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Influences of Feedback and Ascending and Descending Trial Presentations on Perithreshold Odor Detection Performance

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Abstract

The influences of feedback and ascending and descending trial sequences on the ability of 135 college-aged subjects to detect phenyl ethyl alcohol odorant concentrations ranging from 10^{-9} to $10^{-5.5}$ v/v were examined in a two-alternative forced-choice test paradigm. At the highest concentrations, ascending trial sequences produced better performance than descending trial sequences; the reverse was true at the lowest concentrations. There was a tendency for feedback to improve performance marginally at the lowest two odorant concentrations presented. In the region associated with a traditional detection threshold calculation (i.e. at the 75% performance point in a two-choice detection task), no influences of feedback or direction of trial sequence were apparent. These data indicate that the effects of explicit feedback and trial sequence direction depend upon the segment of the peri-threshold stimulus concentration continuum evaluated.

Key words: threshold, phenyl ethyl alcohol, psychophysics, feedback, method of limits

Introduction

A popular means for assessing olfactory function is to measure the lowest odorant concentration that is detectable to a subject (i.e. the so-called detection threshold). A number of methods are currently used to provide such a measure, including the method of limits, various staircase procedures and, on rare occasions, the classical method of constant stimuli [for review, see (Doty and Laing, 2003)]. In general, methods that initially employ ascending presentations of odorant concentrations are more common, since they are presumed to evoke less adaptation than procedures that employ descending stimulus presentations and, consequently, produce lower and possibly more reliable threshold values. Empirical data in support of such a notion, however, is largely lacking. In the only study directly assessing this issue in the chemical senses, Pangborn *et al.* (Pangborn *et al.*, 1964) reported lower thresholds for ascending than for descending trials. However, this work employed only five subjects and a non-forced choice trials paradigm, and no statistical analysis was performed on the data. In contrast, there is limited evidence against the notion of superior performance on tasks employing mainly ascending trials and two-alternative forced-choice responses. Thus, greater detection performance in two-alternative forced-choice staircase detection threshold tasks occurs after long descending trial runs (Doty, 1991), and perithreshold detection performance seems to increase within trial blocks of the same concentration in signal detection paradigms employing either humans or rats (Doty *et al.*, 1981; Doty and Ferguson-Segall, 1989). Hence, despite intuitive appeal, the question as to whether ascending trials result in better threshold performance than descending trials remains open.

The present study examined the influences of ascending and descending trial sequences, as well as the influence of feedback, on the ability of subjects to detect, in a two-alternative forced-choice paradigm, perithreshold concentrations of the rose-like smelling odorant phenyl ethyl alcohol (PEA). To our knowledge, the role of feedback in odor detection performance has never been formally explored, although it is well established in animal chemosensory psychophysical work that feedback decreases the time required to learn a task (Dorries *et al.*, 1991). Phenyl ethyl alcohol was chosen as the stimulus because of its wide use in olfactory psychophysics and the fact that, relative to most odorous chemicals, it has comparatively low intranasal trigeminal reactivity (Doty *et al.*, 1978).

Materials and methods

Subjects

One hundred thirty-five college-aged subjects [mean age (SD) = 20.74 (2.21); 71 men and 64 women] were recruited from advertisements placed on campus bulletin boards at the University of Pennsylvania. A deliberate effort was made to recruit minority students. All subjects were non-users of tobacco products. The ethnic composition of the study group was as follows: Afro-American, 12; Caucasian American, 100; Hispanic Americans, 3; Asian American, 19. The ethnic background of one subject was not recorded. All subjects reported being in good health and none reported having problems smelling or tasting. None were taking medications at the time of testing. Individuals who reported a history of nasal disorder or any other problem (e.g. anosmia) that would interfere with their participation were not included in the study group. The 12-item Brief Smell Identification Test (also termed the Cross-Cultural Smell Identification Test or CC-SIT) (Doty *et al.*, 1996) was administered to a subset of 56 of these individuals; all scored within the normal range on this standardized test [mean (SD) = 11.26 (0.84)].

