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Impact of Health-Risk Perception on Odor Perception and Cognitive Performance

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Abstract Indications of adverse effects of nontoxic malodorous chemical exposure on work performance and safety and the role of health-risk perception on odor perception motivated the present study of the impact of health-risk perception on odor perception and cognitive performance. Healthy young adults were informed that they were to be exposed to an odorous substance that is either potentially health-enhancing (positive information bias, n=24) or hazardous (negative information bias, n=25). The two groups, screened for loss in odor-detection sensitivity, were matched for age, sex, chemical intolerance, and negative affectivity. During each of 14 trials of exposure to 433 mg/m^3 of n-butanol, the participants rated the intensity and valence of odor perception and performed a cognitive task that taxed working memory and attention. The results showed that the negative-bias group rated the odor perception as more unpleasant than did the positive-bias group during the entire session, but significantly more unpleasant only during the first half of the session. The negative-bias group was also found to perform significantly poorer on the cognitive task during both halves of the session. No effect of information bias was found on perceived odor intensity. The results provide experimental support for the hypotheses that belief that exposure to an odorous chemical is hazardous contributes to the odor perception being more unpleasant and to poorer cognitive performance.

Keywords Indoor air quality · Information bias · Odor hedonics · Odor intensity · Olfaction

Introduction

Health problems and adverse effects on work performance due to poor indoor air quality are considerable. Experimental studies suggest that exposure to nontoxic malodorous chemicals at workplaces may interfere negatively with work performance (van Thriel et al. 2003, 2007; Österberg et al. 2003, 2004) and possibly cause safety risks (Dick and Ahlers 1998; Rohlman et al. 2008). These occupational and public health issues can result in adverse impact on quality of life for the afflicted individual and are costly for society. Estimates for the USA alone suggest costs of US$10–20 billion from sick building syndrome symptoms (also referred to as nonspecific building-related symptoms). Additional costs of US$12–125 billion have been estimated for effects on work performance that are unrelated to health (Fisk and Rosenfeld 1997).

Apart from the effects of microbial volatile organic compounds on eye and upper airway irritation at relatively high concentrations, it has not been possible to demonstrate that nonspecific building-related symptoms are caused by organic compounds at concentrations measured indoors (Korpi et al. 2009). Epidemiological studies show that exposure to nontoxic substances evokes annoyance due to its odorous and sensory-irritating properties and results in a variety of health effects (e.g., Neutra et al. 1991; Shusterman 1992).

Importantly, reactions to factors in the environment vary considerably between individuals. Whereas some show no adverse reactions, others show reactions ranging from annoyance to intolerable health symptoms and poor cognitive performance, despite very similar exposure. The mechanisms underlying health effects and reduced productivity from nontoxic odorous/pungent exposure are not well known. The picture seems to be far more complex than a simple exposure–symptom relationship. Hence, there is a reason to believe that factors related to the individual are critical for effects on health and performance.

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The nasal chemical senses appear to play a role in the relation between chemical exposure and health symptoms (Shusterman 2001, 2002; Claeson et al. 2008) and, possibly, also performance. The chemesthetic sensory system is activated by irritants and thus constitutes a chemical warning system that triggers protective physiological reflexes, making the individual alert for danger and starts flight behavior (Cain 1988). Olfaction is also a warning system, suggested to evoke stress under certain conditions. It is commonly claimed that its main task is to direct attention to the odorous source and, by integration with beliefs of the chemical exposure, guide the individual to avoid or approach the source (Engen 1991; Stevenson 2010). It is reasonable to assume that in those cases when the individual believes that the source is hazardous, the odor will evoke negative emotions and increase arousal by activating the autonomic nervous system to evoke stress responses (Djordjevic et al. 2008). This would increase the likelihood of behavioral avoidance of the source. Such a belief can be referred to as health-risk perception. Its impact on how we relate to the environment can be described as top-down processing (Neisser 1967) and can be considered a characteristic feature of olfaction (Dalton 2012). Pidgeon et al. (1992) define risk perceptions as "people's beliefs, attitudes, judgments and feelings, as well as the wider social or cultural values and dispositions that people adopt, towards hazards and their benefits."

