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Perception of Everyday Odors—Correlation between Intensity, Familiarity and Strength of Hedonic Judgement

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Abstract

In this study, 40 Japanese, 44 German and 39 Mexican women were presented with 18 everyday odorants. They were asked to rate them for intensity on a six-point scale from not detectable to very strong, for pleasantness on an 11-point scale from –5, to neutral at 0, to +5, and for familiarity on a six-point scale from completely unknown to extremely familiar. Consistent positive correlations were found between paired rating scores for the three measures, and although they were not particularly strong (r_S range, 0.19–0.60), for most odorants all three correlations were significant. Similar results were obtained whether the data were analyzed on an individual or a national basis. Most notable were the consistent positive correlations between perceived intensity and ratings of familiarity and hedonic strength. It is suggested that the perceived intensity of the odorants depended not only on stimulus concentration but probably also on experience-dependent factors.

Introduction

Odor perception is clearly a complex process. One expression of this is the variety of dimensions commonly used to define odors. In addition to basic sensory measures of detection and discrimination, investigators may ask subjects to rate an odor's intensity, pleasantness, irritation or familiarity, to describe its quality and images or memories it evokes, and to name or otherwise identify it (Henion, 1971; Berglund *et al.*, 1973; Moskowitz *et al.*, 1974, 1976; Doty, 1975; Land, 1979; Jellinek and Köster, 1983; Doty *et al.*, 1984, 1994; Carrasco and Ridout, 1993). Moreover, responses to the same stimulus may vary considerably on any of these measures both between individuals and across test procedures (Doty, 1975; Hyman, 1977; Mower *et al.*, 1977; Degobert, 1979; Land, 1979; Doty *et al.*, 1994). This complexity helps explain why it has proved so difficult to develop a reliable classification of odorants or to identify general rules governing their perception.

The problem is particularly clear in the case of hedonic judgement, that is, the degree to which a stimulus is considered pleasant or unpleasant. Hedonic tone has long been recognized as one of the most salient features of odors and considerable effort has gone into examining its nature and origin (Yoshida, 1964; Moncrieff, 1966; Harper *et al.*, 1968; Engen, 1974; Schiffman, 1974; Doty, 1975; Moskowitz *et al.*, 1976; Land, 1979). Repeated efforts have been made to explain hedonic judgement in terms of perceived intensity, an attribute clearly related to stimulus concentration and thus thought to reflect the operation of objective and universal psychophysical laws (Cain, 1969; Berglund *et al.*, 1971; Engen, 1971; Patte *et al.*, 1975) However, the relationship between hedonic judgement and intensity has proved complex, with some odorants demonstrating a positive correlation between pleasantness and intensity, some a negative correlation, and others variable inverted U-shaped functions or no correlation at all (Moncrieff, 1966; Henion, 1971; Moskowitz *et al.*, 1974, 1976; Doty, 1975; Moskowitz, 1977).

It is now generally agreed that the hedonic value of an odorant may vary widely between individuals or populations, and presumably as a result of experience (Moncrieff, 1966; Engen, 1974, 1988; Moskowitz *et al.*, 1974, 1976; Degobert, 1979; Land, 1979; Moskowitz, 1979; Schaal, 1988; Hvastja and Zanuttini, 1989; Ayabe-Kanamura *et al.*, 1998). The judgement of food odors, for example, may depend on whether they are recognized as such and then on whether they are associated with a preferred food, a

non-preferred food, or even with food poisoning (Engen, 1974; Moskowitz, 1977; Raudenbusch *et al.*, 1994; Ayabe-Kanamura *et al.*, 1998). Such differences may result in the same odor being judged as positive or negative even by individuals from the same population or culture (Land, 1979; Ayabe-Kanamura *et al.*, 1998).

Thus, findings increasingly point to the idiosyncratic and variable nature of odor perception and to the importance of experience in shaping it. This, in turn, suggests the need to test subjects using natural stimuli from everyday life which are presumably capable of eliciting a fuller and psychologically more relevant range of cognitive and emotional responses than the monomolecular stimuli typically used in laboratory testing (Moskowitz, 1977; Rabin and Cain, 1984; Schicker, 1995). Accordingly, in a previous study we compared the responses of Japanese and German subjects to natural, everyday odorants thought to be typically Japanese, European or international (Ayabe-Kanamura *et al.*, 1998). We found significant differences not only in ratings of familiarity and pleasantness but, surprisingly, also in ratings of intensity. The latter was unexpected since the same odor sources and concentrations had been used to test both populations.

We therefore decided to investigate these findings more closely by directly comparing ratings of intensity, familiarity and hedonic judgement given by the original Japanese–German sample and by an equivalent group of Mexican subjects tested using the same stimuli and procedure. More specifically, it was the purpose of the present study to examine the degree of association between the three measures, and to consider whether perceived odor intensity might reflect not only stimulus concentration but also subjects' experience of and hedonic response to the stimuli.

Material and methods

The Japanese and German subjects together with the odorants and test methods have been described in detail in a previous report (Ayabe-Kanamura *et al.*, 1998).

Subjects

To reduce variability arising from possible sex differences in responding to odorants (Cain, 1982; Doty *et al.*, 1984, 1985) only women were tested. All were healthy volunteers with no history of olfactory impairment. A total of 40 Japanese, 39 Mexicans and 44 Germans were recruited in equal numbers from two age groups, 20–30 and 39–50 years.

