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Odor Perception and Beliefs about Risk

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Abstract

Although the perceptual response to environmental odors can be quite variable, such variation has often been attributed to differences in individual sensitivity. An information-processing analysis of odor perception, however, treats both the reception and the subsequent evaluation of odor information as determinants of the perceptual response. Two experiments investigated whether a factor that influenced the evaluation stage affected the judgement of odor quality and the degree of adaptation to the odor. People were surveyed in order to measure their tacit perceptions of the healthfulness or hazardousness of nine common olfactory stimuli, and the instructional context influenced quality perception. In a second experiment subjects were exposed to an ambient odor under one of three different conditions, and odorant characterization influenced the degree of adaptation to the odor. Subjects who were led to believe the odor was a natural, healthy extract showed adaptation; those told that the odor was potentially hazardous showed apparent sensitization; while those told that the odor was a common olfactory test odorant showed a mixed pattern: some exhibited adaptation, whereas others showed sensitization. However, detection thresholds obtained before and after exposure showed adaptation effects that are characteristic of continuous exposure. These findings raise the possibility that cognitive factors may be modulating the overall sensory perception of odor exposure (i) for some individuals who exhibit extreme sensitivity to odors and (ii) in situations where adaptation to environmental odors is expected but does not occur. **Chem. Senses 21: 447–458, 1996.**

Introduction

Our ability to perceive the odors from volatile chemicals often provides information about the surrounding environment. Ambient odors can influence the assessment of indoor and outdoor air quality (Cain, 1987), can serve as a warning agent in the home and the workplace (Cain and Turk, 1985; Ames *et al.*, 1993), and can affect moods and psychological health (Knasko, 1992, 1993; Schiffman *et al.*, 1995). Unfortunately, successful regulation of ambient odor levels in residential or occupational exposures or the utility of odors as environmental cues depends greatly upon the consistency with which people respond to the presence of an odor. In fact, behavioral responses to environmental odors can be quite variable, both over time for a single individual and among individuals exposed to the same odor. Whether the odors emanate from a nearby factory with odorous emissions or from a co-worker who liberally applies personal fragrance, ambient odors can provoke a wide distribution of reactions.

Presumably, some of the differences in the perceived odor intensity can be attributed to differences in exposure history (e.g. frequency or duration of exposure to an odor source). For example, workers with daily exposure to a volatile chemical perceive far less odor and pungency from exposure to that chemical than do non-exposed individuals, due to sensory adaptation (Dalton *et al.*, 1996). Olfactory adaptation has been similarly documented in residential settings, where individuals who receive daily exposure to an air-freshener-type fragrance show both a persistent loss of sensitivity to the odor and a marked decrease in their perception of the odor's intensity in their home (Dalton and Wysocki, 1996). However, even individuals with similar exposure histories can show disparities in the intensity with which they perceive the odor from a volatile substance.

Among olfactory researchers, inter-individual variation in odor perception (e.g. intensity, quality) has long been noted (e.g. Stevens *et al.*, 1988; Cain and Gent, 1991). However, most have attributed the variability to differences in individual sensitivity. Thus, investigators have focused on the perception of threshold stimuli and ascribed much of the documented variability to age or genetic factors (Wysocki and Beauchamp, 1984; Gilbert and Wysocki, 1989; Cain and Gent, 1991). Although age-related changes in receptor density or differences in genetic coding undoubtedly account for some of the observed variance in odor perception, these factors are more likely to mediate the initial reception or encoding of the odor stimulus and less likely to determine the perceptual response that the odor evokes. Contemporary theories of human cognition and perception, such as signal detection theory, account for the variability within and across individuals by assuming that both the initial reception (sensitivity) and the subsequent evaluation (criterion) of the stimulus are determinants of the perceptual response (e.g. Swets *et al.*, 1961; Luce and Krumhansl, 1988). By such reasoning, the cognitive evaluation of an odor is likely to be equally as important in shaping the individual's perceptual response as the sensory reception.

In recent years, the importance of cognitive processes in the perception of odors has gained acceptance. Indeed, various researchers (Cain, 1979; Kirk-Smith and Booth, 1987; Corwin, 1992; Booth, 1996) have pointed out that the response to an odor stimulus is greatly influenced by the complex environment surrounding the exposure, which can include the social context as well as the perceiver's expectations or cognitive capacities. The current studies examined the variation in the perceptual response to an ambient odor produced by cognitive factors influencing the situational context and the perceiver's expectations.

