Trigeminal Perception of Odorant Quality in Congenitally Anosmic Subjects

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Abstract

Twenty congenitally anosmic subjects and 50 normosmic controls were tested for their ability (i) to assign verbal labels from a list of trigeminal-type descriptors to six odorants believed to have a strong trigeminal component; and (ii) to discriminate between intensity-matched pairs of these odorants in an odd-ball paradigm. The following was found: normosmic controls judged menthol and cineole as distinctly cool and fresh, acetic acid as pungent and sour, and acetone as pungent, but showed no clear descriptive profile for ethanol and propanol. The descriptive profiles given by the anosmic subjects correlated significantly with those given by the controls for three of the six odorants (menthol, cineol and ethanol), confirming that the sensations described may indeed be mediated by the trigeminal system. In the odd-ball test, the control subjects correctly identified an average of eight out of the nine items presented, with most mistakes occurring in response to pairs with a similar trigeminal profile. With an average of 7.2 of nine items correct, the performance of the anosmic subjects was not significantly different to that of the normosmics, except in discriminating between acetic acid and menthol. Although additional tests are necessary to decide finally whether differences in stimulus intensity may have contributed to this good discriminatory performance, the present results suggest that the nasal trigeminal system may contribute significantly to the perception of odor quality. **Chem. Senses 22: 447–456, 1997.**

Introduction

It is well established that both the olfactory and trigeminal systems contribute to the perception of the majority of odorants (Doty *et al.*, 1978; Silver, 1987; Doty, 1995). However, while it is generally agreed that the trigeminal system influences the perception of odor intensity in a near-additive manner (Cain, 1974, 1976; Cometto-Muniz and Hernandez, 1990), its contribution to odor quality remains controversial. Whereas animal studies of trigeminal chemoperception using electrophysiological or behavioral methods have generally failed to find evidence for the qualitative discrimination of chemical stimuli via the fifth cranial nerve (Walker *et al.*, 1979, 1990; Silver *et al.*, 1988), results of several psychophysical studies suggest that human subjects may not only be able to separate trigeminal and non-trigeminal nasal stimulants (Hornung *et al.*, 1993) but may have at least a coarse ability to differentiate between odorants using the trigeminal system (Allen, 1929; Elsberg *et al.*, 1935; Moncrieff, 1951; Mozell *et al*, 1990).

Furthermore, in one of the classical works on chemoperception, von Skramlik (1926) claimed that particular odorants possess distinct trigeminal qualities such as 'cool, fresh', 'pungent, painful' or 'warm, burning', and thought that the nasal trigeminal system contributed to the 'sweet' and 'sour' sensations elicited by some odorants (cited in Doty, 1995). In an extensive series of empirical studies, von Skramlik used standardized methods such as odor profiling or the non-verbal paired-comparison paradigm in pioneering investigations into human psychophysics (von Skramlik, 1923), characteristics of chemical stimuli (von Skramlik, 1924a) and all major aspects of apparative stimulus control (von Skramlik, 1937). In addition, he was the first to systematically apply the simple and still widely used method of identifying stimuli with trigeminal properties by testing subjects' ability to localize the side of odor presentation during monorhinal presentation (von Skramlik, 1924b).

Given the continuing uncertainty in the field of nasal trigeminal chemoreception, we decided to re-examine von Skramlik's findings by attempting to answer the following two questions: (i) can distinct 'trigeminal' qualities truly be attributed to particular odorants, and, if so, (ii) could they play a part in the judgement of odor quality? To address these questions, congenitally anosmic subjects completely lacking olfactory function but with apparently intact trigeminal perception were tested for their ability to assign descriptors to odorants believed to have a strong trigeminal component, as well as to discriminate between pairs of such odorants, and their performance in both tests compared with that of normosmic controls.

Materials and methods

Subjects

A total of 20 patients with Kallmann syndrome (mean age 28.1 ± 7.4 years), and 50 male subjects matched for age (mean 27.7 ± 4.9 years) and with no history of olfactory dysfunction, participated in the study. All patients were unequivocally diagnosed as having Kallmann syndrome (hypogonadotropic hypogonadism with congenital anosmia) following endocrinological, genetic and neurological examination. This included magnetic resonance imaging which in all cases confirmed agenesis of the olfactory bulbs (Vogl *et al.*, 1994). Additionally, all patients had previously served in a comprehensive test of chemosensory function confirming their anosmia and presence of trigeminal function (Hudson *et al.*, 1994).