Odorants and stimulus delivery

Eighteen odorants were chosen as stimuli—six which were thought to be typically Japanese, six thought to be typically European and six thought to be international (Table 1). Exactly the same substances and the same methods of stimulus presentation were used in the three laboratories. Except for incense, exact quantities of each substance were presented in 250 ml polyethylene squeeze bottles equipped with a flip-up spout (cf. Laska and Hudson, 1991). To minimize visual, acoustic or proprioceptive cues, substances were secured in disposable teapot filter bags (Cilia®, Melitta, Germany), and these were suspended inside the bottles. Liquids were presented on absorbent surgical strips (Sugi®, Kettenbach, Germany) inside the filter bags. In the case of incense, this was lit and a 200 ml glass jar held over it for several minutes to collect the smoke. The jar was kept closed except when briefly presented to the subject. Substances were renewed either before each session (beer), on each test day (perishable foods) or after 3–7 days (inedible substances as well as the more durable foods).

Test procedure

Testing was carried out over a period of 2 weeks. Each subject was presented with the 18 stimuli in random order in a test session lasting ~30 min. Subjects were allowed to sample each substance freely and were asked to rate in the following sequence: (1) intensity on a six-point scale from not detectable to very strong; (2) pleasantness on an 11-point scale with very unpleasant at –5, neutral at 0 and extremely pleasant at +5; (3) familiarity on a six-point scale from completely unknown to extremely familiar; and (4) edibility on a two-category scale of yes or no. They were also asked to say what the odor reminded them of and, if possible, to name it.

Data analysis

For the purpose of this study the degree of association between rating scores for intensity, familiarity and pleasantness was compared in three ways; for each of the 123 individuals, for each of the 18 odorants and for each of the three nationalities. Eleven trials in which subjects failed to perceive the stimulus were eliminated from statistical analysis: four Japanese for marzipan; three Japanese, two Mexicans and one German for pine wood; and one Japanese for India ink.

Ratings of pleasantness generated by the bipolar ± scale were treated in three ways: as a measure of hedonic strength in which absolute ratings were analyzed without regard to sign (cf. Figure 3b); as a measure of pleasantness in which ratings were treated as values on a single hedonic continuum from least to most pleasant (cf. Figure 3c); and as a measure of valence in which ratings were analyzed according to sign (cf. Figure 3d).

The degree of association between measures was calculated using Spearman's correlation coefficient and the distribution of correlation coefficients for individuals or odorants across the three national groups was compared using the Kruskal–Wallis test followed by post-hoc Mann–Whitney *U*-tests (StatView, Abacus Concepts Inc.). An alpha value of 0.05 was taken as the level of significance throughout. For Spearman's correlation coefficient, significance was reached for individual subjects with $r_s > 0.48$ (n =

