unknown hand preference. Given that 10 percent of these youngsters would have become left-handed, that 70 percent of these are at risk to a right-sided lesion, and that 75 percent of those at risk suffered aphasia, it is reasonable to expect that one of the two aphasics was left-handed. Thus, the estimated *P(A| RL)* adjusted for left-hander contamination is .056 = 1/18. The estimated proportion of aphasias following left-hemisphere lesions (that is, .84) should not be appreciably affected by contamination by left-handers, bilateral lesions, or both, and need not be adjusted. These adjusted proportions are similar to those for adults and result in similar estimates of *P(LS)* and *P(RS)*—.94 and .06, respectively. Stricter inclusion criteria would likely place even less emphasis on right-hemisphere lesions as cause of aphasia (*17*) and thereby result in an even lower estimate of *P(RS)*. Hence, if Basser's study (*9*) is excluded, the childhood aphasia data are consistent with electrophysiological, neuroanatomical, and behavioral data in their support of the developmental invariance position.

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Odor Quality: Semantically Generated Multidimensional Profiles Are Stable

Abstract. *Odors of ten compounds were characterized by approximately 150 subjects who used a list of 146 descriptors. Duplicate profiles correlated highly ($P < .001$) and consistently higher than profiles of different odors. Profiles also agreed with those obtained previously. Thus, profiles based on combined responses of many subjects are stable constructs.*

Methods for characterizing odors have applications in a variety of disciplines. There are two principal methods. In reference odorant methods, the odor is rated for similarities by direct comparison to a series of reference odorants (*1*). In semantic methods, the odor is described by words or rated for the applicability of various odor descriptors (*2, 3*). Both methods can produce multidimensional profiles that can be depicted by two-dimensional bar graphs. The profile depends on the selected reference odorants or descriptors.

The semantic method is logistically simpler, but has been considered significantly "noisy" because of interindividual differences in the meanings of specific descriptors (*4*). I now report the extent to which the semantic profile stabilizes if a large number of subjects are used.

The study was a part of a cooperative exercise conducted by the American Society for Testing and Materials (ASTM) Sensory Evaluation Committee E18, with 15 laboratories, each of which contributed ten subjects (*5*). The samples were 12.5 by 9 by 1.6 mm balsa wood chips impregnated with solutions of odorants in odorless dipropylene glycol (Olin) and enclosed in a rip-apart disposable aluminum packet. Each of 150 participants (*6*) received an individual sample attached to a multidimensional rating form (*3*).

The form utilizes 146 descriptors and is based on Harper's 44-descriptor list (*2*). The 44-descriptor scale gave almost identical profiles for odors that were clearly different, so over a period of years more descriptors were added in stages. The major expansion resulted after the ASTM Sensory Evaluation Committee reviewed literature and industrial sources and collected over 830 odor descriptors in use. A group of participating laboratories screened this long list and reduced it to approximately 160 descriptors judged useful in odor evaluations. The list used here represents most of these descriptors, after some obvious synonyms were removed.

The suitability of each descriptor to the odor being tested was scored on a scale of 0 to 5. Both the sample and the form were coded, and the identity of the odorant was revealed to the experimenters and the subjects only after the test.

The following ten odorants were used (concentrations in grams per liter of the solvent in parentheses): acetophenone (50), anethole (100), 1-butanol (160), *l*-carvone (100), *p*-cresylmethylether (25), cyclohexanol (350), 1-heptanol (350), 1-hexanol (200), phenylethanol (40), and pyridine (150). The same odorants had been used in a previous study (*3*), and at that time were selected to represent several with similar odors (aliphatic alcohols) as well as those with very different odors. All are chemically stable and were of the highest purity available commercially. Each odorant was profiled twice, under different code names, and more than 2 months apart. There was no requirement to use the same subjects either for all samples or for a duplication of the same sample; in practice, most of the subjects remained the same.

Profiling an odor by a group of subjects produces two types of values for each descriptor: frequency of use of the descriptor and a sum of scores assigned to the descriptor. Two profiles of the same odorant expressed in terms of either the frequency or the sum of scores were highly correlated (all $r > .96$, $P < .001$). Since the frequencies alone do not contain information on the scores, a hybrid method was selected in which both types of values are considered (*3*). This "percent applicability" method tends to reconcile cases in which a descriptor was used frequently but with low scores, with cases in which this descriptor was used infrequently but with high scores. The findings apply equally to profiles constructed on the basis of frequency, score sum, or percent applicability.