Table 1 Substances and concentrations used for the stock solutions

Substance	Concentration	Odor quality	Trigeminal quality[c]
1 (–)-Menthol[a]	saturated aqueous solution	peppermint	cool, fresh
2 1,8-Cineole[b]	undiluted	eucalyptus	cool, fresh
3 Acetic acid[a]	1 30 aqueous solution	vinegar	pungent, painful
4. Acetone[b]	undiluted	nail polish remover	pungent, painful
5. Ethanol[a]	undiluted	alcohol	warm, burning
6. *n*-Propanol[a]	undiluted	disinfectant	warm, burning

Obtained from [a]Merck, [b]Sigma
[c]According to von Skramlik (1926)

Odorants

A set of six odorants believed to have a strong trigeminal component (Doty *et al.*, 1978; Silver, 1987; Doty, 1995) and presumed to represent three distinct trigeminal qualities (von Skramlik, 1926; cited in Doty, 1995) was used (Table 1). In an attempt to ensure that odorants were of approximately equal strength, intensity matching was performed by a panel of six normosmics using a saturated aqueous solution of (–)-menthol as standard. Thus, all odorants were well above threshold for normosmic controls and likely to be perceptible for anosmic subjects.

Stimulus delivery

An aliquot of 40 ml of each odorant were presented in 250 ml polyethylene squeeze bottles equipped with a flip-up spout, which for testing was fitted with a hand-made Teflon nose-piece.

Subjects were instructed as to the manner of sampling and at the start of the session were allowed time to familiarize themselves with the bottles and the sampling technique. Care was taken that the nose-piece was only a short distance (1–2 cm) from the nasal septum during sampling of an odorant in order to allow the stimulus to enter both nostrils. To prevent ocular trigeminal irritation from providing additional sensory information, subjects were asked to sample the odorants with their eyes closed.

Each bottle could be sampled twice with an inter-stimulus interval of at least 10 s. Sampling duration was restricted to 1 s per presentation in order to minimize adaptation effects and adsorption of odorants on the facial skin of the subjects.

This method of stimulus self-delivery is well established and widely used in psychophysical studies of olfaction and has been shown to be adequate for obtaining precise and reliable estimates of olfactory sensitivity (Laska and Hudson, 1991) and discrimination ability (Laska and Hudson, 1992).

Table 2 List of trigeminal-type verbal descriptors (German translation)

1. Pungent (*stechend*)	7 Warm (*warm*)	13 Fresh (*frisch*)
2 Burning (*brennend*)	8 Scratching (*kratzend*)	14. Sweet (*süßlich*)
3. Painful (*schmerzhaft*)	9 Tickling (*kitzelnd*)	15. Salty (*salzig*)
4. Sharp (*scharf*)	10. Prickling (*prickelnd*)	16 Bitter (*bitter*)
5 Astringent (*zusammenziehend*)	11. 'Sneeze' (*Niesreiz-erregend*)	17 Sour (*sauer*)
6. Furry (*pelzig*)	12 Cool (*kühl*)	

Test procedure

Subjects were tested for their ability (i) to assign verbal descriptors to odorants, and (ii) to discriminate between odorants as follows.

Descriptive profiles

Subjects were successively presented with six odorants (Table 1) and asked to choose the three adjectives best describing each odorant from a list of 17 trigeminal-type descriptors (Table 2), and to rank their three choices according to suitability. The order of stimulus presentation was always menthol – acetic acid – ethanol – cineole – acetone – propanol in order to avoid successive presentation of odorants which according to von Skramlik (1926) evoke the same trigeminal quality.

All adjectives listed in Table 2 were used by von Skramlik (1926) for describing sensations which he believed to be mediated by the nasal trigeminal system. In order to minimize the possibility of semantic ambiguity, all subjects were explicitly asked if they had difficulty in interpreting any adjective in the list, and in the very few cases in which subjects were uncertain about the meaning of a particular descriptor, they were given appropriate information.