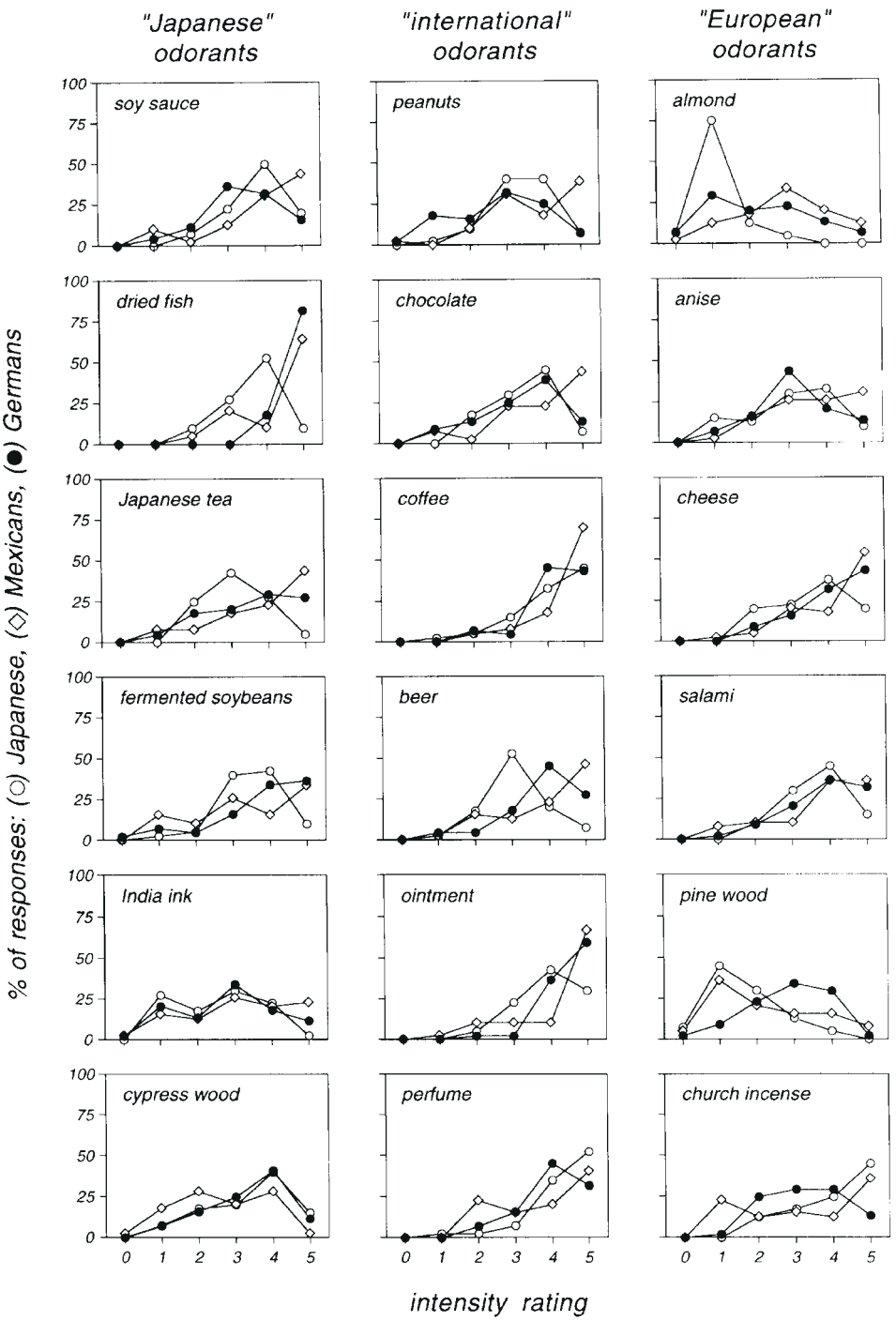

Figure 1 Ratings of intensity for each odorant by each national group: Japanese $n = 40$, Mexicans $n = 39$, Germans $n = 44$.

18 odorants) and for the different odorants with $r_s > 0.19$ ($n = 123$ subjects).

Results

With the exception of the 11 trials mentioned in the methods above, most of the odorants were clearly perceived by all subjects (Figure 1). However, a conspicuous finding was the broad range of judgements given by individuals in response to any particular odorant, that is, the large degree of individual variability in responding to the same stimulus.

Differences between the Japanese and German groups in using the rating scales and in judging the intensity, familiarity and pleasantness of the odorants have been reported

elsewhere (Ayabe-Kanamura *et al.*, 1998). Therefore in this study rating scores have been considered mainly with regard to individual subjects, and the comparison across odorants and nationalities then used to examine the generality of these findings.

Individual subjects

Intensity and familiarity

Among individual subjects, a positive relationship was found between ratings of intensity and familiarity. When Spearman's correlation coefficient was calculated for paired intensity and familiarity ratings given by each of the 123 subjects for the 18 odorants, positive although mostly weak correlations were found in the majority of cases (Figure 2a); for almost 80% of subjects r_s was > 0.2, and for 43.4% the values were significant ($r_s > 0.48$, $n = 18$, $P < 0.05$).

Intensity and hedonic judgement

Similarly, a consistently positive relationship was found between intensity and hedonic strength (rating strength regardless of polarity). In 81% of cases Spearman's correlation coefficient r_s was > 0.2 (Figure 2b), and in 32.8% reached significance. However, when the hedonic rating scale was treated as a continuum of increasing pleasantness from –5 to +5 and then compared with intensity judgements, no consistent relationship was found (Figure 2c). Positive and negative correlations were distributed symmetrically around 0 (23.8% $r_s > 0.2$; 27.9% $r_s < –0.2$), and in only 1.6% of cases were significant positive and in 7.4% significant negative correlations found.

Familiarity and hedonic judgement

When familiarity was compared with hedonic strength, in 53% of cases r_s was >0.2 and in 10% of cases <–0.2 (Figure 2d), with only 22.1% of the positive correlations and 0.8% of the negative correlations reaching significance. However, an almost exclusively positive relationship was found between familiarity ratings and the pleasantness continuum (Figure 2e). Thus, for 83% of subjects r_s was >0.2, reaching significance in 45.1%.

Odorants

When Spearman's correlation coefficient was calculated for each of the 18 odorants using the ratings of all subjects, a significant correlation ($r_s > 0.19$, $n = 123$, $P < 0.05$) between intensity and familiarity was found in all cases (Table 1), and for more than half the stimuli, strongly so ($P < 0.0001$). However, differences between odorants in the strength of correlation were considerable, ranging from $r_s = 0.19$ for coffee to $r_s = 0.52$ for peanuts. For the paired ratings of intensity and hedonic strength, significant positive correlations were found for all but one odorant (perfume), and in 14 cases the coefficients were highly significant ($P < 0.0001$; Table 1). Again, differences between odorants in the strength of correlation were considerable and ranged from

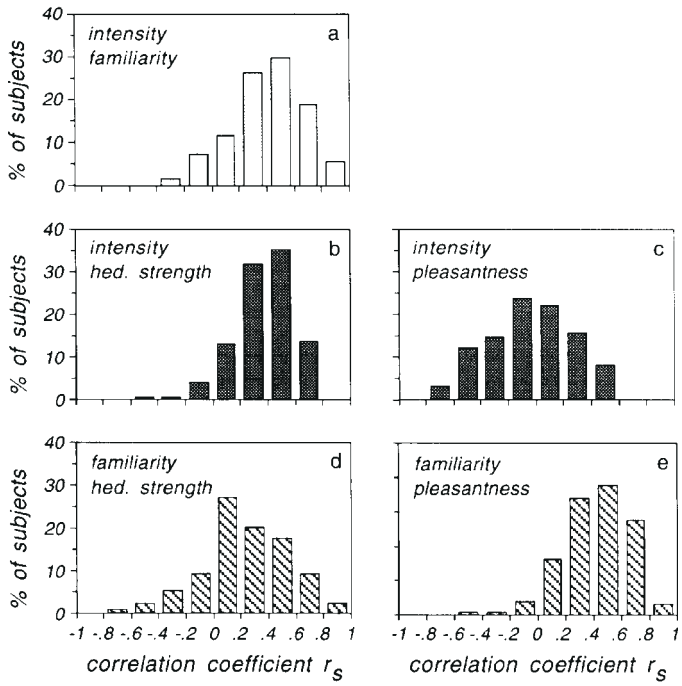

Figure 2 Frequency distributions of Spearman's *r* for individual subjects ($n = 123$) for each combination of parameters. Individual coefficients were calculated from the ratings given for each of the 18 odorants.