Sensory and non-sensory influences on odor perception

In this paper, the process of odor perception is considered as a classic information-processing task. The basic assumption in standard theories of human information-processing is that information from the environment is encoded into sensory memory, and processed through working and long-term memory before a decision stage is reached for the output (e.g. Atkinson and Shiffrin, 1968). Because the output of the system can be influenced both by incoming sensory information and by information that the stimulus activates in long-term memory, perception is assumed to be guided both by data-driven (sensory) and concept-driven (non-sensory) processes (e.g. Solso, 1988; Ashcraft, 1989). Data-driven or 'bottom-up' processing relies almost exclusively on the 'data' or the information presented in the stimulus to guide perception. In contrast, concept-driven or 'top-down' processing relies heavily on information in memory, expectations and even the perceiver's affective or emotional state (Isen, 1984; Erlichman and Bastone, 1992) to guide perception.

To illustrate the distinction between 'bottom-up' and 'top-down' processes in the context of odor perception, consider the example of people returning home and attempting to identify the source of an unpleasant, pungent odor that greets them when they open their front door. The individuals in question will probably resolve the uncertainty much more quickly (and with much less anxiety) if they recall they were scheduled for a monthly pesticide application than if they had no such knowledge. Likewise, encountering an unfamiliar odor in the kitchen will probably activate a different mental set of candidate odors than would be primed if that same unfamiliar odor were encountered in the garage. In both of these situations, information present in the stimulus (strength, quality) plus information stored in long-term memory (probabilistic knowledge about likely sources of the odor in a particular context) are used to guide the process of perception.

Historically, olfactory research has favored the view that odor perception is a 'data-driven' task. Yet observations from real-world environments and the laboratory make a compelling case that 'top-down', associative or affective information is an important determinant of our perception and response to environmental odors.

'Top-down' effects on odor perception

Generally speaking, individuals who are exposed to the same stimulus but whose perceptions differ only as a function of some associative information they possess about the stimulus are engaging in top-down or conceptual processing. Several earlier studies conducted in natural or laboratory environments suggested an important role for top-down processing on the absolute detection of an odor. In an early classroom demonstration of this phenomenon, misinforming individuals that an odorant was being dispersed into the environment induced an 'olfactory hallucination' in which people reported detecting an odor and, in some cases, experiencing discomfort from the exposure (Slosson, 1899). In a more sophisticated attempt to replicate and extend this finding, O'Mahoney (1978) examined the utility of radio and television as a medium for suggestibility effects on odor detection. Informing a television and a radio audience that a signal broadcast at a certain frequency could produce the perception of an odor generated reports of odor detection and, in some cases, reports of discomfort (e.g. allergic reactions). Similar effects on odor perception have also been found under controlled laboratory conditions. Knasko and colleagues (1990) found that informing subjects that an aerosol delivery of deionized water was either a pleasant or unpleasant odorous substance produced reports of odor experience that were consistent with the hedonic characterization received. And, in several studies that examined more indirect influences on human odor perception, enhancing odor stimuli with irrelevant color cues increased the likelihood that an individual would report detecting an odor (Engen, 1972) and increased the perceived odor intensity (Zellner and Kautz, 1990).

The degree to which cognitive factors, such as context or expectations, appear to bias reported odor perceptions in these studies suggests that such non-sensory factors may play a large role in our everyday odor experiences. In fact, demonstrations of 'top-down' effects on ancillary odor qualities, such as preference or acceptability, have been relatively numerous (Moskowitz, 1979; Zellner *et al.*, 1991). There is far less evidence in support of a cognitive or 'top-down' basis for assessing a primary odor quality like intensity (but see Zellner and Kautz, 1990), although differences in perceived odor intensity could be the product of variation in cognitive dimensions (e.g. experiences, attitudes, knowledge) that mediates the subject's expectations or attention allocation in the presence of an odor.

Consequently, the current studies explored the role of 'top-down' processing on perceived odor intensity. The primary goal of the research was to determine whether a purely cognitive factor, such as information concerning the perceived health risk from exposure to an ambient odor, could influence the perceived odor intensity. The perceived health risks from exposure to chemicals have been of rising concern in both residential and occupational environments (Lees-Haley and Brown, 1992). Such an effect would be consistent with survey data indicating that perceived risk from exposure was the most significant correlate of odor annoyance from factories with occasional emissions (McClelland *et al.*, 1990). Moreover, finding a relationship between perceived risk and odor intensity would be relevant to interpreting current concerns about exposures to environmental odors and delineating the relationship between cognitive risk perceptions and the manifestation of chemical sensitivities and symptoms from 'sick building syndrome' (SBS).