Support for the roles of chemosensory perception and health-risk perception in affecting health and performance is provided by data from an epidemiological residential survey of health effects from nontoxic odorous air pollution (Claeson et al. 2013). The results suggest that neither symptoms nor annoyance is directly related to air pollution. Instead, symptoms and annoyance are dependent on the odor pollution being perceived and on the individual believing that the exposure is hazardous. Additional epidemiological data lend further support for the importance of these two factors (Lipscomb et al. 1991; Shusterman et al. 1991). Similar findings have been obtained for air pollution of dust and soot (Stenlund et al. 2009).

The role of health-risk perception has also been demonstrated in controlled experimental trials. In a series of laboratory studies, Dalton and collaborators have shown that informing naïve participants that the chemical exposure is potentially hazardous results in increased perceived chemosensory intensity and more health symptoms compared to participants being informed that the chemical exposure is potentially health-enhancing (Dalton 1996, 1999; Dalton et al. 1997). However, the effects refer predominantly to chemesthetic rather than olfactory stimuli. Moreover, perceived odor intensity does not always seem to be affected by information bias (Kobayashi et al. 2008). Djordjevic and associates (2008) reported that presenting odorants with a negative name (e.g., rotten fish), instead of a positive name (e.g., sea weed), resulted in the odor perception being rated as more unpleasant and intense. They also reported that the effect on unpleasantness was stronger than the effect on intensity. With this in mind, health-related information bias with a paradigm used by Dalton (hazardous vs. health enhancing) is likely to predominantly impact odor valence.

Health-related information bias may also have an effect on cognitive performance. Thus, if the exposure is perceived as hazardous, it may evoke a negative emotion. This, in turn, may negatively influence odor valence (Pollatos et al. 2007) and direct attention to the odor perception. As a result, the individual may pay less attention to the task at hand, leading to reduced task performance.

There is at date no documentation of health-related information bias on odor valence and cognitive performance. The objectives of the present study were therefore to investigate the effect of health-risk perception on odor valence and cognitive performance as well as on odor intensity for comparison. It was hypothesized that belief of the chemical exposure being hazardous, instead of being health-enhancing, would (1) increase the unpleasantness of the odor perception and (2) have a negative impact on cognitive performance (working memory). As the effect of information bias on chemosensory intensity has previously been shown to differ between parts of the test session (Dalton 1996, 1999), we compared the first and second halves of the sessions. Health-risk perception was manipulated experimentally by informing participants that the chemical exposure was either potentially health-enhancing or hazardous. To ensure that olfaction rather than the chemesthetic sensory system was investigated and that an ecologically valid exposure was applied (e.g., for work places), a fairly low concentration of an odorous substance was used.

Material and Methods

Participants

Forty-nine healthy participants ranging in age between 18 and 33 years were recruited by means of advertisement. The participants were screened for tobacco use, pregnancy, asthma and allergy, and self-reported loss in olfactory sensitivity. They were also screened for anosmia with a simplified version of the Connecticut Chemosensory Clinical Research Center (CCCRC) threshold test which has *n*-butanol as the test odorant (Cain 1989). The simplified version describes the participants in terms of normosmia, hyposmia, or anosmia with respect to odor-detection sensitivity. Hyposmia was defined as detecting butanol dilution step 2 (336 ppm) but not dilution step 6 (0.58 ppm), diluted in deionized water, and anosmia was defined as not detecting dilution step 2 (336 ppm). The vapor phase concentration of *n*-butanol was calculated according to the method of Cometto-Muniz et al. (2003).

Chemical intolerance (hypersensitivity to odorous/irritating substances) and negative affectivity (Dalton 2002; Smeets and Dalton 2005) have been shown to affect odor perception, and chemical intolerance, ability to ignore chemosensory stimuli (Andersson et al. 2009). Regarding such effects, none of the participants reported having been diagnosed with multiple chemical sensitivity, nonspecific building-related symptoms, generalized anxiety disorder, depression, or burnout syndrome. Participants with temporary illness (e.g., colds) were rescheduled.

