating* corner of the odor effects diagram. This category is next to *citrus* in the Fragrance Wheel, which corresponds to another corner of the diagram. This observation suggests certain discontinuity between both categories, and we thought that *fougère* may fit in between. This criterion is discussed below.

We counted the number of men's, women's, and unisex fragrances listed under each category of Edwards's (2008) fragrance guide (Table 8). For a given category, if the percentage of men's perfumes was higher than the percentage of women's, the category was regarded as *androgenic* (i.e., perceived with masculine characteristics). If the opposite applied (i.e., percent women $>$ percent men, according to Table 8), the category was regarded as *gynogenic*.

Oriental is a gynogenic category (Table 8), and, moreover, this descriptor is applied more frequently to feminine perfumes (Table 7). *Woody oriental* is the next category in the wheel, but it is androgenic. Owing to this result, the odor wheel was rotated, so that the boundary between both fragrance categories corresponds to the dashed line in Figures 5 and 7, which can be interpreted as a discriminating line between androgenic versus gynogenic fragrances. Consistent with this interpretation, the three floral categories are the ones more distant from the dashed line and they basically comprise feminine fragrances (Table 8). The fact that *soft floral* is the category most distant from this line is appealing, because *soft* appears at the upper corner of the odor effects diagram (Figure 7), and, moreover, *softening* and *feminine* are related descriptors (Figure 6).

Unisex fragrances are not perceived as clearly masculine or feminine, and hence they may be expected to be

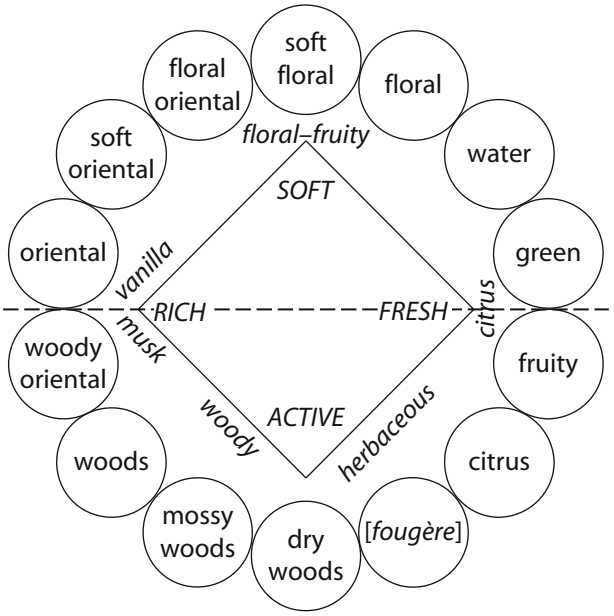

Figure 7. Fragrance Wheel (perfume categories displayed within circles). The sequence of the different categories around the central point is the same as originally was proposed by Edwards (2008), although they were conveniently rotated to achieve the best possible consistency with the odor effects diagram (Calkin & J. S. Jellinek, 1994), which is also illustrated for comparison purposes (inner square, letters in italics). The only exception is [*fougère*], which is located at the hub of the odor wheel in the original representation.

found close to the dashed line in Figure 7. Interestingly, *woody oriental* is the category with the second highest percentage of unisex fragrances (Table 8), and it appears at the boundary of the dashed line. *Citrus* is a masculine descriptor (Table 6) and an androgenic category (Table 8). Its position in Figure 7 is consistent with Figure 6. Nearly one third of unisex fragrances appear under the *citrus* category, suggesting that it is also perceived to be close to the boundary between femininity and masculinity.

Fruity is clearly a feminine descriptor (Table 6, Figure 5), and this category contains only feminine or unisex fragrances. Thus, we expected to find it above the dashed line in Figure 7. The *fruity* category was not included in the 2006 version of the Fragrance Wheel. Edwards (2008) located it between *green* and *citrus*, but the proximity of *fruity–floral* in Figure 5 suggests that the *fruity* and *water* categories of fragrances might be swapped in future versions of the wheel. Interestingly, swapping both categories leads to an interesting property of the odor wheel: All categories above the dashed line contain a higher percentage of feminine than of masculine perfumes. The opposite basically applies for categories below the line, with the exception of *mossy woods*.

According to Edwards (2008), the *mossy woods* category corresponds to *chypre* fragrances. We checked that 23.8% of feminine fragrances in the H&R guide (Glöss, 1991) as well as 35.7% of masculine fragrances are classified as *chypre*. This result suggests that *mossy woods* is an androgenic category, consistent with the position below the dashed line in Figure 7. The fact that *mossy* and *woody* are masculine descriptors (Tables 6 and 7; Figure 5) supports this interpretation. *Chypre* fragrances are characterized by the contrast between a *fresh citrus accord* and *oakmoss* (Glöss, 1991). These materials are perceived as basically masculine (Figure 5). Thus, it was unexpected to find that the percentage of women's fragrances in the *mossy woods* category is slightly higher than that of men's in Edwards's (2008) fragrance guide.