Experiment 1 surveyed people's tacit perceptions concerning the healthy and hazardous character of nine common olfactory stimuli in order to (i) characterize those odorants on a healthy/hazardous dimension and (ii) observe whether the instructional set or context in which an odor is to be judged can influence how the character (i.e. healthy or hazardous) of that odor is perceived. The results of this study were used to select the most malleable odor from the set to use in experiment 2. In experiment 2, subjects judged the intensity of this perceptually malleable ambient odor under one of three different bias conditions, to determine the degree to which bias could influence perceived odor intensity during a 20 min exposure.

Experiment 1

It is well established that perceptual judgements are influenced by the context or frame in which the judgements are made (e.g. Lockhead, 1992; Dunnegan, 1993). The goal of experiment 1 was to identify the healthy or hazardous character for each of a set of commonly used olfactory stimuli, and to determine whether the judgements for any of those odorants could be biased by the context of the rating task. Although it seemed likely that some highly familiar odorants are readily and consistently judged as healthy or hazardous smelling (i.e. are context-independent), the perceived character of other odorants may be greatly influenced by the context of the rating task. Identifying such 'malleability' in an odor would be important for maximizing the likelihood of observing cognitive effects on odor perception in the second experiment.

Method

Subjects

Sixty individuals (34 females, 26 males) were recruited from the metropolitan Philadelphia area to participate in this study. Their mean age was 36.5 years. They were paid for their participation.

Stimuli

Odorants were diluted in odorless, light, white mineral oil (Sigma), propylene glycol (Sigma) or glycerol (Sigma), and presented in 270 ml polypropylene squeeze bottles with plastic flip-top caps. Each bottle contained 10 ml of the diluted odorant. Nine odorants were used: vanillin (3% wt/vol), methyl salicylate (wintergreen; 20% vol/vol), acetic acid (vinegar; 2% vol/vol), butanol (sweet alcohol; 5% vol/vol), phenylethyl alcohol (rose; 5% vol/vol), benzaldehyde (almond, cherry; 2% vol/vol), citralva (lemon, citrus; 10% vol/vol), isobornyl acetate (balsam; 10% vol/vol) and amyl acetate (banana; 2% vol/vol). These odorants were chosen from a larger set of olfactory stimuli commonly used in our laboratory, and were selected on the basis of prior testing to represent a range of familiarity and pleasantness. In pilot testing these concentrations were judged to be perceptually equivalent in intensity and, on average, were rated as moderate.

Procedure

Each subject was assigned to one of two groups (n = 30 for each group). The healthy group was told that the purpose of the experiment was to gather information on odors that could be added to products to reinforce the perception of healthiness. They were asked to rank the nine odors from most healthy to least healthy. The hazardous group was told that the purpose was to gather information on odors that could be added to dangerous chemicals to reinforce the perception of hazard. They were asked to rank the same nine odors from most to least hazardous. Instructions to both groups emphasized that they were not to rank the odors on the basis of preference. All subjects were given unlimited time and opportunity to sniff and rank the odorants.

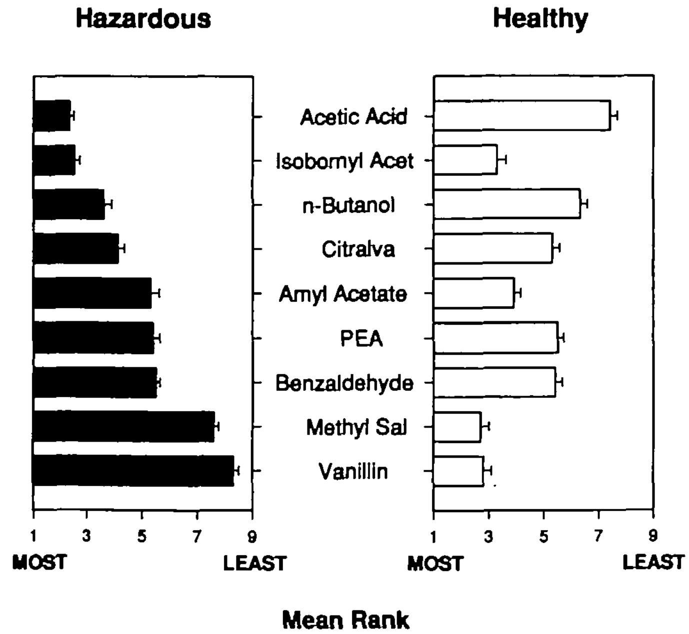

Figure 1 Mean rank (and SEM) for the nine test odorants judged under each instructional context. Bars on the left represent the mean rank when the odorant was judged in the context 'from most to least hazardous' (1 = most, 9 = least) Bars on the right represent the rank when the odorant was judged 'from most to least healthy'.