The participants were randomly assigned to either being given positive (n=24) or negative (n=25) information bias regarding the chemical exposure. The two groups are described in Table 1 with respect to affective reactions to and behavioral disruptions by odorous/pungent substances (Chemical Sensitivity Scale) (Nordin et al. 2003), anxiety and depression (Hospital Anxiety and Depression Scale) (Zigmond and Snaith 1983), perceived stress (Perceived Stress Scale) (Cohen et al. 1983), and worry about the impact of environmental and technological aspects on personal health (Modern Health Worries Scale) (Petrie et al. 2001). On average, the participants in the two groups were 0.46 SD below the normative score on the Chemical Sensitivity Scale for young adults (Nordin et al. 2004), providing further support for the groups not being chemically intolerant. The participants are also categorized in Table 1 as normosmic or hyposmic (CCCRC threshold test) (Cain 1989). Ambient temperature and relative humidity during the test session are also given in Table 1. One-way analyses of variance (ANOVAs) and χ^2 tests showed no significant differences between the two groups on any of the variables in Table 1 (p>0.1).

Odorous Exposure

Four identical 500-mL glass bottles were used with 100 ml of a dilution (distilled and deionized water) of n-butanol that generated a concentration in the air space of 433 mg/m^3 (143 ppm) of n-butanol. The vapor phase concentration of n-butanol was calculated following a procedure proposed by Cometto-Muniz et al. (2003). The dosage of n-butanol in the present study (28 inhalations of 143 ppm) is approximately 4.6 % of the dosage corresponding to the Swedish threshold limit value for occupational health purposes (AFS 2011) based on 12 inhalations per minute. The concentration was set to be moderate in perceived intensity, yet was below the detection threshold for nasal pungency of 912 ppm (Cometto-Muniz et al. 2000). All bottles were equipped with two-way polyethene/polypropylene valves, silicone rubber/polycarbonate respirator masks (Respironics Contour Mask^{TM}), and silicone rubber stoppers.

Ratings of Odor Perception

Perceived odor intensity and odor valence were rated with the Labeled Magnitude Scale. This scale consists of a verbally labeled line with quasi-logarithmic spacing between each label of descriptive adjectives describing different intensities (e.g., "weak" and "moderate"). The participant is instructed to place a mark on the line corresponding to the perceived magnitude (Green et al. 1993). The verbal anchors are spaced based on calibration using ratio scaling. For valence, the participant also reported whether the valence was pleasant or unpleasant.

Table 1 Description (mean±SD) of the participants in the positive and negative information-bias groups and of the ambient air during the test session

	Positive bias (n=24)	Negative bias (n=25)
Age (years)	23.7±3.4	24.0±2.2
Sex (n, women/men)	12/12	11/14
Affective/behavioral impact of odorous/pungent substances[a]	54.9±11.7	54.2±13.9
Anxiety[b]	6.04±3.75	5.84±2.98
Depression[b]	2.92±2.21	2.92±3.28
Perceived stress[c]	20.8±2.4	21.5±3.3
Modern health worries[d]	60.8±22.6	55.7±18.8
Butanol odor-detection sensitivity[e] (n; normosmic/hyposmic)	15/9	16/9
Ambient temperature (°C)	22.5±0.7	22.4±0.6
Ambient relative humidity (%)	19.4±2.5	19.1±2.0

[a] Chemical Sensitivity Scale (Nordin et al. 2003)

[b] Hospital Anxiety and Depression Scale (Zigmond and Snaith 1983)

[c] Perceived Stress Scale (Cohen et al. 1983)

[d] Modern Health Worries Scale (Petrie et al. 2001)

[e] Connecticut Chemosensory Clinical Research Center Threshold Test (Cain 1989)

Cognitive Task

The task was a plus/minus task based on Jersild (1927) and can be considered a task of working memory (Monsell 2003), but it was assumed to be related to general cognitive performance. The task consisted of performing as many correct arithmetic calculations as possible for 30 s by shifting between adding and subtracting seven from a list of two-digit numbers. Each of 14 lists of numbers given to the participant was different, but the set of 14 lists and their order were identical for each participant.

Information Bias

The information about the chemical exposure was provided prior to the exposure session by having the participant read information about the stimulus. To establish positive information bias, the following text was used: "The stimulus is a natural scent that is an alcohol, used for producing ethereal oils. It has in prior research been described as a substance with relaxing properties. Butanol is found in boiled rice and fermented corn. It is used as a natural taste enhancer in certain types of beer, ice cream and pastries." The following text was used for negative information bias: "The stimulus is a chemical solvent that is a petrochemical product from propylene, and used industrially as brake fluid, thinner, and for wood impregnation." Due to the diverse use of *n*-butanol, both the positive and negative information about the substance is in fact true.