Discrimination

In nine further tests, always conducted in the order listed below, subjects were asked to compare three bottles and to identify the one containing the *odd stimulus*:

1. (–)-Menthol versus *ethanol*
2. Propanol versus *acetone*
3. Acetic acid versus *(–)-menthol*
4. Ethanol versus *propanol*
5. Acetone versus *1,8-cineole*
6. Ethanol versus *acetic acid*
7. (–)-Menthol versus *1,8-cineole*
8. Acetic acid versus *acetone*
9. 1,8-Cineole versus *propanol*

Care was taken (i) to present subjects both with odor pairs assumed to have similar trigeminal qualities (items 4, 7 and 8) and pairs assumed to have different trigeminal qualities (items 1–3, 5, 6 and 9); and (ii) to avoid presenting the same odorant in successive odor pairs.

After each decision subjects were asked whether they had based their choice mainly on differences in stimulus quality or intensity.

Data analysis

Descriptive profiles were analysed in three ways: (i) the frequency of all namings per odorant was calculated for each group and expressed as a percentage (relative to the number of subjects per group); (ii) the three namings per odorant and subject were weighted by assigning three points to the first-mentioned adjective, two points to the second, and one point to the last-mentioned descriptor, and these points then summed for each group; and (iii) only the descriptors which were first-mentioned (i.e. presumably best describing the odorant) by each subject in response to each odorant were considered.

Preliminary analyses revealed that all three methods of obtaining descriptive profiles led to similar results which significantly correlated with each other. However, while subjects usually had only few difficulties in assigning one of the descriptors to each odorant, many participants, and anosmics in particular, had considerable difficulty choosing more than one adjective from Table 1 as appropriate. Therefore, the results obtained from method 3, the first descriptor mentioned, were used for statistical comparisons.

Comparisons between descriptive profiles derived from

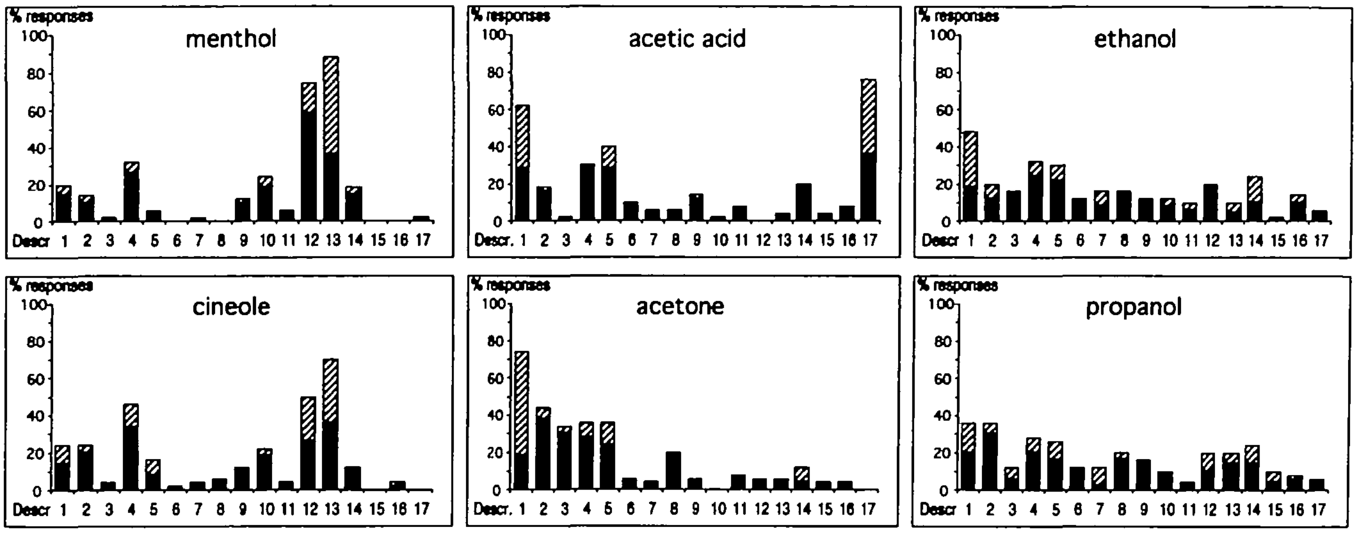

Figure 1 Descriptive profiles derived from the six-item test of odor labeling in which control subjects ($n = 50$) were asked to choose the three adjectives best describing each odorant from a list of 17 trigeminal-type descriptors Shown are the percentages of subjects assigning particular adjectives as the first choice (shaded) and second or third choice (black) Descriptor numbers correspond to those in Table 2

the labeling of odorants were performed using the Spearman rank correlation coefficient. Frequencies in discrete categories were compared using the χ^2 test, and deviations from a chance distribution of correct decisions were calculated using the binomial test corrected for continuity (Siegel and Castellan, 1988). All tests were two-tailed and, if not otherwise stated, the alpha level was set at 0.05.