Results

For each condition, rank order was averaged across all subjects for each odorant. Kendall's coefficient of concordance revealed agreement among the individuals who were asked to rank odors from most to least hazardous [$W = 0.51$, χ^2 (59) = 270.8, $P < 0.001$] as well as those asked to rank odors from most to least healthy [$W = 0.30$, χ^2 (59) = 212.4, $P < 0.001$]. However, some differences emerged in the rankings for the same odors under different instructional sets. Figure 1 depicts the mean rank of each odor when ranked from most to least healthy and from most to least hazardous. If there were perfect agreement in the rankings under the two instructional sets, then the graph on the right would be the inverse of the graph on the left. As can be seen by comparing the two graphs, this was not always the case. Subjects consistently ranked some odorants as healthy (vanillin and methyl salicylate) and some as hazardous (acetic acid and butanol), regardless of instructional set. However, some odorants (isobornyl acetate and amyl acetate) were ranked differently when the instructional set was changed. Isobornyl acetate, in particular, seemed susceptible to the effect of instructional context; it was ranked second (M = 2.3) by the subjects who judged odors from most to least hazardous and ranked third by the subjects who judged odors from most to least healthy (M = 3.3). Thus, the results of this experiment indicate that while subjects exhibited moderate agreement on odor qualities like healthiness or hazardousness, the instructional context under which an individual evaluates odors influences the way some odorants are perceived. This latter result formed the basis for selecting an odorant for experiment 2 (isobornyl acetate) that could be biased, as either healthy or hazardous, by experimenter-provided characterizations.

Experiment 2

Because concern about health risks from environmental odors is correlated with continued annoyance from such odors (e.g. Miedema and Ham, 1988; McClelland *et al.*, 1990), it was hypothesized that risk perception could influence perceived odor intensity. The goal of experiment 2 was to examine how the characterization of an odor affected two measures of an individual's response to that odor during prolonged exposure: the time course of odor intensity during exposure and the change in sensitivity from pre- to post-exposure. Typically, prolonged exposure to an odor in laboratory conditions results in olfactory adaptation, evidenced by (i) a marked decrease in the perceived intensity of odor and (ii) transiently elevated thresholds following exposure (e.g. Berglund *et al.*, 1971; Cometto-Muniz and Cain, 1995). However, in real-world environments, exposure to an ambient odor does not always produce adaptation (Miedema and Ham, 1988; Neutra *et al.*, 1991; Schiffman *et al.*, 1995). Two tasks were used to index the degree of adaptation to an odor in this study. Although threshold shifts are often used to predict shifts at suprathreshold levels, these methods are not necessarily interchangeable (Steimmetz *et al.*, 1979). Discrepancies in the degree of adaptation in these tasks could be due to their differential reliance on 'bottom-up' and 'top-down' features of the odorant stimulus. Odor detection may utilize more 'bottom-up' processing, whereas intensity judgements may utilize 'top-down' processing as well. If a cognitive factor such as the pre-exposure characterization of the odorant alters how sensory input is evaluated, then risk characterization should influence judgements of stimulus intensity to a greater extent than it influences the amount of stimulus necessary for detection.

Method

Subjects

Forty-five subjects were recruited from the metropolitan Philadelphia community using advertisements placed in local newspapers. They were paid for their participation. Their ages ranged from 18 to 62, with a mean of 35 years. All subjects were screened for the absence of active head cold or allergy. None had participated in experiment 1.

Stimuli and apparatus

Exposure stimuli

The exposure odorant was isobornyl acetate. This was chosen based on the outcome of experiment 1, in which this odorant revealed itself to be 'perceptually malleable'. That is, different groups of people judged isobornyl acetate to be hazardous or healthy smelling, depending on the instructional context of the judgement task. It seemed likely that an odorant with such properties would be susceptible to experimental manipulations of odor characterization.