Procedure

All participants were tested individually. Seated in a comfortable armchair, the participant was handed a bottle, placed its respirator mask over the nose and mouth, and took a deep sniff (approximately 1 s) with closed mouth. Directly following the sniff, the participant performed the cognitive shifting task for 30 s. The participant was thereafter again handed a bottle for another sniff. Directly following this second sniff, the participant first rated the intensity and then the valence of odor perception. This cycle was repeated seven times (part 1: trials 1–7), followed by a 10-min break, and then by seven additional cycles (part 2: trials 8–14). The interval between cycle onset was approximately 45 s, and the entire exposure session lasted for about 20 min. The participant was told that the stimulus may vary in concentration (although the concentration in fact was the same throughout the session). The four bottles used were alternated to ensure saturation of the air space before a sniff. They were concealed to the participant when not being used to avoid revealing the number of bottles, which may have affected the participant's belief of the number of different concentrations. The study was approved by the Umeå Regional Ethics Board, and all participants gave their informed consent to participate.

Statistical Analysis

For each of the variables, perceived odor intensity, odor valence, and cognitive performance (number of correct calculations), the values for trials 1–7 and 8–14 were averaged to provide values representing parts 1 and 2, respectively, of the session. Mixed-model two-way ANOVAs with information-bias group (bias: positive vs. negative) as a between-subject factor and session part (part: 1 vs. 2) as a within-subject factor were conducted separately for the data on odor intensity, odor valence, and cognitive performance. The α level was set at 0.05.

Results

The two information-bias groups were similar in their ratings of odor intensity and gave lower ratings as the exposure proceeded, as depicted in Fig. 1. This is supported by the results from ANOVA, yielding a main effect of part, but no main effect of bias, and no bias × part interaction (Table 2). Whereas the positive-bias group rated the odor perception as rather neutral in valence across the entire session, the negative-bias group rated the perception initially as clearly unpleasant but approached the positive-bias group towards less unpleasantness as the session proceeded (Fig. 2). Indeed, ANOVA showed no main effects of either bias or part, but a significant bias × part interaction (Table 2). Post hoc one-way ANOVAs for odor valence showed a significant group difference for part 1 (F=4.92, p<0.05), but not for part 2 (F=1.39, not significant). The number of correct calculations in the cognitive task was consistently lower in the negative-bias group than in the positive-bias group, with generally higher number in the second compared to the first half (Fig. 3). Accordingly, ANOVA yielded significant main effects of bias and part, but no bias × part interaction (Table 2).

Discussion

The present study tested the hypotheses that belief of the chemical exposure being hazardous, instead of being health-enhancing, would increase the unpleasantness of the odor perception and have a negative impact on cognitive performance. These hypotheses were, to a large extent, empirically supported. Thus, the health-related negative-bias group rated the odor as significantly more unpleasant than did the positive-bias group during the first half of the session (but not the second half), and the negative-bias group performed significantly poorer than the positive-bias group on the cognitive task on both session halves. These group differences are not likely to be explained by differences in age, sex, chemical intolerance, negative affectivity, or odor detection sensitivity for the