$r_s = 0.09$ for perfume to $r_s = 0.58$ for Japanese tea. For ratings of familiarity and pleasantness, 14 of the 18 correlations were significant, strongly so for nine ($P < 0.0001$; Table 1). Whereas beer produced the weakest correlation, $r_s = 0.02$, almond produced the strongest, $r_s = 0.60$.

National groups

When the data were analyzed according to nationality, the distributions of correlation coefficients of individual subjects were found to be very similar. Of the five possible comparisons between measures, a significant difference across national groups was found only for the coefficients of intensity and familiarity (Kruskal–Wallis, $H_3 = 8.88$, $P < 0.05$), and then only for the Mexicans compared with the Germans and Japanese (post-hoc Mann–Whitney U, $P < 0.05$ and 0.01 respectively); among the Mexicans the correlation between these two measures was weaker than for the other two groups ($r_s > 0.2$: 69 versus 84 and 85% respectively).

When the data were analyzed by nationality and odorant, both similarities and differences were found in the degree of correlation for particular odorants (Table 2). For example, in none of the national groups was the familiarity and intensity of soy sauce or cheese correlated to a significant degree, although in all three this was the case for dried fish, cypress wood and ointment. On the other hand, among Japanese a significant correlation between intensity and

Table 1 Spearman's correlation coefficients and levels of significance for paired rating scores of the 18 odorants by all subjects (n =123)

	Intensity and familiarity		Intensity and hedonic strength		Familiarity and pleasantness	
	r_s	$P\leq$	r_s	$P\leq$	r_s	$P\leq$
'Japanese' odorants						
Soy sauce	0.23	0.05	0.37	0.0001	0.33	0.0002
Dried fish	0.40	0.0001	0.41	0.0001	0.12	>0.2
Japanese tea	0.20	0.05	0.58	0.0001	0.27	0.01
Fermented soybeans	0.23	0.05	0.43	0.0001	0.24	0.01
India ink	0.50	0.0001	0.38	0.0001	0.17	>0.06
Cypress wood	0.35	0.0001	0.35	0.0001	0.49	0.0001
'International' odorants						
Peanuts	0.52	0.0001	0.50	0.0001	0.46	0.0001
Chocolate	0.40	0.0001	0.52	0.0001	0.56	0.0001
Coffee	0.19	0.05	0.36	0.0001	0.43	0.0001
Beer	0.52	0.0001	0.44	0.0001	0.02	>0.8
Ointment	0.43	0.0001	0.27	0.01	0.29	0.01
Perfume	0.21	0.05	0.09	>0.3	0.40	0.0001
'European' odorants						
Almond	0.50	0.0001	0.50	0.0001	0.60	0.0001
Anise	0.49	0.0001	0.27	0.01	0.41	0.0001
Cheese	0.22	0.05	0.48	0.0001	0.10	>0.1
Salami	0.38	0.0001	0.25	0.01	0.40	0.0001
Pine wood	0.46	0.0001	0.45	0.0001	0.25	0.01
Church incense	0.29	0.01	0.38	0.0001	0.35	0.0001

Table 2 Significant correlations of paired rating scores for the 18 odorants by national group (n = 40 Japanese, 39 Mexicans, 44 Germans)

	Intensity and familiarity			Intensity and hedonic strength			Familiarity and pleasantness		
	Japanese	Mexican	German	Japanese	Mexican	German	Japanese	Mexican	German
'Japanese' odorants									
Soy sauce				*		*	*		*
Dried fish	*	**	*		**	*			
Japanese tea	*	*		***	**		***		***
Fermented soybeans	*		**	*			*		***
India ink	***		***	*					***
Cypress wood	**	*	**	***	*	**	**	***	*
'International' odorants									
Peanuts		**	***		***	**	*	**	
Chocolate	*		*	***	***	***		*	***
Coffee	*		*	*		**	*	**	*
Beer		***	*		*				**
Ointment	**	*	*	*	*			*	
Perfume			*			**		**	*
'European' odorants									
Almond	***		**			**	***	***	
Anise	**		***	*		**			**
Cheese					**	**	***		
Salami	**		**		**	**		**	*
Pine wood	***		***	*	**	*	**		*
Church incense			*			*	**	*	*

*$r_s \geq 0.30$, $P \leq 0.05$; **$r_s \geq 0.40$, $P \leq 0.01$; ***$r_s \geq 0.50$, $P \leq 0.001$.