The ambient exposure was accomplished in the following manner: a fragrance cartridge filled with absorbent material and covered with a membrane to control evaporation rate (supplied by the Waterbury Company, Waterbury, CT) was filled with 28 g of a 50% solution containing isobornyl acetate in light, white mineral oil. The fragrance cartridge was placed into a battery-powered fan-driven fragrance dispenser (World Wind Dispensers, Waterbury Co., Waterbury, CT), which continuously forced air across the top of the odorant cartridge. Diffusion took place in a test chamber at Monell, equipped with a laminar airflow system that was set to exchange the room air at a rate of once every 5 min. Room temperature was maintained at 27°C (±2°C) and relative humidity at 50% (±7%). Odorant diffusion was begun 15 min before the subject entered the room; following each session, the room air was purged for 30 min. In pilot testing, using employees at Monell, the concentration achieved by this method was consistently rated as moderate.

Threshold stimuli

Pre-and post-exposure thresholds were determined for two odorants: isobornyl acetate (test) and citralva (control). Both odorants were diluted in mineral oil and presented in squeeze bottles as described in the previous experiment. Blanks consisted of 10 ml of mineral oil without odorant. A 26-step binary dilution series was prepared for each odorant. The dilution scheme for isobornyl acetate (mol. wt = 196.3) ranged from 5.01 mM (step 0: 1 × 10–1% vol/vol) to 1.36 μM (step 25: 3 × 10–8% vol/vol). The dilution scheme for citralva (mol. wt = 149.2) ranged from 5.96 mM (step 0: 1 × 10–1% vol/vol) to 1.98 μM (step 25: 3 × 10–8% vol/vol).

Procedure

Prior to the chamber exposure, odor detection thresholds for citralva and isobornyl acetate were obtained for each subject. Immediately after threshold determination, each subject spent 20 min in the test chamber into which the isobornyl acetate was being actively diffused. Immediately following this exposure, detection thresholds for citralva and isobornyl acetate were again obtained.

Instructions

The subject's task in the experiment was to judge the intensity of the odor at 1 min intervals during the exposure. All subjects were told that the concentration of odorant diffused into the test chamber during the 20 min session could vary throughout the session or could stay the same. In fact, the concentration of the odorant was the same for all subjects throughout the exposure. What did differ, however, was the information about the odorant that subjects received prior to exposure.

Subjects were randomly assigned to one of three groups, each of which received different characterizing information or bias about the nature and consequence of exposure to the odorant. The positive group was told they would be exposed to a natural extract from balsam trees that was often used in aromatherapy and had been reported to have positive effects on mood and health. In contrast, the negative group was told they would be exposed to an industrial solvent which, following long-term exposures, had been reported to cause problems with health and cognitive functioning. The neutral group (control) was told they would be exposed to a standard odorant that had been approved for olfactory research.

Measures of olfactory adaptation

Ambient odor intensity

Intensity ratings of the ambient odor were made on a computer that displayed the labeled magnitude scale (LMS), a category-ratio scale that has six categories of intensity as indicated by natural language descriptors (Green *et al.*, 1993). The scale yields ratio-level data and absolute intensity estimates, and has been validated against magnitude estimation for use with olfactory stimuli (Green *et al.*, 1996). Subjects entered the chamber and made an immediate rating of their first impression of the odor's intensity. Thereafter, the computer prompted them at 1 min intervals to rate the intensity of the room odor. At the end of the 20 ratings, the computer signaled that the exposure phase of the experiment was over.

Detection threshold

Prior to and immediately following the exposure session, detection thresholds were obtained for isobornyl acetate (test) and citralva (control), using a two-alternative forced-choice, up–down staircase procedure. All threshold tests were administered in a separate, non-odorized test room.

Results

Intensity ratings

Because ratings made with the LMS are logarithmically distributed (Green *et al.*, 1993), all intensity ratings were log-transformed prior to analysis. The means for ratings of perceived intensity as a function of bias condition are shown in Figure 2. The intensity ratings of the ambient odor differed depending upon how the experimenter characterized the source of the ambient odor. This difference was most evident during the second half of the exposure period. A repeated-measures ANOVA performed on the intensity ratings as a function of exposure time and instruction group revealed a main effect of time [$F(19,798) = 2.098$, $P < 0.004$] and a significant interaction between time and group [$F(38,798) = 1.805$, $P < 0.003$]. *Post hoc* tests on the means revealed that the intensity ratings made by subjects in the positive bias condition were significantly different from the ratings made by subjects in the negative or neutral bias condition. The positive group showed a typical, negatively accelerating adaptation function. The largest decline in rated intensity occurred in the first minute