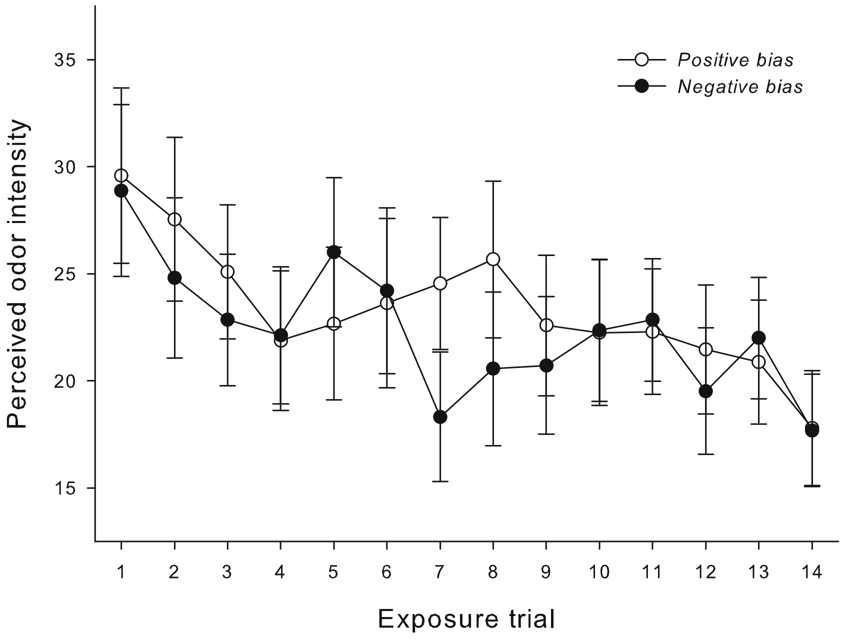

Fig. 1 Mean (±SE) ratings of perceived odor intensity for each information-bias group across exposure trials

substance used (*n*-butanol, Table 1). However, the fact that the unpleasantness ratings for the negative-bias group decreased over the first half of the session may partly be explained by the decrease in perceived intensity. The lists of numbers given to the participants for the cognitive task differed across the 14 sessions, which is likely to have generated differences across lists also in difficulty in performing the task (e.g., some numbers are easier than other from which to subtract seven). Importantly, the set of 14 lists and their order were identical for each participant in both bias groups. This can explain the strikingly parallel performance on the cognitive task between the two bias groups, albeit a generally poorer performance in the negative-bias group.

In contrast to odor valence, no effect of information bias was found on perceived odor intensity. This distinction is in agreement with prior results for which odorants were presented with a positive vs. negative name (Djordjevic et al. 2008). It is reasonable considering that valence, and not intensity, is the most important perceptual dimension in olfaction (Richardson and Zucco 1989). The consistently lower ratings for odor intensity as the exposure proceeded can be explained by habituation, which is a characteristic feature of olfaction (Engen 1991). The results suggest that healthy persons without chemical intolerance and negative affectivity, who believe that the exposure is potentially hazardous, leads to the odor being perceived as more unpleasant and to poorer cognitive performance, irrespective of whether the exposure is actually toxic or not.

Table 2 *F* values from two-way analyses of variance with information bias and part of the session as factors

	Odor intensity	Odor valence	Cognitive task
Bias	0.07ns	3.27ns	4.89*
Part	9.77**	1.35ns	108.98***
Bias × part	0.01ns	4.09*	1.93ns

ns nonsignificant

*$p<0.05$; **$p<0.01$; ***$p<0.001$

Notably, the *n*-butanol concentration in the present study (143 ppm) was set to be clearly below the detection threshold for nasal pungency (912 ppm) (Cometto-Muniz et al. 2000). Importantly, health-risk perception appears to have an impact on perceived chemesthetic intensity. Dalton and associates (1997) found effects for the irritant acetone, but not for the nonirritant phenylethyl alcohol. This implies that irritation intensity may be more sensitive than odor intensity to the impact of health-risk perception.

Regarding the effect of health-risk perception on cognitive performance, Rohlman and collaborators (2008) postulate that malodors in particular may elicit an automatic call for attentional resources to evaluate the chemical working environment. Directing the attention towards significant stimuli across different modalities is needed for the individual to be aware of novel or threatening events from the environment and to disregard irrelevant stimuli. In this respect, they claim that malodors are biological signals of particular significance in our environment indicating potential health hazards. Thus, the odors have to be attended and, if believed to be dangerous, avoided. Andersson and colleagues (2009) reported results from electrophysiological brain recordings of event-related potentials, suggesting that persons with chemical intolerance have difficulties ignoring irritating and odorous stimuli. Persons with such intolerance also score high in health-risk perception for various aspects of environmental exposure, including air pollution (Bailer et al.

