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SHORT COMMUNICATION

Bilateral Detection Thresholds in Dextrals and Sinistrals Reflect the More Sensitive Side of the Nose, Which Is Not Lateralized

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Abstract

Several fundamental questions remain enigmatic concerning human olfactory sensitivity, including (i) whether detection threshold differences exist between the two sides of the nose (and, if so, whether such differences are influenced by handedness) and (ii) whether bilateral (i.e. binasal) stimulation leads to lower thresholds than unilateral stimulation (and, if so, whether the degree of facilitation is inversely related to general olfactory ability). In this study, a reliable and well-validated single staircase procedure was used to establish bilateral and unilateral detection thresholds for the cranial nerve I stimulant phenyl ethyl alcohol in 130 right- and 33 left-handed subjects. No differences in sensitivity between the left and right sides of the nose were observed in either group. Bilateral thresholds were lower, on average, than unilateral thresholds when the latter were categorized in terms of left and right nares. However, the bilateral thresholds did not differ significantly from those of the side of the nose with the lower threshold. Overall smell ability, as measured by the University of Pennsylvania Smell Identification Test, did not interact with any of the test measures. These data imply that (i) the left and right sides of the nose do not systematically differ in detection threshold sensitivity for either dextrals or sinistrals and (ii) if central integration of left:right olfactory threshold sensitivity occurs, its effects do not exceed the function of the better side of the nose.

Among the senses, the sense of smell is unique in that its second-order neurons (whose cell bodies lie within the olfactory bulb) send information directly, and largely ipsilaterally, to the cerebral cortex before reaching the thalamus (Gordon and Sperry, 1969; Youngentob *et al.*, 1982). This pattern of projection has fueled speculation concerning whether each side of the nose primarily subserves functions of the ipsilateral hemisphere, reflecting such underlying functional asymmetries as handedness and emotion (for review see Doty *et al.*, 1997). However, one cannot overlook the fact that contralateral afferent and efferent connections exist between the two sides of the olfactory system via the anterior commissure (AC), the corpus callosum and conceivably the poorly understood hippocampal commissure (Gordon and Sperry, 1969).

The present study focuses on two basic questions: first, whether detection threshold differences exist between the two sides of the nose (and, if so, whether such differences are influenced by handedness); and second, whether bilateral stimulation leads to lower thresholds than unilateral stimulation (and, if so, whether the degree of facilitation is inversely related to general olfactory ability). Little agreement among studies is found with regard to the first question. Toulouse and Vaschide (1900) reported asymmetries between the left and right sides of the nose to the odor of camphor, noting lower thresholds on the left than on the right side in 56/64 dextrals and the reverse in five sinistrals. In contrast, Youngentob *et al.* (1982) reported a weak tendency for 10 dextrals to have lower *n*-butanol thresholds on the right side of the nose and a strong tendency for nine sinistrals to have lower thresholds on the left side of the nose. More recently, Cain and Gent (1991) found, in a study employing the same stimulus in 22 right-handed and five left-handed subjects, that 'both right-handed and left-handed groups favored the right nostril'. Subsequently, Frye *et al.* (1992) found a slight tendency for lower thresholds to methyl ethyl ketone on the right side of the nose in 37 dextrals but the reverse in 38 sinistrals. However, Tempelaar (1913), Koelega (1979), Eskenazi *et al.* (1988) and Zatorre and Jones-Gotman (1990) have all reported no lateralized differences in detection sensitivity to such stimuli as *n*-amyl acetate and phenyl ethyl alcohol (PEA).

Interest in the second question—whether the olfactory system integrates information across the two sides of the nose at low stimulus concentrations—stems from reports that bilateral facilitation occurs at the suprathreshold level for tests of odor intensity estimation, identification and memory (von Skramlik, 1926; Cain, 1977; Hornung *et al.*, 1990; Bromley and Doty, 1995). von Skramlik (1926) succinctly described bilateral facilitation as follows (translated from the German): '. . . the olfactory sensation is markedly increased when an odorant-filled bottle is applied to both nostrils compared with a condition where a bottle filled with odorant is applied to one nostril and a bottle filled with water is applied to the other nostril'. Whether such facilitation occurs at perithreshold stimulus levels, where one might expect a particular need for such summation, is not known.