Procedures

The general experimental paradigm was straightforward. The subjects were assigned to the following experimental groups: Ascending Trial Sequence Group with Feedback (A-F) (n = 35); Ascending Trial Sequence Group without feedback (A-NF) (n = 34); Descending Trial Sequence Group with Feedback (D-F) (n = 31); and Descending Trial Sequence Group without Feedback (D-NF) (n = 35).

Fourteen two-alternative forced-choice trials were presented to each subject at each of eight stimulus concentrations ranging in half-log steps from $10^{-9.0}$ to $-10^{-5.5}$ v/v. A trial consisted of the bilateral presentation of two glass sniff bottles in rapid succession to the subject. These 120 ml bottles were 8.5 cm tall with 3.8 cm i.d. openings and 4.4 cm i.d. widths. One contained 20 ml of a given concentration of PEA (Aldridge Chemical, Chicago, IL) dissolved in USP grade light mineral oil; the other contained mineral oil diluent alone. The bottles were opened and immediately placed over the subject's nose in a standardized manner depicted elsewhere (Doty *et al.*, 1978). The subject's task was to report which of the two bottles produced the stronger sensation. Even if no sensation was perceived or if no difference was apparent between the bottles, the subject was required to choose one or the other bottle (i.e. the task was forced-choice). The order of the presentation of the two bottles of a trial was random, with the stipulation that, in a block of 14 trials, the odorant was presented first on half of the trials, and the diluent on the other half of the trials. A 15 s interval was maintained between trials.

In the ascending trial sequence conditions, the trials began at the lowest concentration and all 14 trials at a given concentration were completed before moving to the next highest concentration. The reverse was true for the descending trial sequence condition. Under the feedback conditions, the experimenter verbally indicated to the subject whether his or her response on each trial was correct of not. Under the no-feedback conditions, no such indication was provided.

Results

To determine the influence of the independent measures of this study on detection performance, the percentage of correct trials was calculated for each subject at each odorant concentration level and subjected to a trial sequence (descending, ascending) × feedback condition (yes, no) × odorant concentration analysis of variance (ANOVA), with replications on the last factor. Neither of the between subjects factors—trial sequence and feedback condition—was statistically significant [respective Fs(1,131) = 0.64 and 0.00, respective Ps = 0.43 and 0.99). The trial sequence ×

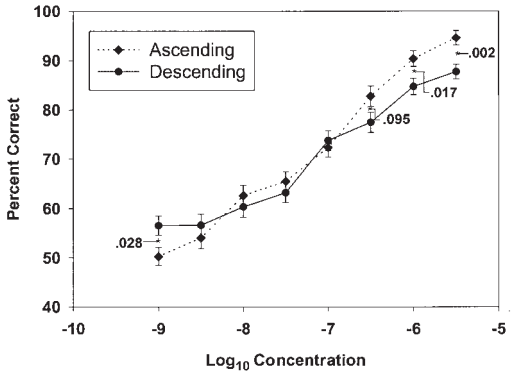

Figure 1 Detection performance of subjects as a function of odorant concentration and direction of trial block sequence, i.e. ascending or descending. *P*-values from one-way analyses of variance performed at each odorant concentration. See text for details.

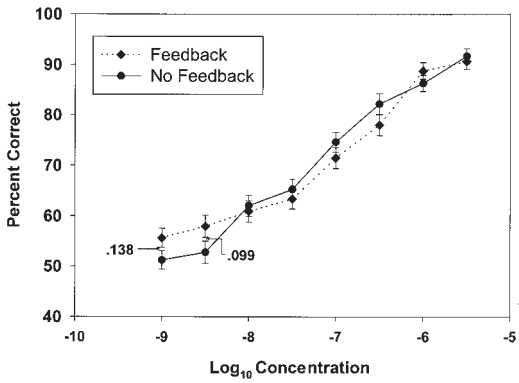

Figure 2 Detection performance of subjects as a function of odorant concentration and feedback condition. *P*-values from one-way analyses of variance performed at each odorant concentration. See text for details.

feedback interaction was also not significant [$F(1,131) = 0.05$, $P = 0.83$). However, the within-subject factor of odorant concentration, as well as the odorant concentration × trial sequence interaction and the odorant concentration × feedback interaction, were significant [respective Fs(7,917) = 161.8, 3.87 and 2.37; respective Ps < 0.00001, 0.002 and 0.021] (Figures 1 and 2).