Table 3 Correlations[a] between the descriptive profiles given by the control subjects

r_s	Cineole	Acetic acid	Acetone	Ethanol	Propanol
Menthol	0 76**	–0 06 ns	0 09 ns	0 50*	0 31 ns
Cineole		0.19 ns	0 28 ns	0 40 ns	0 38 ns
Acetic acid			0 53*	0 03 ns	–0 16 ns
Acetone				0.30 ns	0 30 ns
Ethanol					0 64*

[a]Spearman rank correlation coefficients r_s

$*P < 0.05$, $**P < 0\ 01$, ns not significant

Results

Descriptive profiles

Figure 1 shows the descriptive profiles derived from the adjectives assigned to each odorant by the control group. Normosmics judged menthol and cineole as distinctly cool and fresh, with >50% of subjects assigning these descriptors to both odorants. Using the same criterion, acetic acid was labeled as pungent and sour, and acetone as pungent. In contrast, judgements for ethanol and propanol were widely scattered with no clear preference shown for any descriptor.

Table 3 summarizes the Spearman rank correlation coefficients as a measure of similarity between the descriptive profiles given by the control group. Not surprisingly, the profiles for menthol and cineole, which both had been clearly judged as cool and fresh, correlated significantly (Spearman, $P < 0.01$). Further, the qualitative judgements for acetic acid and acetone, which had both been described as pungent, for ethanol and propanol, which both lacked clear-cut descriptive profiles, as well as for menthol and ethanol, correlated significantly (Spearman, $P < 0.05$).

Figure 2 shows the descriptive profiles derived from the labels assigned to each odorant by the group of anosmic subjects. In accordance with the control group, >50% of anosmic subjects judged both menthol and cineole as distinctly cool and fresh. Acetic acid was clearly labeled as pungent, whereas only one out of 20 anosmics assigned the label 'sour' to this odorant (as his third choice). Acetone was judged as pungent, sharp and painful and ethanol and propanol were both judged as 'sweet'.

Table 4 summarizes the Spearman rank correlation coefficients as a measure of similarity between the descriptive profiles given by the anosmic group. Again, in accordance with the control group, the profiles for menthol