The *dry woods* family is often called *leather*, after the dry, smoky scent of Russian leather. It is characterized by dry notes of tobacco and burnt wood (Edwards, 2008). This category is androgenic (Table 8) probably because *dry*, *woody*, *leathery*, and *tobacco* are masculine descriptors (Table 6).

According to Moran (2000), the *green* category of perfumes is characterized by dominant green notes: vigorous pine, dry herbs (e.g., sage and rosemary), as well as fresh notes from grasses, leaves, lavender, basil, chamomile, and galbanum. The *green* family of the Fragrance Wheel is characterized by the impact of the classic resinous galbanum accord, which is clearly present in many green fragrances (Edwards, 2008). In the B–H database, galbanum resinoid was the reference for *tart (dry)*. Figure 5 suggests that this descriptor is perceived as masculine, as well as *coniferous*, *vegetable*, *lavender*, and *green*. These observations suggest that the *green* category should be regarded as androgenic. But *green* is used in the H&R fragrance guide as a feminine descriptor (Table 6). The percentage of men's fragrances under the *green* category is nearly the same as that of women's (Table 8). Thus, it is somewhat unclear whether *green* should be categorized as gynogenic or androgenic. Nevertheless, the position of *green* in Figure 7 is intuitively appealing, because this category appears at the boundary line that discriminates androgenic from gynogenic categories, and because an equivalent position for *green* in the odor effects diagram was proposed by P. Jellinek (1997).

The *fougère* category takes its name from the legendary fragrance *Fougère Royale*, which was created in 1882. In perfumery, *fougère* is the name of a combination of fresh herbaceous lavender notes on a mossy foundation (Müller, 1992). These materials are basically perceived as masculine (Figure 5), and consequently *fougère* is an androgenic category (Table 8). Its position could be obtained approximately by averaging the coordinates of *fresh*, *herbaceous*, *lavender*, and *mossy* in Figure 5. The resulting position is highly coincident with the one that we propose for the *fougère* category in Figure 7. The two-dimensional map of fragrances proposed by J. S. Jellinek (1992) is based on the dimensions *warm*/*cool* and *floral*/*nonfloral*. Taking into account these dimensions, *fougère* fragrances were mapped in the direction intermediate between *cool* and *nonfloral* (J. S. Jellinek, 1992). The same position for the *fougère* category was proposed in J. S. Jellinek (1990), which is consistent with Figure 7. *Floral* and *fougère* are the main categories of feminine and masculine fragrances, respectively. It is appealing that both categories are located at symmetrical positions with respect to the dashed line.

GENERAL DISCUSSION

Olfactory perception is based on the activation by odorant molecules of olfactory receptors (ORs) located at the cilia of olfactory neuronal endings (see Zarzo, 2007). Humans exhibit high variability of both general olfactory thresholds and sensitivities toward specific odorants—that is, partial anosmia (see Lawless, 1997). These phenotypes can be attributed partly to genetic variation in the OR genome. Some OR genes show both functional and inactive alleles in the human population, which are referred to as *segregating pseudogene*s (SPG). The variability of OR genes among individuals is one of the most pronounced cases of functional population diversity in the human genome. One study found 38 SPGs among the 384 intact human OR genes likely to encode functional ORs (Menashe, Aloni, & Lancet, 2006). Individualized SPG combinations generate an *olfactory barcode*, whereby every human nose is genetically different. Thus, the olfactory qualities of complex mixtures, such as fragrances, are not perceived identically by everybody.

Taking into account this intersubject olfactory variability, and given the high dimensionality of odor perception space, it was rather unexpected to find that the multivariate analysis of two odor profile databases obtained in the context of perfumery led to rather coincident two-dimensional representations of the odor descriptor space (Figures 5 and 6). Moreover, these odor maps are highly consistent with other studies (e.g., Thiboud, 1991) as well as with odor representations such as Jellinek's odor map and Edwards's Fragrance Wheel, which are derived basically from the experience of perfumers. These results encourage further attempts to achieve standard odor maps for perfumery. Moreover, the reported evidence supports the hypothesis that, apart from individual exceptions, the effect of a given odorous material is basically the same for all people if the odor is perceived under a similar context and concentration (P. Jellinek, 1997).

Other authors have applied multivariate statistical methods such as PCA, factor analysis, or cluster analysis to the B–H database in order to classify compounds into groups with similar odor aspect patterns (Boelens & Haring, 1981; Ennis et al., 1982). Other studies have used this database in an effort to relate molecular structure with odor character (Palen, 1983; Seeman, Palen, & Ennis, 1987). None of these studies has attempted to interpret the correlation structures among odor attributes. Our work is the first study showing that PC1 and PC2 of this database are consistent with the odor effects diagram.