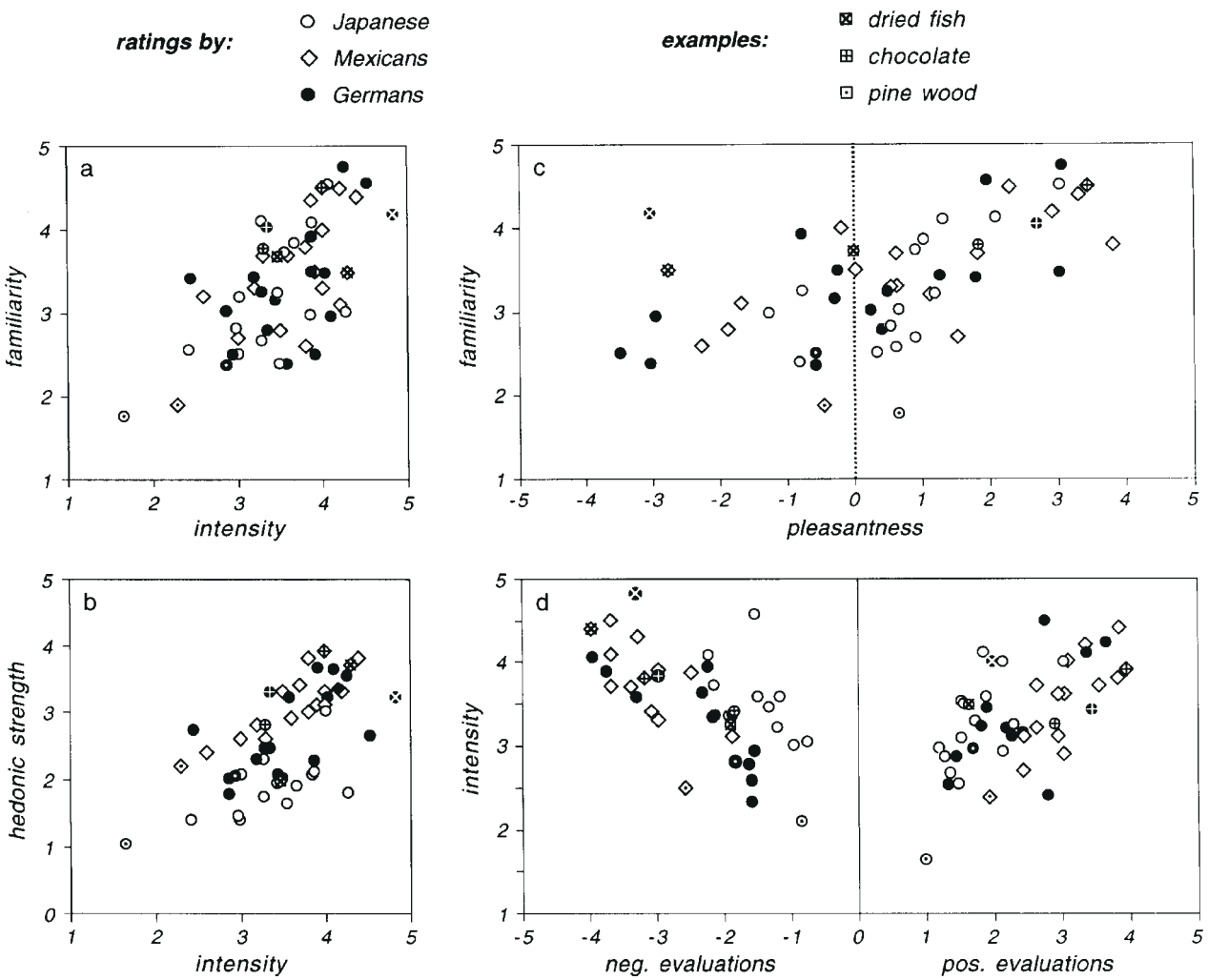

Figure 3 Mean rating scores for the main pairs of parameters. Each point represents the mean for a particular odorant and national group: Japanese n = 40, Mexicans n = 39, Germans n = 44. Pleasantness scores are represented in three ways: in **panel b** as absolute mean scores without regard to sign, in **panel c** as mean scores on a single continuum from least to most pleasant, and in **panel d** as means after separating scores according to sign, resulting in most odorant/nationality combinations being represented twice, on either side of the neutral point at 0.

hedonic strength was more often seen for Japanese than for European odorants, and vice versa for the Germans. Nevertheless, no generally consistent pattern of correlations could be identified, and no statistically significant differences were found between national groups.

To better demonstrate the contribution of odorants and national groups to the correlations described above, mean rating scores have been calculated for each odorant and national group and the data presented as scatter plots (Figure 3).

As can be seen in Figure 3a, the distribution of mean intensity and familiarity ratings overlapped to a considerable degree across national groups. Comparing particular odorants showed that differences in familiarity across groups were often but not always accompanied by corresponding differences in intensity. For example, mean scores for pine wood—a generally less familiar and less intensive odor—increased rather uniformly from Japanese, to Mexicans, to Germans, and the scores for chocolate from Japanese, to Germans, to Mexicans. On the other hand, this was not the case for dried fish, which Japanese and Mexicans judged as equally familiar but Mexicans as less intense.

The distribution of mean ratings for intensity and hedonic strength appeared similar to the distribution of ratings for intensity and familiarity (Figure 3b). However, on closer inspection it was evident that the Japanese gave consistently lower judgements of hedonic strength than the Mexicans, while the Germans were on average intermediate (cf. Ayabe-Kanamura *et al.*, 1998). However, for each of the national groups the judgements were significantly correlated (Table 3).