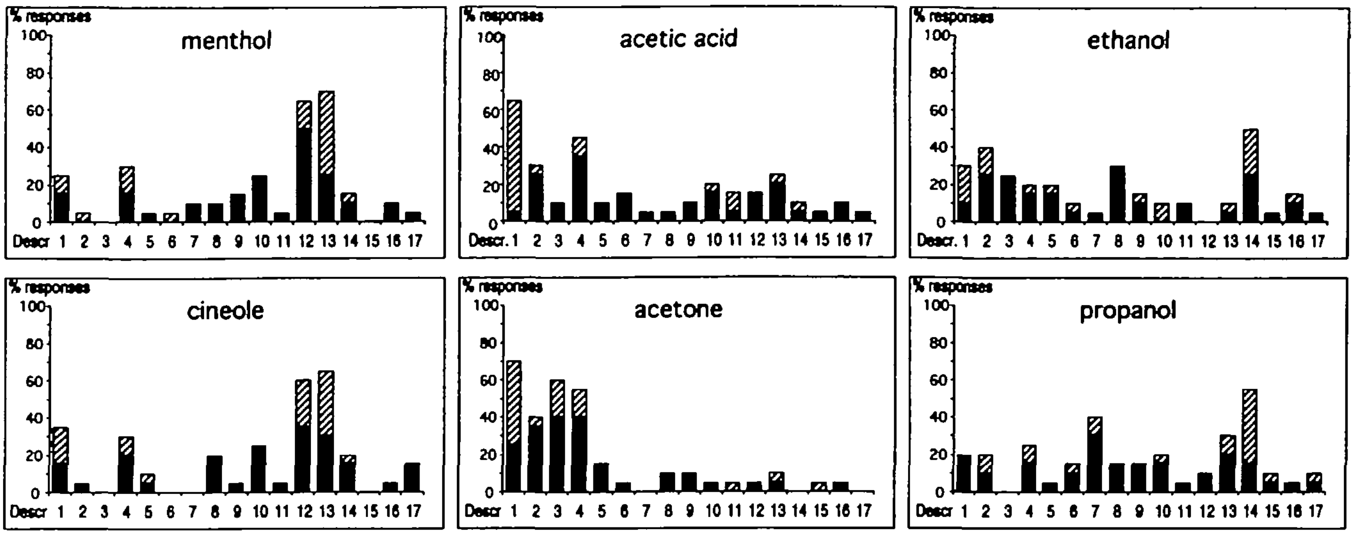

Figure 2 Descriptive profiles derived from the six-item test of odor labeling in which anosmic subjects (n = 20) were asked to choose the three adjectives best describing each odorant from a list of 17 trigeminal-type descriptors (Table 2) Shown are the percentages of subjects assigning particular adjectives as the first choice (shaded) and second or third choice (black) Descriptor numbers correspond to those in Table 2

and cineole, which both had been judged as cool and fresh, correlated significantly (Spearman, P < 0.01), and the judgements for acetic acid and acetone, which both had been labeled as pungent, correlated at the 5% level of significance. Further, a weaker but statistically still significant correlation was found between the profiles assigned to menthol and acetic acid.

A comparison of the descriptive profiles given by the anosmic and the control groups revealed that for three of the six odorants (menthol: $r_s = 0.73$; cineole: $r_s = 0.75$; ethanol: $r_s = 0.65$) the judgements of the two groups for a given odorant correlated significantly (Spearman, $P < 0.01$), and for a fourth odorant (acetone: $r_s = 0.46$) correlated considerably but just failed to reach the 5% level of significance (Spearman, $P = 0.07$). Thus, normosmic and anosmic subjects showed a considerable degree of conformity in the descriptors assigned to these odorants.

Discrimination

Figure 3 summarizes the performance of the anosmic and control groups when asked to compare three sniff bottles and identify the odd stimulus. With the exception of one item (acetic acid versus menthol), there was no significant difference in performance between the two groups (χ^2, $P >$ 0.05 for all other items). However, whereas the control group performed significantly above chance level in all nine discriminations (binomial test, $P < 0.01$ for all items), the anosmic group failed to solve two of the tasks (acetic acid versus menthol and ethanol versus propanol, binomial test, $P > 0.05$ for both items).

Table 4 Correlations[a] between the descriptive profiles given by the anosmic subjects

r_s	Cineole	Acetic acid	Acetone	Ethanol	Propanol
Menthol	0.80**	0.50*	0 34 ns	0.42 ns	0.39 ns
Cineole		0.41 ns	0 25 ns	0.31 ns	0 13 ns
Acetic acid			0.58*	0.45 ns	0.30 ns
Acetone				0.07 ns	0.03 ns
Ethanol					0.33ns

[a]Spearman rank correlation coefficients r_s

*P < 0 05, ** P < 0 01, ns not significant

Again, with the exception of the discrimination between acetic acid and menthol, the overall pattern of performance was quite similar between the groups, with both anosmic and control subjects clearly having more difficulty discriminating between ethanol and propanol compared with most of the other odor pairs.

The two odor pairs resulting in the lowest number of correct responses in the control group (ethanol versus propanol, and menthol versus cineole) showed the highest degree of correlation in the descriptive profiles of their constituent odorants, whereas the odor pair resulting in the highest number of correct responses in this group (acetic acid versus menthol) showed the lowest correlation in the respective descriptive profiles (cf. Table 3). Similarly, the