The applicability of each descriptor was calculated as follows. Suppose that six of ten subjects used a particular descriptor for a specific odor, and the sum of the scores given by these six was 20. The frequency and the sum of scores were expressed as percentages of the maximum possible value (10 is maximum for the frequency and 50 is maximum for the sum of scores, so in this case, the frequency was 60 and sum 40 percent). The geometric mean of the two percent-

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Table 1. Comparison of several profiles as percent applicability, rounded down to the nearest 5 percent. Applicabilities below 5 percent do not appear.

Descriptors	1-Hexanol		Anethole	Pyridine
	Profile 1	Profile 2		
Fruity, citrus	5			
Lemon				
Grapefruit				
Orange				
Fruity, noncitrus	10	5		
Pineapple				
Grape juice				
Strawberry				
Apple				
Pear				
Melon				
Peach				
Banana				
Floral	15	10		
Rose	10	5		
Violet	5			
Lavender	5	5		
Cologne	5	5		
Musky	5	10		
Perfumery	10	10	5	
Fragrant	35	25	40	5
Aromatic	25	25	45	15
Honey				
Cherry	5	5		
Almond	20	10	5	
Nail polish remover	10	5		
Nutty	10	5		
Spicy	10	5	20	
Cinnamon			5	
Laurel leaves				
Tea leaves				
Seasoning				
Black pepper				
Green pepper				
Dill				
Caraway				
Oak wood, cognac	10	5		
Woody, resinous	25	30		
Cedarwood	10	5		
Mothballs	5	5		
Minty, peppermint	5	5	10	
Camphor	10	10		
Eucalyptus	5	5	5	
Chocolate				
Vanilla				
Sweet	20	10	35	
Maple syrup				
Caramel				
Malty				
Raisins				
Molasses				
Coconut		5		
Anise, licorice	5	5	90	
Alcoholic	10	5		5
Etherish, anesthetic	20	20	5	5
Cleaning fluid	10	10		5
Gasoline, solvent	10	10		5
Turpentine, pine oil	10	10		
Geranium leaves	10			
Celery				
Green vegetables	5	5		
Crushed weeds	5	5		
Crushed grass	10	5		
Herbal, green	20	20		
Raw cucumber				
Hay	5			
Grainy				
Yeasty				
Bakery, fresh bread				
Sour milk				
Fermented fruit		5		
Beery				

Descriptors	1-Hexanol		Anethole	Pyridine
	Profile 1	Profile 2		
Soapy		5		
Leather	5	5		
Cardboard				
Rope				
Wet paper				
Wet wool, wet dog				
Dirty linen				
Stale		5		5
Musty, earthy	15	10		5
Raw potato				
Mouse-like				
Mushroom				
Peanut butter				
Beany				
Eggy (fresh eggs)				
Bark, birch bark	5			
Cork		5		
Burnt, smoky	10	5		5
Fresh tobacco smoke				
Incense	5	5	5	
Coffee				
Stale tobacco smoke				
Burnt paper				
Burnt milk				
Burnt rubber				
Tar	5	5		
Creosote	5	5		5
Disinfectant	10	10		5
Medicinal	15	10	10	10
Chemical	20	20		30
Bitter	5	5		5
Sharp, pungent	15	20	5	35
Sour, vinegar	5			15
Sauerkraut				
Ammonia		5		10
Urine				
Cat urine				5
Fishy				20
Kippery, smoked fish				5
Seminal, spermlike				
New rubber		5		
Sooty				
Burnt candle		5		
Kerosene		5		
Oily, fatty	10	15		10
Buttery				
Paint	10	10		
Varnish	10	10		
Popcorn				
Fried chicken				
Meaty, cooked meat				
Soupy				
Cooked vegetables				
Rancid	5	5		15
Sweaty	5	5		10
Cheesy				
Household gas				5
Sulfidic	5			10
Garlic, onion				10
Metallic	5	5		
Blood, raw meat				5
Animal				5
Sewer odor				5
Putrid, foul				30
Fecal, like manure				5
Cadaverous				10
Sickening	10	10		60
Dry, powdery		5		
Chalky				
Light	10	10	5	
Heavy	25	25	20	35
Cool, cooling	10	10	15	
Warm	10	10	15	5

ages was termed the percent applicability of the particular descriptor to the particular odor, for that group of subjects (in this case, $\sqrt{60 \times 40} = 49$). The purpose of using the percentages is to normalize data in cases of different group sizes. The mean of all 15 laboratories served as the grand percent applicability and was used to construct the multidimensional profiles.

The average number of descriptors per panelist used for an odor ranged from 7 for anethole to 11 for acetophenone. However, when the responses of all participants are examined (separately for any of the ten odorants), only a small number of the 146 descriptors remain unused, from 3 for phenylethanol to 25 for anethole and carvone. Several of the obtained profiles are shown in Table 1 (which has been simplified by eliminating applicabilities below 5 percent).