In Figure 3c the distribution of mean familiarity and pleasantness judgements is shown. Notable examples are

Table 3 Spearman's correlation coefficients and levels of significance for paired mean rating scores of the odorants ($n = 18$)

	Intensity and familiarity		Intensity and hedonic strength		Familiarity and pleasantness	
	r_s	$P\leq$	r_s	$P\leq$	r_s	$P\leq$
Japanese	0.63	0.01	0.62	0.05	0.65	0.01
Mexicans	0.54	0.05	0.79	0.01	0.67	0.01
Germans	0.53	0.05	0.60	0.05	0.55	0.05
All subjects	0.66	0.01	0.72	0.01	0.50	0.05

the pleasant and familiar odor of chocolate, the rather unfamiliar and hedonically neutral odor of pine wood and the odor of dried fish—the latter being judged rather familiar and unpleasant by the Mexicans and Germans but apparently neutral by Japanese as a result of the averaging of positive and negative scores (cf. Figure 3d).

Discussion

The findings of this study provide consistent evidence for positive correlations between judgements of intensity, familiarity and hedonic strength made in response to everyday odors. This was the case for a clear majority of subjects (Figure 2), and although individual correlation coefficients varied considerably, the pattern was similar across nationalities and measures. While considerable variability in correlation coefficients was also observed across odorants (Table 1), for 13 of the 18 stimuli the values were significant on all three measures. Although these correlations were in general not particularly strong (r_s range, 0.19–0.60), when mean rating scores for the 18 odorants were considered, and thus individual variability in the degree of correlation reduced, the values were substantial (r_s range, 0.50–0.79; Table 3).

A potential criticism of the present findings concerns stimulus control, particularly the precise control of concentration across sessions and laboratories. Although some variability in the presentation of perishable substances such as beer cannot be excluded, non-perishable substances such as ointment could be presented in precise amounts and thus at the same or very similar concentrations (Ayabe-Kanamura *et al.*, 1998). More importantly, the fact that subjects from the three nationalities showed the same pattern of correlations argues against the possibility that differences between stimulus sets significantly affected the findings.

A more substantial concern is that subjects, having judged the intensity of a particular odorant, might have given similar scores to the other measures simply as a result of perseveration. While this cannot be excluded, the high variability in correlation coefficients across odorants and measures (Table 1) argues against it as the only explanation since perseveration should have operated rather uniformly to produce a similar degree of correlation across conditions. Furthermore, the fact that hedonic strength correlated well with intensity but less so with familiarity and, conversely, that pleasantness correlated well with familiarity but not with intensity (Figure 2) suggests that subjects did not simply perseverate in their rating behavior but differentiated between the tasks. Thus, the correlations found here between measures seem to represent real phenomena.

In accounting for these findings two basic questions need to be considered: to what extent can the observed correlations be attributed to odorant concentration or reception, and to what extent might they have been shaped by experience?

Perceived intensity is clearly dependent on stimulus concentration (Cain, 1969; Berglund *et al.,* 1971; Engen, 1971; Patte *et al.*, 1975). However, as shown in Figure 1, intensity ratings can vary considerably between individuals even when concentration is kept constant. Variability in thresholds and psychophysical intensity functions have been reported in previous studies (Rabin and Cain, 1986; Gross-Isseroff and Lancet, 1988; Laska and Hudson, 1991), and are usually attributed to genetic differences in olfactory receptors (Amoore, 1971; Berglund *et al.*, 1973; Schiffman, 1974). Whether this can explain the type of variability seen in the present study is doubtful; in the previous cross-cultural analysis (Ayabe-Kanamura *et al.*, 1998), differences in intensity ratings were found between nationalities which could not be simply attributed to differences in the use of the rating scale or—given the chemical complexity of the stimuli—to genetic differences in receptors (cf. Laska and Hudson, 1991).

Nevertheless, considering hedonic strength, several studies have shown that pleasantness ratings frequently correlate either positively or negatively with odor concentration (Henion, 1971; Doty, 1975; Moskowitz *et al.*, 1976; Moskowitz, 1977), and our finding of a correlation between intensity and hedonic strength is consistent with this. Furthermore, it seems sensible that there should be a close relation between the two measures (Henion, 1971) given that in a natural context they convey similar information: the likely proximity and quantity of an odor source and whether it should be approached or avoided. However, several of the studies cited above (Doty, 1975; Moskowitz *et al.*, 1976; Moskowitz, 1977) also show that for some odorants pleasantness ratings may be completely independent of concentration, suggesting that in explaining hedonic judgement other factors must also be taken into account.

Although there is virtually no experimental information on the influence of concentration on the judgement of familiarity, it is conceivable that stimuli perceived as intense may also be more easily recognized or elicit stronger associations, and thus be judged more familiar. Thus, in answer to

the first question, it is quite possible that odorant concentration and/or reception influenced subjects' ratings of hedonic strength and familiarity in the present study.