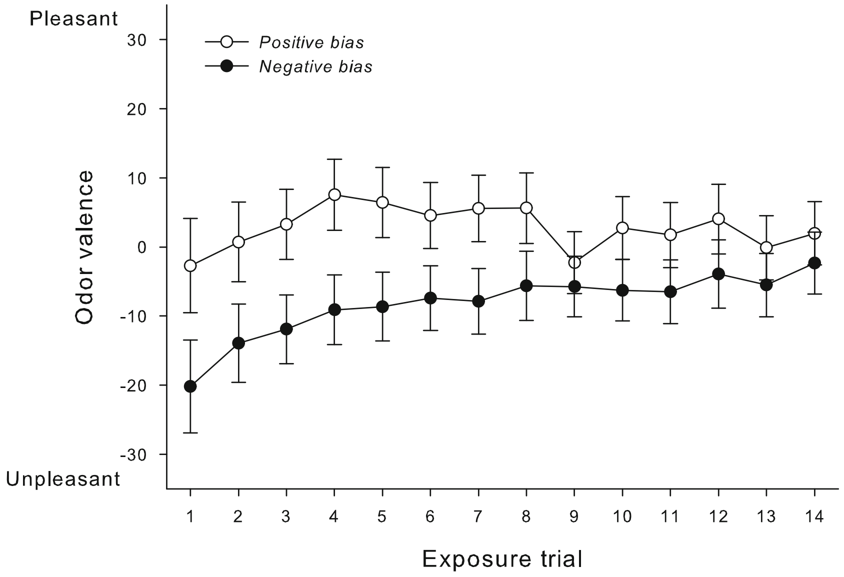

Fig. 2 Mean (±SE) ratings of odor valence for each information-bias group across exposure trials

2008). Not surprisingly, effects of odorous exposure on cognitive performance are particularly strong on persons with chemical intolerance (van Thriel et al. 2003, 2007; Österberg et al. 2003, 2004). Although the participants in the present study did not have chemical intolerance, it seems reasonable that the temporarily heightened health-risk perception that was experimentally induced resulted in difficulties ignoring the odorous exposure. Hence, attention may have been directed towards the odorous stimuli, making the individual pay less attention to the task at hand, leading to the compromised cognitive performance.

It is also reasonable to assume that state anxiety and worry evoked by belief of the exposure being hazardous, irrespective of whether an odorant is present or not, can distract the individual while performing a cognitive task. Lapointe and associates (2013) have recently shown that state anxiety is linked with impairment in cognitive performance, whereas worry is predominantly related to distractibility. Attentional bias toward threat was linked with variance common to both anxiety and worry.

The postulated tie between unpleasant odors (malodors) and their call for attentional resources with consequences for cognitive performance (Rohlman et al. 2008) is supported by the presented data, suggesting that health-risk perception is not only associated with poor cognitive performance but also with odor unpleasantness. Thus, the negative-bias group rated the odorous stimuli as more unpleasant than did the positive-bias group. The causal relation between health-risk perception

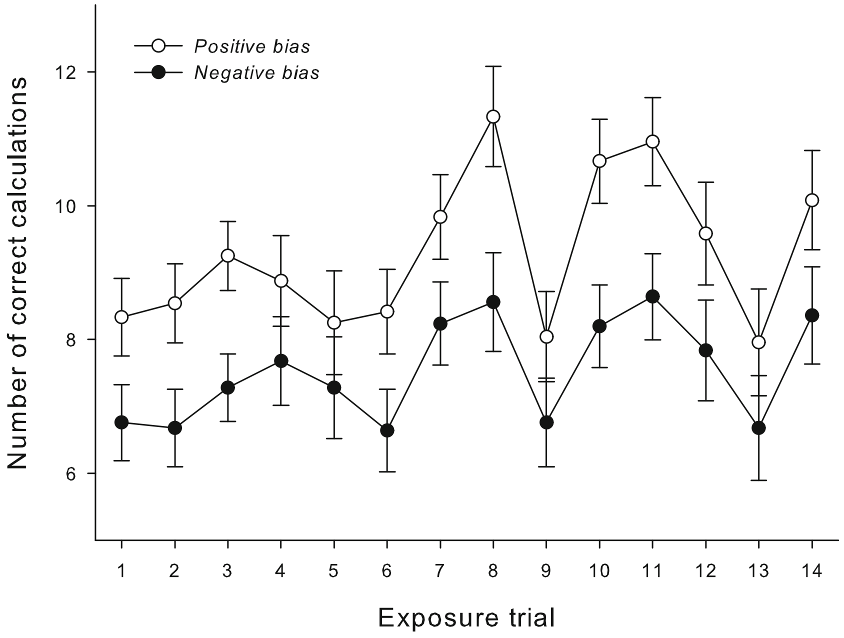

Fig. 3 Mean (±SE) number of correct arithmetic calculations for each information-bias group across exposure trials

and odor unpleasantness seems to function in both directions since odor unpleasantness may contribute to belief of the exposure being hazardous. Notably, odor unpleasantness was early shown to negatively affect cognitive performance (Rotton 1983).