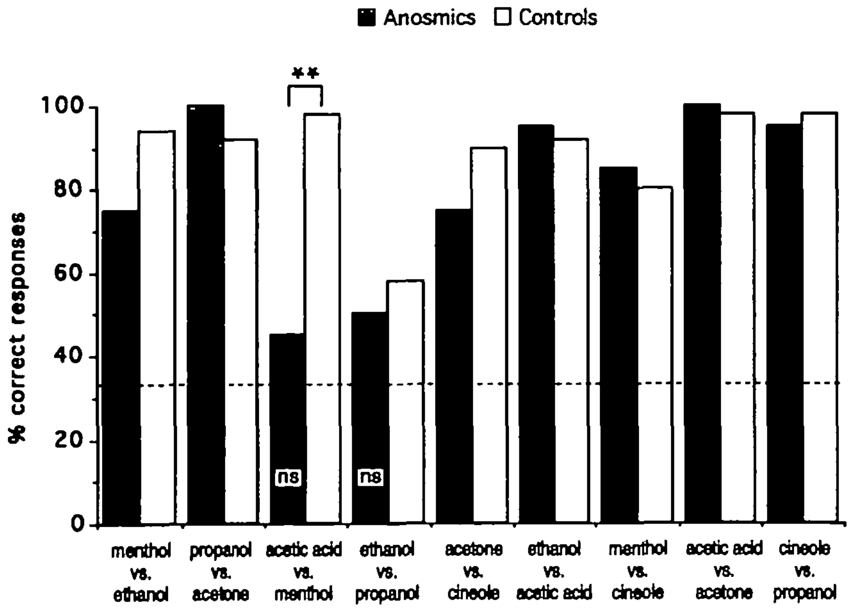

Figure 3 Performance of anosmic and control groups in the nine-item discrimination test in which subjects were required to compare three sniff bottles and identify the odd stimulus. Given are percentages of correct responses per group The dotted line represents the chance level of performance (**$P < 0.01$, χ^2)

odor pair resulting in the highest number of correct responses in the anosmic group (propanol versus acetone) showed the lowest correlation in the profiles, and the odor pair generating the lowest number of correct responses (acetic acid versus menthol) showed a significant correlation in the respective profiles. However, in both groups there were also odor pairs which were easily discriminable despite significant correlations in their descriptive profiles.

At the individual level, control subjects averaged eight out of nine correct responses, with individual performances ranging from six to nine out of nine correct discriminations. Anosmic subjects scored only slightly worse and averaged 7.2 out of nine correct decisions, with no individual making more than three mistakes. Thus, all individuals from both groups performed significantly above chance level (binomial test, $P < 0.05$).

Table 5 shows the percentage of judgements reported to be based mainly on differences in stimulus intensity rather than stimulus quality in the nine discriminations. With the exception of two items (menthol versus cineole, and ethanol versus propanol), <10% of all decisions made by the control group were reportedly based on differences in intensity. These two items were the ones with the highest correlations in their descriptive profiles and the lowest scores of correct responses for this group (cf. Table 3 and Figure 3). In the anosmic group the percentage of judgements reported to be based on differences in intensity rather than quality tended to be higher but showed a similar overall pattern compared with the controls, with the same two odor pairs yielding the highest scores.

Table 5 Percentage of judgements reported to be based mainly on differences in perceived stimulus intensity rather than stimulus quality in the nine-item discrimination task

Odor pair			Anosmics	Controls
(–)-Menthol	versus	ethanol	35	8
n-Propanol	versus	acetone	10	8
Acetic acid	versus	(–)-menthol	20	2
Ethanol	versus	*n*-propanol	40	40
Acetone	versus	1,8-cineole	15	2
Ethanol	versus	acetic acid	20	0
(–)-Menthol	versus	1,8-cineole	50	40
Acetic acid	versus	acetone	10	6
1,8-Cineole	versus	*n*-propanol	10	0

Discussion

Two main findings emerge from the present study:

1. The descriptive profiles given both by anosmic subjects and normosmic controls in response to substances

believed to have a strong trigeminal component differed markedly between several of the odorants tested and at the same time showed a considerable degree of conformity between the two groups. This suggests that the nasal trigeminal system may indeed contribute to the perception of odor quality.

2. Anosmic subjects could discriminate between the majority of odorants tested, and their overall performance was only slightly poorer than that of normosmic controls. Thus, the nasal trigeminal system may also contribute to odor discrimination.

The results from the first part of the study essentially confirm von Skramlik's (1926; cited in Doty, 1995) claim that particular odorants possess distinct 'trigeminal' qualities. The fact that both anosmic and normosmic subjects clearly judged menthol and cineole as cool and fresh, and acetic acid and acetone as pungent is in accordance with his findings (cf. Table 1) and strongly suggests that these sensations are indeed likely to be mediated by the fifth cranial nerve. However, several findings of the present study contrast with those of von Skramlik; for example, his report that ethanol and propanol evoke warm and burning sensations could be only partially replicated (cf. Figures 1 and 2). Instead, and to our surprise, we found that >50% of anosmics and even 25% of normosmics described these substances as sweet. Although von Skramlik (1926) explicitly included taste-related adjectives in the list of sensations which he supposed to be mediated by the nasal trigeminal system, he assigned the descriptor sweet to substances like bromoform, chloroform and iodoform, but not to ethanol and propanol.