The present study employed a comparatively large number of subjects whose olfactory ability ranged from poor to excellent to achieve five major objectives: (i) to determine whether detection threshold performance for the relatively pure CN I stimulant, PEA, differs between the left and right sides of the nose; (ii) to determine whether left-handers differ from right-handers in regards to such left:right sensitivity, if present; (iii) to establish whether PEA detection threshold performance is facilitated by bilateral, as compared with unilateral, testing (and, if so, whether the facilitation exceeds the functioning of the more sensitive side of the nose); (iv) to ascertain whether a sex difference is present in PEA threshold values; and (v) to determine whether bilateral facilitation, if present, is associated with the degree of overall olfactory ability. The latter question arose from the notion that central facilitation might be of more value to individuals whose overall olfactory function is compromised.

Materials and methods

Subjects

Seventy-six men [16 left-handers and 60 right-handers; respective mean ages (SD) = 35.63 (19.20) and 51.53 (19.37) years] and 74 women [17 left-handers and 70 right-handers; respective mean ages (SD) = 30.53 (13.47) and 60.57 (19.88) years] served as subjects. Most received $20.00 for participation. These individuals were chosen because they exhibited a wide range of olfactory abilities, as determined from scores on the University of Pennsylvania Smell Identification Test (UPSIT; Doty, 1995b): 20–25 (n = 25), 26–29 (n = 17), 30–33 (n = 38) and ≥34 (n = 83) (see Doty, 1995). The olfactory ability of the left-handers was superior to that of the right-handers [respective mean UPSIT (SEM) values = 36.06 (0.93) and 32.09, (0.47); $F(1,161) = 14.55$, $P < 0.001$], reflecting the fact that they were nearly 25 years younger in age.

To exclude anosmics from the study group, only subjects scoring 20 or above on the UPSIT were recruited for participation. Furthermore, only persons with high scores on the 40-item Picture Identification Test (PIT) [mean score (SD) = 39.56 (0.98) (Vollmecke and Doty, 1985)] and the 30-item Mini-Mental State Examination (MMSE) [mean score (SD) = 29.13 (1.68) (Folstein *et al.*, 1975)] were allowed to participate to ensure that only cognitively competent persons were tested. Handedness was determined, in most cases, using the Briggs and Nebes (1975) handedness inventory. Persons with positive scores were deemed right-handed and negative scores left-handed. Twenty-one of the subjects were residents of the Medford Leas Retirement Community, Medford, NJ, and eight were residents of the Ashton Terrace Retirement Home, Philadelphia, PA. The remainder were otherwise healthy volunteers from the general community or non-anosmic patients from the Center's clinic whose olfactory dysfunction was not due to tumors or disturbances in peripheral airflow access to the receptors.

Threshold testing procedure

A two-alternative forced-choice staircase detection threshold procedure was used to establish PEA detection thresholds for each of the three test conditions (i.e. bilateral, left, right), which were presented in a counterbalanced order across subjects. PEA is a rose-like odorant with minimal intranasal trigeminal stimulative properties (Doty *et al.*, 1978). The details of this test are presented elsewhere (Doty *et al.*, 1986). Unilateral testing was done by occluding the opposite naris with a piece of Microform™ tape (3M Corporation, Minneapolis, MN) to minimize or eliminate retronasal stimulation of the contralateral side (Doty *et al.*, 1992).