Whereas the negative-bias group rated the odor perception as more unpleasant than did the positive-bias group throughout the entire test session, the group difference was statistically significant only for the first half of the session. The positive-bias group was rather stable throughout the session in rating the stimulus as neutral in valence. In contrast, the negative-bias group rated the stimulus as becoming less unpleasant as the exposure session proceeded and approached the ratings of the positive-bias group. It is conceivable that a lack of severe health symptoms during exposure, in combination with the participants not being chemically intolerant or high in negative affectivity, gradually contributed to a weakening of the health-risk perception among those with negative bias, resulting in the exposure being perceived as less unpleasant. The research field may gain from future studies on interaction effects between health-risk perception, chemical intolerance, and negative affectivity.

A limitation of the current study is the use of smell bottles. In contrast to continuous full-body exposure with an exposure chamber, intermittent stimulation does not provide a natural exposure condition, and the participant can choose to take weak or strong sniffs for exposure. Another limitation is that data on preexposure performance on the cognitive task were not collected. Thus, it cannot be excluded that the two information-bias groups differed in their predisposition to successful performance on this task.

Conclusions

In conclusion, the results provide support for the hypotheses that belief that the chemical exposure is potentially hazardous results in the odor being perceived as more unpleasant as well as in poorer cognitive performance. These findings, in combination with the limitations of the study, encourage further investigation of the impact of health-risk perception on chemosensory perception, health, and performance.

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Compliance with Ethics Requirements

Conflict of Interest Steven Nordin declares that he has no conflict of interest.

Anna-Sara Claeson declares that she has no conflict of interest.
Maria Andersson declares that she has no conflict of interest.
Louise Sommar declares that she has no conflict of interest.
Jakob Andrée declares that he has no conflict of interest.
Klas Lundqvist declares that he has no conflict of interest.
Linus Andersson declares that he has no conflict of interest.

All procedures followed were in accordance with the ethical standards of the Swedish Central Ethical Review Board and with the Helsinki Declaration of 1975, as revised in 2008. Informed consent was obtained from all participants for being included in the study.

References

AFS (2011) Hygieniska gränsvärden: Arbetsmiljöverkets föreskrifter och allmänna råd om hygieniska gränsvärden. Arbetsmiljöverkets författningssamling, AFS 2011:18. Stockholm, Sweden

Andersson L, Bende M, Millqvist E, Nordin S (2009) Attention bias and sensitization in chemical sensitivity. J Psychosom Res 66:407–416

Bailer J, Witthöft M, Rist F (2008) Modern health worries and idiopathic environmental intolerance. J Psychosom Res 65:425–433

Cain WS (1988) Olfaction. In: Atkinson RC, Herrnstein RJ, Lindzey G, Luce RD (eds) Handbook of experimental psychology. Perception and motivation, vol 1. Wiley, New York, pp 409–459

Cain WS (1989) Testing olfaction in a clinical setting. Ear, Nose Throat J 68:78–86

Claeson A-S, Lidén E, Nordin M, Nordin S (2013) The role of perceived pollution and health risk perception in annoyance and health symptoms: a population-based study of odorous air pollution. Int Arch Occup Environ Health 86:367–374

Claeson A-S, Nordin S, Sunesson A-L (2008) Effects on perceived air quality and symptoms of exposure to microbially produced metabolites and compounds emitted from damp building material. Indoor Air 19:102–112

Cohen S, Kamarck T, Mermelstein R (1983) A global measure of perceived stress. J Health Soc Behav 24:386–396

Cometto-Muñiz JE, Cain WS, Abraham MH (2003) Quantification of chemical vapors in chemosensory research. Chem Senses 28:467–477

Cometto-Muñiz JE, William CS, Hiraishi T, Abraham MH, Gola JMR (2000) Comparison of two stimulus-delivery systems for measurement of nasal pungency thresholds. Chem Senses 25:285–291

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

Dalton P (1999) Cognitive influences on health symptoms from acute chemical exposure. Health Psychol 18:579–590

Dalton P (2002) Odor, irritation and perception of health risk. Int Arch Occup Environ Health 75:283–290

Dalton P (2012) There's something in the air: effects of beliefs and expectations on response to environmental odors. In: Zucco GM, Herz R, Schaal B (eds) Olfactory cognition: from perception and memory to environmental odours and neuroscience. John Benjamins Publishing, Amsterdam, pp 23–38