On the other hand, in considering the second question, several lines of evidence suggest that experience may also have contributed to the correlations. First, it is quite evident that judgements of familiarity should be closely connected to experience and thus should reflect the subjects' degree of knowledge about the various odorants. Moreover, it is likely that experience affects judgements of pleasantness. Support for this comes from the earlier finding of a clear positive association between identification of the stimuli as culture-typical food odors and pleasantness ratings (Ayabe-Kanamura *et al.*, 1998). Another possibility relates to the phenomenon of neophobia, in which repeated exposure may lead to greater acceptance of previously neutral or mildly aversive stimuli (Rozin, 1976). However, as demonstrated by subjects for whom significant correlations between familiarity and hedonic strength were found (Figure 2d), a positive correlation between familiarity and pleasantness did not always apply. When mean familiarity and pleasantness ratings for single odorants (Figure 3) are examined it is evident that for some stimuli values do not conform to the general correlation pattern. An example is dried fish, which was often judged both highly familiar and highly unpleasant.

Evidence for the role of experience and cognitive factors in modifying odor perception comes from several previous reports. For example, Moskowitz (1979) presented 14 professionals in the cosmetics field with five cologne fragrances and found, after revealing the brand names, unexpectedly strong changes in liking, estimated sweetness and even intensity judgements. Furthermore, in an evaluation of individual differences in reported food preferences, a consistently positive association was found between ratings of pleasantness and intensity (Frank *et al.*, 1994). More recently, it has also been demonstrated by manipulating subjects' expectations of the potential danger of an ambient odor that cognitive factors may strongly influence the perception of odor intensity. Subjects believing the odor to be benign showed adaptation while those suspecting it be hazardous showed sensitization (Dalton, 1996; Dalton *et al.*, 1997).

In summary, it would seem to make sense that odorants that have acquired meaning—particularly of an emotional or motivational nature—should be perceived and attended to more readily than stimuli of little relevance, and that this should result in a stronger subjective perception of stimulus strength. How this might come about and at what level(s) of processing within the olfactory system is unknown. While higher-order cortical processes are almost certainly involved, evidence from animal studies suggest that experience may also result in odor-specific enhancement at the sensory surface itself (Wang *et al.*, 1993; Nevitt *et al.*, 1994; Semke *et al.*, 1995). It is not known if such processes operate in humans or whether they contribute to the phenomena reported here, but it is a possibility deserving further investigation (Wysocki *et al.*, 1989; Hudson and Distel, 1999). Whatever the case, the present findings suggest that in investigating odor perception not only physico-chemical properties of the stimulus but also subjects' experience and expectations should be taken into account.

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References

Amoore, J.E. (1971) *Olfactory genetics and anosmia*. In Beidler, L.M. (ed.), Handbook of Sensory Physiology, Vol. 4, pt 1. Springer Verlag, Berlin, pp. 245–256.

Ayabe-Kanamura, S., Schicker, I., Laska, M., Hudson, R., Distel, H., Kobayakawa, T. and **Saito, S.** (1998) *Differences in the perception of everyday odors—a Japanese–German cross-cultural study.* Chem. Senses, 23, 31–38.

Berglund, B., Berglund, U., Ekman, G. and **Engen, T.** (1971) *Individual psychophysical functions for 28 odorants*. Percept. Psychophys., 9, 379–384.

Berglund, B., Berglund, U., Engen, T. and **Ekman, G.** (1973) *Multidimensional analysis of twenty-one odors*. Scand. J. Psychol., 14, 131–137.

Cain, W.S. (1969) *Odor intensity: differences in the exponent of psychophysical function*. Percept. Psychophys., 6, 349–354.

Cain, W.S. (1982) *Odor identification by males and females: predictions vs performance*. Chem. Senses, 7, 129–142.

Carrasco, M. and **Ridout, J.B.** (1993) *Olfactory perception and olfactory imagery: a multidimensional analysis*. J. Exp. Psychol.: Human Percept. Perform., 19, 287–301.

Dalton, P. (1996) *Odor perception and beliefs about risk*. Chem. Senses, 21, 447–458.

Dalton, P., Wysocki, C.J., Brody, M.J. and **Lawley, H.J.** (1997) *The influence of cognitive bias on the perceived odor, irritation and health symptoms from chemical exposure*. Int. Arch. Occup. Environ. Health, 69, 407–417.

Degobert, P. (1979) *Hedonic and intensity ranking of different malodours by category estimation and paired comparison.* In Kroeze, J.H.A. (ed.), Preference Behaviour and Chemoreception. IRL Press, London, pp. 107–122.

Doty, R.L. (1975) *An examination of relationships between the pleasantness, intensity, and concentration of 10 odorous stimuli*. Percept. Psychophys., 17, 492–496.

Doty, R.L., Shaman, P. and **Dann, M.** (1984) *Development of the University of Pennsylvania Smell Identification Test: a standardized microencapsulated test of olfactory function*. Physiol. Behav., 32, 489–502.

Doty, R.L., Applebaum, S., Zusho, H. and **Settle, R.G.** (1985) *Sex differences in odor identification ability: a cross-cultural analysis.* Neuropsychologia, 23, 667–672.

Doty, R.L., Smith, R., McKeown, D.A. and **Raj, J.** (1994) *Tests of human olfactory function: principal components analysis suggests that most*

measure a common source of variance. Percept. Psychophys., 56, 701–707.

Engen, T. (1971) *Olfactory psychophysics*. In Beidler, L.M. (ed.), Handbook of Sensory Physiology, Vol. 4, pt 1. Springer Verlag, Berlin, pp. 216–244.

Engen, T. (1974) *The potential use of sensations of odor and taste in keeping children away from harmful substances*. Ann. NY Acad. Sci., 237, 224–228.