Jellinek's odor map is based on two primary dimensions of odor effects: erogenous versus antierogenous (refreshing) and narcotic versus stimulating. The former dimension corresponds to PC1 of the B–H database, because *fresh* is the descriptor with highest p[1] loading. P. Jellinek (1997) assumed that *erogenous* and *refreshing* were opposite polarities of the same underlying dimension. But *erogenous* and *animal* determine an independent dimension (Figure 3) that is orthogonal to PC1. Thus, PC1 seems better interpreted with the polarity *refreshing* versus *warming*, or maybe as a psychological dimension that evokes natural environments associated with the presence of water versus dry environments. The *narcotic*/*stimulating* dimension of the odor effects diagram corresponds to PC2, which basically accounts for the polarity *feminine*/*masculine* as suggested by P. Jellinek (1997). The results of the B–H database are intuitively appealing, because most of the 30 references are raw materials commonly used to formulate perfumes. Moreover, this database was obtained from a panel of perfumers, and their expertise is probably heavily imprinted in the resulting perceptual space. The fact that a similar odor map was obtained from the analysis of Thiboud's database supports the hypothesis that the two dimensions of the odor effects diagram are the most salient in the analysis of cosmetic scents. The consistency among odor maps provides clues to explain why some descriptors were mapped in different relative positions.

Although the PC1/PC2 plot from the B–H database is rather similar to the one from Thiboud's (1991) database, the former seems more reliable. Actually, we were able to interpret all of the discrepancies found between this plot and Jellinek's odor map, but this was not the case with Thiboud's database. Moreover, our results suggest that the B–H database contains more information to identify further relevant dimensions. The main disadvantage of numeric methods is that they are time consuming, and hence they are usually restricted to a limited number of descriptors. By contrast, semantic methods allow for a rapid generation of data and permit a larger number of attributes, which is a great advantage with respect to interpreting the psychological aspects involved in olfaction. The approach followed in the present work, combining the information from numeric and semantic profiles in order to characterize odor descriptor space, appears to be a good alternative. The database obtained by Dravnieks (1985) is relevant to olfactory research, because it contains numeric odor profiles based on 146 descriptors. It would be of interest to study whether the basic dimensions of odor effects would also be salient in a multivariate analysis of this database.

All attempts to categorize odorants or odor descriptors on the basis of the analysis of odor profile databases are obviously limited by the finite set of chemical stimuli that participants evaluate. Taking into account that the perfumer's palette now consists of approximately 4,000 raw materials, it is necessary to determine the most appropriate sample size to assess. Obviously, using a large number of materials is more likely to better represent the whole population, but this would be restricted to semantic methods. The sensory study reported by Higuchi et al. (2004) using 11 odorant materials found three relevant factors, which the authors interperted as clarity (i.e., freshness), softness (i.e., femininity), and intensity. Their results suggest that the basic dimensions of the odor-effects diagram are salient even with a reduced number of materials. Similar results were reported by others using only 10 fragrances (J. S. Jellinek, 1990, 1992; J. S. Jellinek et al., 1992), but this number is obviously too low to achieve a detailed map of odor descriptors. The fact that consistent results were obtained from Thiboud's (1991) database, with a sample size of 119 materials, suggests that it is unnecessary to as-

sess many hundreds of compounds. Conversely, it seems more convenient to focus on the psychophysical method of odor description. Nonetheless, some descriptors such as *minty* and *lavender* were discordantly mapped, probably because the database lacked enough representative odorants with a camphoraceous note.

Our analysis of the B–H database also revealed that the resulting odor representation was affected strongly by the materials chosen as a reference for each descriptor. Thus, in order to guarantee consensus in the development of sensory maps for cosmetic odor descriptors, it is necessary to first achieve certain agreement among perfumers about the reference materials to be used for each attribute. The use of references is strongly recommended, because each individual's preconceptions about a given odor descriptor are not necessarily the same as another's. Perfumers think about odors in terms of the odors' use in a fragrance. Selecting the right reference material at the right concentration for each odor descriptor is important for reproducibility purposes, given that the similarities between attributes are partly determined by the odor similarities of the reference materials. Harper (1975) provides a list of reference materials chosen by a group of experts for 44 descriptors. The International Organization for Standardization (ISO) proposes 24 reference substances for training in the recognition of odors (ISO, 2006). Further efforts will be necessary in order to reach a consensus about which standards should be used for the basic attributes in the description of perfumery odors.

Some olfactory researchers suggest that it is an oversimplification to attempt to reduce the high number of odor qualities to a few dimensions (Lawless, 1997). However, this view is not shared by perfumers, who consider odor maps to be a valuable tool (J. S. Jellinek, 1992). One of the world's most comprehensive guides to commercial fragrances is the one developed by Edwards (2008). It classifies more than 5,700 mass-market and direct-sale fragrances available worldwide, cross-referenced by gender (i.e., women, men, or unisex) and by fragrance families that are displayed on the Fragrance Wheel. This sensory wheel was created in order to simplify fragrance classification as well as to show the relationships among each of the individual families. We compared the Fragrance Wheel with Jellinek's odor map as well as with the resulting odor maps from the two databases analyzed (Figures 5 and 6), and we observed a remarkable coincidence (shown in Figure 7). One of the practical outcomes of the present work is that we propose some modifications of the Fragrance Wheel so that it can be more consistent with other studies. Work in progress suggests that the Discodor (Harder, 1979) is rather consistent with the odor effects diagram. By contrast, the Natural Perfume Wheel (Aftelier, 2006) should be modified significantly in order to reproduce properly the underlying dimensions of odor perception space.

AUTHOR NOTE

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