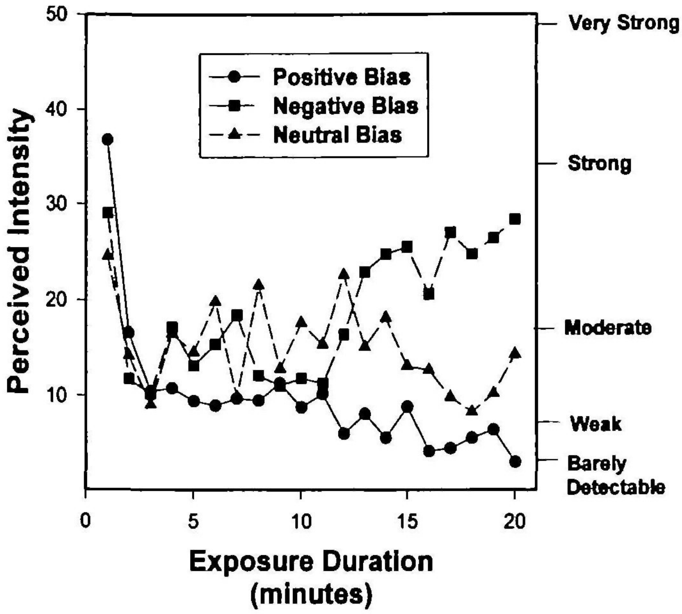

Figure 2 Averaged ratings of ambient odor intensity of isobornyl acetate, for subjects in the positive, negative and neutral bias condition, collected at 1 min intervals during a 20 min odor exposure.

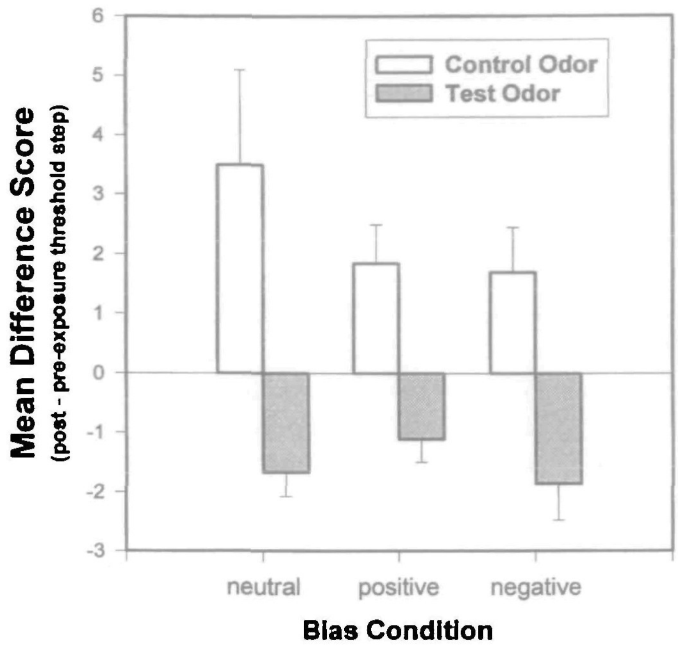

Figure 3 Average shift in thresholds for isobornyl acetate (test) and citralva (control) following a 20 min exposure to isobornyl acetate, for subjects in the positive, negative and neutral bias conditions. The change in threshold sensitivity is represented as the difference (in binary dilution steps of the odorant series) between the pre-exposure and post-exposure thresholds for that odorant, where positive numbers represent increased sensitivity and negative numbers represent decreased sensitivity.

of exposure and, during the 19 min of exposure that followed, on average the odorant was rated as weak. The group that received the negative bias showed the same level of initial adaptation. In marked contrast, however, halfway through the exposure they began to rate the odor as intensifying. By the end of the exposure session, the group receiving negative bias rated the average odor intensity as 'strong'. On average, the group that was given the neutral bias showed a final degree of adaptation to the odor that was intermediate between the negative and the positive groups.

A closer look at the individual data contributing to these means was informative. In the group that received a positive bias, all subjects gave final intensity ratings that were >75% lower than their initial judgement of odor intensity (M = 92%). In contrast, all but four individuals in the negative bias condition made final judgements that were >5% higher than their initial judgement of odor intensity; all subjects in this condition gave final intensity estimates that were significantly higher than their rating of odor intensity at 2 min (M = 65%). Using these criteria to analyze subjects in the neutral bias group revealed a mixed pattern of responders. Nine of the subjects showed sensitization (>5% increase) while seven showed adaptation (>50% decrease).