Engen, T. (1988) *The acquisition of odour hedonics*. In Van Toller, S. and Dodd, G.H. (eds), Perfumery: The Psychology and Biology of Fragrance. Chapman & Hall, London, pp. 79–90.

Frank, R.A. and **Klaauw van der, N.J.** (1994) *The contribution of chemosensory factors to individual differences in reported food preferences*. Appetite, 22, 101–123.

Gross-Isseroff, R. and **Lancet, D.** (1988) *Concentration-dependent changes of perceived odor quality.* Chem. Senses, 13, 191–204.

Harper, R., Smith, E.C. and **Land, D.G.** (1968) Odour Description and Odour Classification. American Elsevier, New York.

Henion, K.E. (1971) *Odor pleasantness and intensity: a single dimension*. J. Exp. Psychol., 90, 275–279.

Hudson, R. and **Distel, H.** (1999) *Induced peripheral sensitivity in the developing vertebrate olfactory system*. Ann. NY Acad. Sci., in press.

Hvastja, L. and **Zanuttini, L.** (1989) *Odour memory and odour hedonics in children*. Perception, 18, 391–396.

Hyman, A.M. (1977) *Factors influencing the psychophysical function for odor intensity*. Sens. Processes, 1, 271–291.

Jellinek, J. and **Köster, E.P.** (1983) *Perceived fragrance complexity and its relationship to familiarity and pleasantness II*. J. Soc. Cosmet. Chem., 34, 83–97.

Land, D.G. (1979) *Hedonic response and perceived characteristics of odours in man.* In Kroeze, J.H.A. (ed.), Preference Behavior and Chemoreception. IRL Press, London, pp. 193–204.

Laska, M. and **Hudson, R.** (1991) *A comparison of the detection thresholds of odour mixtures and their components*. Chem. Senses, 16, 651–662.

Moncrieff, R.W. (1966) Odour Preferences. Leonard Hill, London.

Moskowitz, H.R. (1977) *Intensity and hedonic functions for chemosensory stimuli*. In Kare, M.R. and Maller, O. (eds), The Chemical Senses and Nutrition. Academic Press, New York, pp. 71–101.

Moskowitz, H.R. (1979) *Mind body and pleasure: an analysis of factors which influence sensory hedonics.* In Kroeze, J.H.A. (ed.), Preference Behavior and Chemoreception. IRL Press, London, pp. 131–141.

Moskowitz, H.R., Dravnieks, A. and **Gerbers, C.** (1974) *Odor intensity and pleasantness of butanol*. J. Exp. Psychol., 103, 216–223.

Moskowitz, H.R., Dravnieks, A. and **Klarman, L.A.** (1976) *Odor intensity and pleasantness for a diverse set of odorants*. Percept. Psychophys., 19, 122–128.

Mower, G.D., Mair, R.G. and **Engen, T.** (1977) *Influence of internal factors on the perceived intensity and pleasantness of gustatory and olfactory stimuli*. In Kare, M.R. and Maller, O. (eds), The Chemical Senses and Nutrition. Academic Press, New York, pp. 103–121.

Nevitt, G.A., Dittman, A.H., Quinn, T.P. and **Moody, W.J., Jr** (1994) *Evidence for a peripheral olfactory memory in imprinted salmon.* Proc. Natl Acad. Sci. USA, 91, 4288–4292.

Patte, F., Etcheto, M. and **Laffort, P.** (1975) *Selected and standardized values of suprathreshold odor intensities for 110 substances*. Chem. Senses Flavor, 1, 283–305.

Rabin, M.D. and **Cain, W.S.** (1984) *Odor recognition: familiarity, identifiability, and encoding consistency*. J. Exp. Psychol.: Learn. Mem. Cognit., 10, 316–325.

Rabin, M.D. and **Cain, W.S.** (1986) *Determinants of measured olfactory sensitivity.* Percept. Psychophys., 39, 281–286.

Raudenbusch, B., Flaspohler, P. and **Frank, R.A.** (1994) *Odor pleasantness ratings predict food preference patterns*. Chem. Senses, 19, 541.

Rozin, P. (1976) *The selection of foods by rats, humans, and other animals*. In Rosenblatt, J.S., Hinde, R.A., Shaw, E. and Beer, C. (eds), Advances in the Study of Behavior VI. Academic Press, New York, pp. 21–76.

Schaal, B. (1988) *Olfaction in infants and children: developmental and functional perspectives*. Chem. Senses, 13, 145–190.

Schicker, I. (1995) Mentale Repräsentation von Alltagsgerüchen. Doctoral Dissertation, München.

Schiffman, S.S. (1974) *Physicochemical correlates of olfactory quality*. Science, 185, 112–117.

Semke, E., Distel, H. and **Hudson, R.** (1995) *Specific enhancement of olfactory receptor sensitivity associated with fetal learning of food odors in the rabbit*. Naturwissenschaften, 82, 148–149.

Wang, H.-W., Wysocki, C.J. and **Gold, G.H.** (1993) *Induction of olfactory receptor sensitivity in mice*. Science, 260, 998–1000.

Wysocki, C.J., Dorries, K.M. and **Beauchamp, G.K.** (1989) *Ability to perceive androstenone can be acquired by ostensibly anosmic people.* Proc. Natl Acad. Sci. USA, 86, 7976–7978.

Yoshida, M. (1964) *Studies of psychometric classification of odors*. Jap. Psychol. Res., 6, 145–154.

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