Assessment of differences at each odorant concentration level using one-way ANOVAs revealed significant differences only within the trial sequence group data, although, as seen in Figure 2, there was a non-significant tendency for the feedback group to be superior to the non-feedback group at the lowest two odorant concentrations. As shown in Figure 1, significantly greater performance was noted within the ascending trials group, relative to the descending trials group, at the higher odorant concentrations; the reverse was true at the lowest odorant concentration.

Discussion

The present study suggests that the direction of trial sequences—ascending or descending—has a clear influence on odor detection performance only at the extremes of the perithreshold stimulus concentration range. Specifically, better performance occurs at lower perithreshold odorant concentrations when the trials begin at the higher concentrations and subsequently descend to the lower concentrations. Conversely, better performance occurs at higher perithreshold odorant concentrations when trials begin at lower concentrations and ascend to higher concentrations. No meaningful influences of trial sequence on performance was observed for odorant concentrations midway in the concentration series—i.e. concentrations that would typically be used in the calculation of a threshold estimate.

The basis of the differential influences of ascending and descending trial blocks at the two ends of the perithreshold odorant concentration continuum is not immediately clear. If adaptation were a pervasive phenomenon, then one would expect performance to be poorer for subjects of the descending trial sequence at all odorant concentrations, with perhaps even greater attenuation occurring at the lower concentration levels. However, poorer performance in these subjects was only observed at the higher odorant concentrations; at the lower odorant concentrations, the performance of the subjects in the descending trial sequence group actually exceeded that of the ascending series group. Although it is possible that less adaptation occurred at the lower odorant concentrations (e.g. due to the relatively low concentrations of the more immediate prior trials and reversal of adaptation due to earlier exposure to higher concentrations), this alone would not explain the better performance in the descending than in the ascending trials group at the lowest concentration levels employed in this study. Moreover, it is unlikely that a simple warm-up effect is the primary basis of this phenomenon, since more than an adequate number of trials was presented at each of the initial concentrations in both the ascending and descending groups to overcome most such effects.

Perhaps the most parsimonious explanation of the present findings is that subjects simply improve performance over time in peri-threshold detection tasks. Thus, on ascending trials, better *relative* performance would be expected at the higher odorant concentrations, whereas on descending trials better *relative* performance would be expected at the lower odorant concentrations. Such enhancement, however, may not be the same magnitude for ascending and descending trials. The descending group would be expected, for example, to obtain considerable information in recognizing the difference between the blank and the odorant on initial trials, whereas this is not the case in the ascending group, where the odorant:blank distinction is less clear. This is suggested by the fact that feedback tended to improve performance at the lower, but not higher, odorant concentrations (Figure 2). A number of investigators have noted that improvement occurs across trials, indeed in some cases even across days, in odor detection tasks in which perithreshold-level stimuli are repeated presented (Pfaffman *et al.*, 1954; Engen, 1960; Pangborn *et al.*, 1964; Doty *et al.*, 1981; Rabin and Cain, 1986), a phenomenon that is present even in rats (Doty and Ferguson-Segall, 1989).

The present study employed a single chemical—phenyl ethyl alcohol—in the detection task, begging the question as to whether similar results would occur with other odorants and, if so, which ones. Although, in an ultimate sense, the latter question is not testable (given the tens of thousands of odorous chemicals available for assessment), most studies find high correlations among thresholds for different compounds obtained from the same subjects (Yoshida, 1984; Doty *et al.*, 1994). Such observations, along with recent evidence that odorant receptor cells tuned to various physiochemical moieties are found somewhat randomly distributed within zones of the olfactory epithelium (making them vulnerable generally to damage of the epithelium) (Sullivan *et al.*, 1994), suggest that the present findings are likely quite general.