However, our finding that normosmic controls consistently described acetic acid as sour and anosmics almost completely failed to do so calls into question the extent to which such taste-related sensations are really evoked by chemical stimulation of trigeminal fibers. A more likely explanation for the frequently reported phenomenon of odorants being consistently described as possessing a taste-related quality (Rozin, 1982; Dravnieks, 1985) is that associative mechanisms may underlie the development of odor sweetness or sourness. This hypothesis is supported by findings from Stevenson and Prescott (1995) and Prescott *et al.* (1996), who report that adding an appropriate odor to a sucrose solution enhances its perceived sweetness, and conversely, selected odors can be made to smell sweeter or more sour when paired with sucrose or citric acid. They plausibly argue that the acquisition of taste properties by odors may result from the co-occurrence of certain odors and tastes outside the laboratory. Given the complete lack of olfactory input in congenitally anosmic subjects, they would not be able to form such taste–odor associations.

It nevertheless remains an open question why anosmics, while obviously unable to associate acetic acid with sourness, described ethanol and propanol as sweet. One possible explanation for this finding is that the concentrations of ethanol and propanol used in the present study may have been sufficiently high to reach the oral cavity retronasally and elicit neural responses in sugar-best taste receptors, which recently have been shown to be the only type of taste cells to respond to alcohols (Danilova *et al.*, 1996), whereas the concentration of acetic acid used here may have been too low to excite sour-responsive taste cells. An alternative explanation for this finding is that Kallmann patients may present with some form of dysgeusia, although the few studies which have included tests of gustatory perception in this group of patients (Henkin, 1967; Lieblich *et al.*, 1982) provide no evidence of elevated taste thresholds.

The inconsistencies in the use of taste-related adjectives raise the question as to the general reliability of the findings with regard to the descriptive profiles. Although a certain degree of inexactness is inherent in methods relying on verbal descriptors, particularly as subjects may differ slightly in their interpretation of them, Dravnieks (1982) has shown that semantically generated odor profiles are stable and robust constructs. This is supported by our finding of clear descriptive profiles for the majority of odorants tested which, moreover, were generally in accordance with earlier reports by other authors (von Skramlik, 1926; Dravnieks, 1985). Further, the failure of anosmic subjects to use the descriptor sour for acetic acid and of both groups to assign particular descriptors to certain odorants clearly demonstrates that subjects did not choose descriptors at random. This is remarkable given that the anosmic subjects of our study, in contrast to most previous studies using human subjects with an impaired sense of smell, all congenitally lacked olfactory function and thus were unable to rely on previous olfactory experience or associations in generating appropriate labels. Thus, the considerable degree of consistency in the descriptive profiles given by normosmic and anosmic subjects strongly suggests that the nasal trigeminal system may indeed contribute to the perception of odor quality.

In the second part of the study, anosmic subjects were able to discriminate between odorants believed to have a strong trigeminal component almost as well as normosmic controls. This unexpected finding is in accordance with earlier reports by Allen (1929) and Elsberg *et al.* (1935), who found that anosmics were not only able to distinguish between stimulus pairs such as benzaldehyde versus xylol, ether versus ammonia, and oil of cade versus oil of turpentine, but that after some training, they were even able to reliably identify these odorants. Elsberg *et al.* concluded that 'at least some odors which have both an olfactory and a trigeminal effect are identified not only by their odor but by the characteristic trigeminal sensation'.

This raises the question to what extent the good performance of the anosmics was actually based on their ability to perceive and make use of different trigeminal qualities. The existence of at least two distinct trigeminal qualities, namely, 'cool–fresh' and 'pungent–painful', is supported by our study as well as by findings from other authors. Thus, Green (1986) reported that menthol applied to the vermilion border of the lip specifically inhibits the perception of warming but not of pain, and proposed a desensitization of low-threshold warm receptors as the underlying mechanism. Furthermore, intranasal application of nicotine has been shown to evoke burning or stinging sensations depending on the concentrations used (Hummel *et al.*, 1992), and the two sensations follow different time courses, suggesting that they might be mediated by different types of trigeminal pain fibers.