Detection thresholds

No systematic variation by condition was observed for the detection thresholds. Analysis of detection thresholds provided evidence that differences among the groups on the ratings of perceived intensity reflected cognitive evaluation of the odor rather than true changes in sensitivity. ANOVAs conducted on the threshold scores revealed only a main effect of odor type (exposure or control) [$F(1,44) = 45.155$, $P < 0.001$] and a significant interaction between odor type and test session [$F(1,44) = 36.25$, $P < 0.001$]. Of greatest significance, there was no effect of bias condition on post-exposure threshold. Figure 3 depicts the shift in threshold (using difference scores) from pre- to post-exposure for both the test odorant and the control odorant. Exposure to isobornyl acetate significantly raised detection thresholds to isobornyl acetate ($P < 0.01$), but this loss of sensitivity was comparable across all bias conditions.

Thresholds for the control odorant were significantly lowered during the post-exposure test ($P < 0.01$). This apparent increase in sensitivity is a common occurrence after repeated testing, and may reflect some degree of perceptual learning about the odorant stimulus (Rabin and Cain, 1986; Dalton and Wysocki, 1996). The most important observation from these data, however, is that the cognitive bias condition influenced judgements of supra-threshold intensity but did not affect threshold sensitivity.

As a manipulation check, immediately prior to debriefing, subjects were asked whether they believed the odor to which they had been exposed was hazardous to health. The percentage of individuals in the positive, negative and neutral conditions that reported believing the odor was hazardous was 8, 75 and 42% respectively.

Discussion

The two experiments reported here present convincing evidence that the perceived intensity of clearly supra-threshold odors can be influenced by factors that promote a cognitive or 'top-down' processing of odor information. These results are consistent with previous studies that have examined the role of expectation on odor perception (e.g. Slosson, 1899; Engen, 1972; O'Mahoney, 1978; Knasko *et al.*, 1990). By demonstrating that an effective 'top-down' influence on odor perception is the perceived risk or hazard from an odor exposure, the present study illustrates the importance of non-sensory influences on odor perception.

Several potential mechanisms of cognitive influence on sensory experience have been suggested in previous studies (O'Mahoney, 1978; Knasko *et al.*, 1990) that may be applicable to the present findings. First, information about the toxicity of the odor may have changed a subject's criterion for reporting an odor's intensity. Numerous studies employing the methods of signal detection theory (Broadbent, 1971) have shown that expectations about the stimulus can shift apparent thresholds simply by altering the subject's motivation to report the presence/absence of a stimulus. Second, information about the potential toxicity of an odor during exposure may have produced changes in the allocation of attentional resources, from the visual or auditory domain to the chemosensory. If so, monitoring of the always 'noisy' background odor level could have enhanced the perceptual experience of odor. Alternatively, varying levels of arousal or stress, induced by exposure to a 'perceived toxin' in the present study, could have produced differences in perceived odor intensity among groups given different odor characterization. A relationship between stress and olfactory function has been suggested previously (Schneider, 1967). In two studies, inhibition of olfactory adaptation and elevated olfactory sensitivity (hyperosmia) were observed among individuals reporting high levels of anxiety or stress (Rovee *et al.*, 1973; Schneider, 1974). In the current study, stress may have been present for individuals in the negative or even the neutral bias condition at levels that exceeded those in the positive bias condition. However, because stress was not measured, either behaviorally or physiologically, in the present study, it remains a variable in need of further investigation.

An interesting issue raised in the present study concerns whether the observed effect of odorant characterization on perceived intensity depends upon the 'malleability' of the odorant. Isobornyl acetate was selected based on its malleability in experiment 1; rankings of isobornyl acetate changed from healthy to hazardous, depending on the instructional context in which the ranking was made. Presumably, this could have occurred because the odorant (and its source) was less familiar to participants than the other odorants. From comments the subjects made while ranking the odors in experiment 1, it appeared that most of the ambiguous odors (e.g. PEA, amyl acetate, isobornyl acetate) were judged as much less familiar than the odors that were normatively ranked healthy or hazardous. It will obviously be of importance to examine whether cognitive factors can exert a similar influence on the perception of odorants whose perceived characters are less dependent upon the situational context.