Feedback as a concept in psychophysical studies is complex. In descending runs, for example, a clear distinction can be made on the part of the subject between correct and incorrect trials, resulting—even when no 'explicit feedback' is provided by the examiner—in the production of 'implicit feedback'. No implicit feedback exists, however, in ascending runs at low odorant concentrations. In other words, under a 'no feedback' paradigm, trials at higher concentrations of a descending series provide a form of task-related feedback, in that implicit information as to the correctness of the response is present (i.e. the subject has no doubt as to which stimuli are odorants and which are blanks). Such information is not available, however, at lower stimulus concentrations. Thus, ascending and descending stimulus presentation may be asymmetric in terms of their intrinsic

sequential feedback properties. The data of the present study are in accord with this notion, in that at higher perithreshold odorant concentrations intrinsic feedback presumably maximized performance (hence no effects of extrinsic feedback were evident), whereas at lower odorant concentrations extrinsic feedback tended to improve detection performance. However, the effects, while present, were not marked in this study, likely because of the stable performance induced, in part, by the use of a relatively large number of trials at each concentration step and a two-alternative forced-choice response paradigm.

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References

Dorries, K.M., Adkins-Regan, E. and **Halpern, B.P.** (1991) *Sex difference in olfactory sensitivity to the boar chemosignal, androstenone, in the domestic pig*. Anim. Behav., 42, 403–411.

Doty, R.L. (1991) *Olfactory system*. In Getchell, T.V., Doty, R.L., Bartoshuk, L.M. *et al*. (eds), Smell and Taste in Health and Disease. Raven Press, New York, pp. 175–203.

Doty, R.L. and **Ferguson-Segall, M.** (1989) *Influence of adult castration on the olfactory sensitivity of the male rat: a signal detection analysis*. Behav Neurosci 103, 691–694.

Doty, R.L. and **Laing, D.** (2003) *Psychophysical measurement of human olfactory function, including odorant mixture assessment*. In Doty, R.L. (ed.), Handbook of Olfaction and Gustation, 2nd edn. Marcel Dekker, New York, pp. 203–228.

Doty, R.L., Brugger, W.E., Jurs, P.C., Orndorff, M.A., Snyder, P.J. and **Lowry, L.D.** (1978) *Intranasal trigeminal stimulation from odorous volatiles: psychometric responses from anosmic and normal humans*. Physiol. Behav., 20, 175–185.

Doty, R.L., Snyder, P.J., Huggins, G.R. and **Lowry, L.D.** (1981) *Endocrine, cardiovascular, and psychological correlates of olfactory sensitivity changes during the human menstrual cycle*. J. Comp. Physiol. Psychol. 95, 45–60.

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.

Doty, R.L., Marcus, A. and **Lee, W.W.** (1996) *Development of the 12-item Cross-cultural Smell Identification Test (CC-SIT)*. Laryngoscope, 106, 353–356.

Engen, T. (1960) *Effect of practice and instruction on olfactory thresholds*. Percept. Mot. Skills, 10, 195–198.

Pangborn, R.M., Berg, H.W., Roessler, E.B. and **Webb, A.D.** (1964) *Influence of methodology on olfactory response*. Percept. Mot. Skills, 18, 91–103.

Pfaffmann, C., Schlosberg, H. and **Cornsweet, J.** (1954) Variables affecting difference tests. In Peryam, D.R., Pilgrim, F.J. and Peterson, M.S. (eds), Food Acceptance Testing Methodology. Washington, DC: National Academy of Science, Nat Res Council, pp. 4–17.

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

Sullivan, S.L., Ressler, K.J. and **Buck, L.B.** (1994) *Odorant receptor diversity and patterned gene expression in the mammalian olfactory epithelium*. Prog. Clin. Biol. Res., 390, 75–84.

Yoshida, M. (1984) *Correlation analysis of detection threshold data for 'standard test' odors*. Bull. Fac. Sci. Eng. Cho. Univ., 27,343–353.

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