However, there are several animal studies arguing against quality discrimination by the nasal trigeminal system. Using multiunit recordings from the fifth cranial nerve of tiger salamanders, Silver *et al* (1988) found complete cross-adaptation in response to amyl acetate versus cyclohexanone and butanol versus limonene. Further, they reported that animals with olfactory nerve lesions failed to discriminate these two odor pairs in a behavioral paradigm, and thus concluded that the trigeminal system cannot be used to discriminate between these compounds when they are matched for equal intensity. Similarly, Walker *et al.* (1979, 1990) reported that pigeons were unable to perform a previously learned olfactory discrimination between amyl acetate and butyl acetate after resection of the olfactory nerve.

Although both these studies were carefully conducted and the results are not questioned, two caveats should be applied with regard to a generalization of the findings. Firstly, multiunit recordings from the trigeminal nerve allow only limited conclusions about the response characteristics of single fibers and thus of discriminative abilities based on possible sub-populations of units. And second, it may well be that the stimuli used in the above-mentioned studies were similar in their trigeminal quality and that this explains the failure of subjects to discriminate between them using the trigeminal system. This explanation seems quite likely, at least in the study by Walker *et al.* (1979, 1990), since the two compounds employed belonged to the same chemical class and even represent direct neighbors in a homologous series of substances which, analogous to findings for the olfactory system (Mori and Yoshihara, 1995), may increase their probability of interacting with the same kind of receptor.

An alternative explanation for the good performance of the anosmic subjects in distinguishing between odorants found in the present study is that despite efforts to present stimuli in intensity-matched concentrations, discrimination might have been based on subjects' ability to perceive and make use of subtle differences in stimulus intensity rather than stimulus quality. Although this possibility cannot be completely ruled out, it seems unlikely to be the full explanation, for several reasons. (i) In an earlier study (Hudson *et al.*, 1994) the same anosmic subjects were unable to rank four bottles containing different log-step concentrations of butanol according to intensity, with only two out of 20 subjects correctly ranking the dilution series and the majority of subjects even confusing non-neighboring concentrations. (ii) Part-way through the present study, 10 of the 20 anosmic subjects were additionally asked to rank four bottles containing either a 1:10 dilution of acetic acid or 50-, 250- and 1250-fold dilutions according to intensity. None of the anosmics was able to identify the correct sequence, with the majority of subjects again confusing non-neighboring concentrations and half of them even misidentifying the bottle containing the highest concentration. (iii) An analysis of the results from the nine-item discrimination task failed to indicate any differences in the frequency of correct choices between decisions reported to be mainly based on differences in stimulus intensity and decisions based on stimulus quality (e.g. propanol versus acetone, acetic acid versus menthol, ethanol versus propanol in Table 5 and Figure 3). Although additional tests are necessary to decide finally whether differences in stimulus intensity or involvement of other chemosensitive systems such as the vomeronasal organ or the terminal nerve may have contributed to the good discrimination performance, the present results strongly suggest that the nasal trigeminal system may contribute to the discrimination of odorants based on perceived differences in odorant quality.

Given the above indications that the nasal trigeminal system can code, at least coarsely, for quality, how might this be understood in neural terms? Keverne *et al.* (1986) report unpublished work by Tucker, who recorded from single trigeminal fibers in the rabbit which appeared to respond differentially to different odorants, suggesting that trigeminal chemoreceptors may exhibit some degree of specificity. More recently, Sekizawa and Tsubone (1994) recorded single unit activity from the ethmoidal nerve of the guinea pig in response to nasal stimulation with capsaicin, ammonia and nicotine and found that the majority of fibers responded to only one of each of these substances and none of them to all three stimuli. Using the same methodology and animal model, Sekizawa *et al.* (1996) reported that the activity of single trigeminal fibers in response to stimulation with menthol was indistinguishable from the response to stimulation with cool air, and that these menthol-responsive fibers were unaffected by treatment with capsaicin which is known to desensitize pain-mediating C-fibers. They concluded that different types of trigeminal fibers may mediate different sensations. Taken together, these findings indicate that individual chemosensitive trigeminal fibers may differ in their response characteristics, thus providing a prerequisite for quality coding by the nasal trigeminal system.

The results of the present study lend further support to the proposition that the nasal trigeminal system may be used to discriminate between odorants and thus may contribute significantly to the perception of odor quality.

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