The outcome of this study is mirrored in many real-world situations, where individuals report considerable sensory annoyance (e.g. unpleasant odor, irritation, headache) from a perceived toxic exposure (Lees-Haley and Brown, 1992). Many of these reports are mediated by the occurrence of unfamiliar odors. Although most individuals who receive prolonged exposure to an ambient odor in a residential or occupational environment adapt to the odor, some individuals not only fail to adapt but may report increased sensitivity (Buchwald, 1972; McClelland *et al.*, 1990). Not surprisingly, for those who do not adapt, the presence of the odor becomes a stressor and elicits health symptoms and concerns (Buchwald, 1972; Cavalini *et al.*, 1991). In fact, perceived odor is the most significant correlate of perceived health risk for individuals whose neighborhoods have been sprayed with pesticide (Ames *et al.*, 1993), or who are living near landfills (McClelland, Schulze and Hurd, 1990) or near factories thought to be the source of pollution (Cavalini *et al.*, 1991). This study presents evidence to support a relationship between the perception of risk from an odor and odor intensity.

The findings are relevant to interpreting variation in odor perception in the laboratory as well as the real world. It is quite common that experimental subjects receive only limited information about the stimuli to which they will be exposed. In such circumstances, as in the neutral bias condition of experiment 2, subjects' responses may reflect the tacit perceptions and beliefs that they bring with them to the experimental situation—factors that are well beyond the control of the experimenter. The results of experiment 2 suggest that providing the same information to all experimental participants about the stimuli to which they will be exposed can reduce the influence of subjects' pre-existing biases and attitudes.

The present results also have important implications for remedying situations where unfamiliar odors produce discomfort and apparent illness, e.g. by reassuring exposed individuals about the benign nature of the odor source. Such situations are many and varied. The mere presence of an unfamiliar or unpleasant odor has been shown to increase symptom reporting (Smith *et al.*, 1978; Roht *et al.*, 1985; Alexander and Fedoruk, 1986; Neutra *et al.*, 1991; Stahl and Lebedun, 1996), as can an 'imagined' ambient malodor (Knasko *et al.*, 1990). In a recent review, >50% of the documented outbreaks of psychogenic illness (the collective occurrence of physical symptoms and related beliefs among two or more persons in the absence of an identifiable pathogen) were triggered by the appearance of an unidentified odor (Colligan and Murphy, 1982). Lingering, unidentified odors, albeit at low levels, are a dominant feature of 'sick building syndrome', in which individuals report health symptoms that they attribute to features of the environment, including air quality, carpets or furniture (Finnegan *et al.*, 1984). With increasing frequency, exposure to environmental odors appears to be spawning perceived health consequences. The most extreme example of this is the syndrome of multiple chemical sensitivity (MCS), a constellation of symptoms characterized by heightened responsiveness to chemical exposures at levels that are not annoying to most other people (Brodsky, 1983; Terr, 1986). Currently, no consensus exists among the medical community as to whether MCS or SBS are examples of pyschogenic illness or represent immunological/allergic responses. However, individuals who suffer from either condition often report a magnified perceptual response to odors (Bell *et al.*, 1993; Kurtz *et al.*, 1993).

It is significant to note that although health symptoms were not assessed following exposure, thirteen individuals spontaneously reported headaches, lethargy, dizziness or irritation from the odorant exposure. All but two of these individuals were in the negative bias condition, with the remaining two in the neutral condition. No individuals from the positive condition reported odor-associated symptoms. Higher symptom frequency following exposure to unpleasant (feigned or real) odors has been observed in other studies where symptoms were explicitly surveyed (e.g. Knasko *et al.*, 1990; Hudnell *et al.*, 1992; Knasko, 1992). In the present study, the spontaneous nature of the symptom complaints to the experimenter is a striking indicator of how readily people will attribute health problems to an ambient odor that they believe is hazardous.

The relationship between perceived health risk and odor perception also has implications for environmental regulators and industry. The perceived risk of exposure to hazard can be a crucial factor guiding the reaction or response to toxic spills, occupational accidents or incidental exposure to chemicals in the environment (Lees-Haley and Brown, 1992). Similarly, the perceptions of health risk that accompany environmental odors can fuel public demands for remediation even when experts judge the risk from exposure to be minimal or non-existent (Roht *et al.*, 1985; Miedema and Ham, 1988; Neutra *et al.*, 1991). Successful remedies for odor annoyance problems may be contingent on identifying whether the concern stems from sensory ('bottom-up') properties of the odorant or cognitive ('top-down') factors associated with the odorant.

As the present analysis has revealed, variation in the perception intensity of odors can result from the explicit characterization given to the odor. This outcome lends considerable support to the position that odor perception is both a sensory and a cognitive task (Kirk-Smith and Booth, 1987; Corwin, 1992; Booth, 1996). Incorporating a perspective from information-processing theories of cognition and perception in olfactory research can be a useful adjunct to the study of human perception of environmental odors, in both laboratory and natural environments.

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