Two sets of data were used to estimate the reproducibility of the profiles. One set was the result of this study; the other consisted of odor profiles obtained earlier on the same ten odorants (*3*). In the earlier study, odors were evaluated in duplicate by smelling odorant vapors from dipropylene glycol solutions in flasks; 50 subjects from four laboratories had participated in that study, and only a few subjects were common to both studies.

Two profiles of each odor were constructed and correlated; r ranged from .95 for 1-hexanol (Table 1) to .99 for anethole. The data are reproducible ($P < .001$, $N = 146$) even for the 1-hexanol. The coefficients remained the same even when those descriptors with zero values in both profiles were excluded from the calculation, probably because only a few descriptors fell into this category. However, such exclusion of "inapplicable" descriptors in a comparison of any two profiles may be improper: the absence of a certain odor note in the two profiles points to a partial similarity between the profiles, just as the presence of a certain note in both profiles indicates some similarity.

The arithmetic mean of the standard deviations of the descriptor percent applicability over such pairs of profiles ranged from 0.54 percent for anethole to 1.56 for cyclohexanol, so that the percent probability values should be stable within a few percent absolute (difference by 3 percent would correspond to 2 standard deviations and should occur by chance in less than one case in 20).

In the earlier study, the descriptor list was shorter (136 instead of 146), and some important descriptors such as alcoholic were not included, even though the odorants included several alcohols. The earlier method of calculation utilized an "editing" feature, disregarding those descriptors used by only one subject in the particular laboratory, and also those used more often but by only one laboratory out of four. The two profiles of the same odor (duplicate profiles) were combined into one, for each study separately, by averaging the percent applicability values for each descriptor. The correlation coefficients of the new and the earlier profiles of the same odor (considering only 136 descriptors common to both studies) ranged from .85 to .97, again demonstrating reproducibility ($P < .001$, $N = 136$) despite the differences in the sample presentation and profiling procedures. Thus, profiles based on the responses of a large number of panelists are stable representations of the odor character.

Table 2. Comparisons of odor profiles taken in pairs. The values are the residual variances after a comparison by a linear regression.

Odorant	Code									
	ACPH	ANET	BUTA	CARV	CRME	CYCL	HEPT	HEXA	PHET	PYRI
Acetophenone	.04	.70	.64	.73	.22	.62	.24	.20	.57	.89
Anethole		.01	.93	.70	.72	.93	.73	.78	.83	.99
1-Butanol			.07	.95	.38	.38	.47	.45	.95	.43
l-Carvone				.01	.77	.94	.75	.78	.80	1.00
p-Cresylmethylether					.06	.35	.19	.15	.78	.79
Cyclohexanol						.08	.54	.48	.97	.77
1-Heptanol							.08	.11	.66	.84
1-Hexanol								.09	.67	.83
Phenylethanol									.03	.99
Pyridine										.04

Although the duplicate profiles of the same odor were highly correlated, the question arises whether profiles of two different odors (heteropairs) also could have correlated as well as, or better than, the duplicate profiles (homopairs). In other words, can the profiles discriminate the duplicates from heteropairs? A convenient means for inspecting the data for such a possibility is to consider the variances. When two profiles of the same odor are compared, the residual variance (RV) = $1 - r^2$ indicates the extent of disagreement between two profiles caused by experimental factors such as instability of human judgments (Table 2).

The 10 values of RV for an odor versus itself are all lower than the 45 RV values for pairs consisting of two different odors [Wilcoxon-White rank-sum test, $T = 12.6$, $P < .001$ (*7*)]. Among heteropairs, the heptanol and hexanol have the most similar odors in a direct comparison (*3*) and the lowest residual variance, although it is higher than any of the homopairs. The components of the pairs anethole-pyridine, carvone-pyridine, and phenylethanol-pyridine are most dissimilar in a direct comparison, and they have the largest RV's in Table 2.

Thus, if derived from responses of a large number of individuals (preferably > 100), the odor profiles expressed in terms of percent applicabilities are stable and robust constructs. It seems possible to identify which profiles represent the same odor and to distinguish those profiles from profiles of other odors, even if similar. An accumulation of such profiles for many additional odors may permit broader classifications of odors by techniques such as cluster analysis and construction of multidimensional odor spaces. The collected profiles may also serve as a stable data base for the many branches of odor science.

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8. I am grateful to F. C. Bock, a statistical consultant with the IIT Research Institute in Chicago for statistical advice.

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