Results

The data related to laterality were initially submitted to a side of testing (bilateral, left, right; B, L, R) by a gender (male, female) × handedness (L, R) analysis of variance (ANOVA). Because the left-handed subjects were much younger than the right-handed subjects and, unlike the right-handed subjects, did not represent a wide range of ages, age could not be used in the analysis either as a covariate or as a categorical variable. The bilateral thresholds were nearly half a log unit lower than the left- and right-side threshold values, which did not differ from one another (Figure 1); [$F(2,318) = 9.20$, $P < 0.0001$]. Neither the gender main effect nor any of the interactions among the variables were statistically significant (all Ps > 0.30). As expected from their ages (see Doty, 1984), the young left-handers had much lower thresholds than the older right-handers [$F(1,159) = 16.19$, $P < 0.0001$; dextrals, respective mean (SEM) B, L and R threshold values: –5.37 (0.12), –4.94 (0.13) and –4.91 (0.14); sinistrals, –6.57 (0.31),

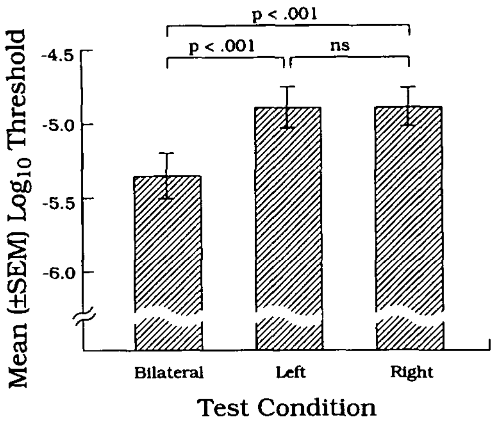

Figure 1 PEA odor detection threshold values (log vol/vol in USP grade light mineral oil) under bilateral and unilateral (left and right) test conditions. See text for details.

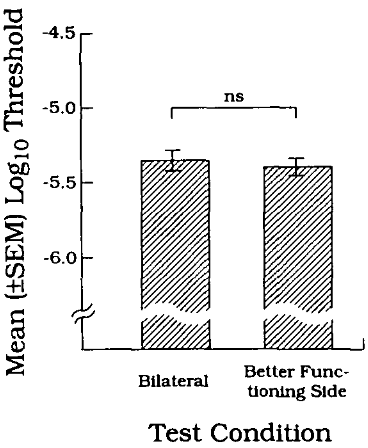

Figure 2 PEA odor detection threshold values (log vol/vol in USP grade light mineral oil) under bilateral and better functioning side test conditions. See text for details.

–5.90 (0.26) and –6.06 (0.28)]. Handedness *per se* is not likely to have been the basis of this difference, since the handedness main effect in an ANOVA performed on data from the subgroup of left- and right-handed subjects who could be matched for age (27 dextrals and 27 sinistrals) was not statistically significant [$F(1,50) = 0.36$, $P = 0.55$].

The number of the left- and right-handed subjects who exhibited greater left- or right-side thresholds was subjected to χ^2 analysis. There was no meaningful tendency for the left- and right-handers to differ proportionately in exhibiting left- or right-sided laterality [χ^2 (1) = 1.40, P = 0.237], corroborating the finding that left- and right-handers do not differ from one another in terms of their more sensitive side of the nose.

To determine whether the bilateral threshold was lower than the threshold of the better functioning side of the nose and, if so, whether such facilitation was greater in persons with lesser overall smell ability, we subjected the threshold data to an ANOVA with the factors of test condition (bilateral, better functioning side), gender (male, female) and smell ability [normosmia, mild hyposmia, moderate hyposmia and severe hyposmia, as determined from UPSIT scores and norms (Doty, 1995b)]. Although the smell ability main factor was statistically significant [$F(3,155) = 11.97$, $P < 0.0001$], none of the other factors or their interactions were significant (all Ps > 0.35), and the mean bilateral and best side threshold values were nearly identical (Figure 2). Thus, there was no evidence of bilateral facilitation at the threshold level in this study.

Discussion

The present data suggest that PEA detection thresholds do not differ significantly between the left and right sides of the nose, regardless of whether the subjects are left- or right-handed. The general finding of no left:right differences is in accord with the only other study to address this issue using PEA (Zatorre and Jones-Gotman, 1990), as well as the studies of Koelega (1979) and Zatorre and Jones-Gotman (1991) using *n*-amyl acetate, Eskenazi *et al.* (1988) using butanol, and Tempelaar (1913) using several different stimuli. Our finding is in contrast to the observation of Youngentob *et al.* (1982) of a 'weak tendency' towards greater sensitivity for *n*-butanol on the right in dextrals and a strong tendency towards greater sensitivity on the left for sinistrals, as well as the findings of Cain and Gent (1991) and Frye *et al.* (1992). Cain and Gent reported that a composite threshold measure of several substances was 25% lower on the right than on the left, whereas Frye *et al.* reported, for *n*-butanone, a slightly lower threshold on the left than on the right. The reason for such discrepancies is not clear. It is noteworthy, however, that studies other than the present one and the one by Zatorre and Jones-Gotman (1990) used stimuli with comparatively greater propensity to stimulate intransal trigeminal nerve afferents than PEA (see Doty, 1995a). It is well established that only 'trigeminal stimuli' can be localized to the left or right sides of the nose (von Skramlik, 1926; Kobal *et al.*, 1989), and it is conceivable that trigeminal stimulation may be more likely to elicit left:right differences. However, the likelihood of this happening is mitigated by the fact that the trigeminal impact of odorants is minimal at perithreshold concentrations.

Although the present experiment demonstrates that bilaterally obtained threshold values are lower than unilaterally obtained ones when the unilateral data are averaged or categorized in terms of left and right, this is not the case when the bilateral thresholds are compared with those of the better functioning side of the nose. This observation suggests that bilateral facilitation, in terms of central neural summative integration, may not be occurring. Indeed, a more parsimonious explanation of this phenomenon is that the brain identifies the input of the better side and either neglects the input from the contralateral side or gives it less weight when integrating the information from the two sides of the nose. The former argument was posed by Hornung *et al.* (1990) to explain a similar phenomenon for an odor identification task. It is of interest that, as early as 1848, Valentin reported that when one odorant was introduced to one side of the nose and another to the other, the odor producing the stronger sensation prevailed over the weaker one. This led Valentin to conclude that a dominance phenomenon analogous to interocular visual dominance is present for the sense of smell. Other early investigators also observed this effect, particularly for odorants that differed considerably in intensity (e.g. Aronsohn, 1886; Zwaademaker, 1925). Interestingly, there are data that suggest the bilateral detection performance of non-human forms may be equivalent to that of the better functioning side of the nose: Slotnick and Pazos (1990) found that detection thresholds of rats with only the olfactory bulb removed were equivalent to those of normal rats.

Despite such observations, data exist which suggest that, at suprathreshold levels, perceived bilateral odor intensity is not equivalent to that of the more highly functioning side of the nose. Cain (1977), using magnitude estimation, presents data suggesting that bilateral additivity occurs across the two sides of the nose, resulting in a bilaterally perceived intensity that is greater than that obtained for either side of the nose, in accord with von Skramlik's (1926) observations. Bromley and Doty (1995) found, in their multiple-target odor memory paradigm, that under unilateral test conditions a decay in odor memory performance occurs across retention intervals whereas under bilateral test conditions it does not, implying some type of central summative integration. Bilateral facilitation has been reported for a variety of tasks in vision (e.g. Blake and Fox, 1973), audition (e.g. Marks, 1978, 1980) and the skin senses (e.g. Hardy and Oppel, 1937; Rozsa and Kenshalo, 1977). Nevertheless, in light of the present findings and analogous findings of Hornung *et al.* (1990) for suprathreshold odor identification scores, it may be prudent to further investigate the nature of bilateral facilitation or integration seen in various olfaction-related suprathreshold tasks to clearly establish the extent to which the more sensitive side of the nose contributes to the bilateral effect.

In the present study, no sex difference in olfactory sensitivity to the target odorant was observed. It has been previously reported that women generally outperform men on a number of suprathreshold olfactory tasks, although highly variable findings are reported for threshold tasks, even for the same odorants (see Le Magnen, 1952; Koelega and Köster, 1970; Doty *et al.*, 1975, 1984, 1985; Doty, 1986; Koelega, 1994). In studies using PEA, we have found slightly lower thresholds in women than in men in some studies (e.g. Doty *et al.*, 1986, 1988b) but not in others (Deems and Doty, 1987; Doty *et al.*, 1988a). The reason for such variation is not clear; what is clear, however, is that in the present work there was not even a hint towards lower thresholds in women as compared with men.

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