Dalton P, Wysocki CJ, Brody MJ, Lawley HJ (1997) The influence of cognitive bias on the perceived odor, irritation and health symptoms from chemical exposure. Int Arch Occup Environmental Health 69:407–417

Dick RB, Ahlers H (1998) Chemicals in the workplace: incorporating human neurobehavioral testing into the regulatory process. Am J Ind Med 33:439–453

Djordjevic J, Lundstrom JN, Clément F, Boyle J, Pouliot S, Jones-Gotman M (2008) A rose by any other name: would it smell as sweet? J Neurophysiol 99:386–393

Engen T (1991) Odor sensation and memory. Prager Publishers, New York

Fisk WJ, Rosenfeld AH (1997) Estimates of improved productivity and health from better indoor environments. Indoor Air 7:158–172

Green BG, Shaffer GS, Gilmore MM (1993) Derivation and evaluation of a semantic scale of oral sensation magnitude with apparent ratio properties. Chem Senses 18:683–702

Jersild AT (1927) Mental set and shift. Arch Psychol 14:1–81

Kobayashi T, Sakai N, Kobayakawa T, Akiyama S, Toda H, Saito S (2008) Effects of cognitive factors on perceived odor intensity in adaptation/habituation processes: from 2 different odor presentation methods. Chem Senses 33:163–171

Korpi A, Järnberg J, Pasanen A-L (2009) Microbial volatile organic compounds. Crit Rev Toxicol 39:139–193

Lapointe M-L B, Blanchette I, Duclos M, Langlois F, Provencher MD, Tremblay S (2013) Attentional bias, distractibility and short-term memory in anxiety. Anxiety Stress Coping Int J 26:293–313

Lipscomb JA, Goldman LR, Satin KP, Smith DF, Vance WA, Neutra RR (1991) A follow-up study of the community near the McColl waste disposal site. Environ Health Perspect 94:15–24

Monsell S (2003) Task switching. Trends Cogn Sci 7:134–140

Neisser U (1967) Cognitive psychology. Prentice-Hall, New York

Neutra R, Lipscomb J, Satin K, Shusterman D (1991) Hypotheses to explain the higher symptom rates observed around hazardous waste sites. Environ Health Persp 94:31–38

Nordin S, Bende M, Millqvist E (2004) Normative data of the Chemical Sensitivity Scale. J Environ Psychol 24:399–403

Nordin S, Millqvist E, Löwhagen O, Bende M (2003) The Chemical Sensitivity Scale: psychometric properties and comparison with the Noise Sensitivity Scale. J Environ Psychol 23:357–365

Petrie K, Sivertsen B, Hysing M, Broadbent E, Moss-Morris R, Eriksen H, Ursin H (2001) Thoroughly modern worries: the relationship of worries about modernity to reported symptoms, health and medical care utilization. J Psychosom Res 51:395–401

Pidgeon N, Hood C, Jones D, Turner B, Gibson R (1992) Risk perception. In: Royal Society Study (ed) Risk: analysis, perception, and management. The Royal Society, London, pp 89–134

Pollatos O, Kopietz R, Linn J, Albrecht J, Sakar V, Anzinger A, Schandry R, Wiesmann M (2007) Emotional stimulation alters olfactory sensitivity and odor judgment. Chem Senses 32:583–589

Richardson JT, Zucco GM (1989) Cognition and olfaction: a review. Psychol Bull 105:352–360

Rohlman DS, Lucchini R, Anger WK, Bellinger DC, Christoph van Thriel C (2008) Neurobehavioral testing in human risk assessment. NeuroToxicol 29:556–567

Rotton J (1983) Affective and cognitive consequences of malodorous pollution. Appl Soc Psychol 4:171–191

Shusterman D (1992) Critical review: the health significance of environmental odor pollution. Arch Environ Health 47:76–87

Shusterman D (2001) Neurobehavioral testing in human risk assessment. Chem Senses 26:339–343

Shusterman D (2002) Review of the upper airway, including olfaction, as mediator of symptoms. Environ Health Perspect 110(suppl 4):649–653

Shusterman D, Lipscomb J, Neutra R, Satin K (1991) Symptom prevalence and odor-worry interaction near hazardous waste sites. Environ Health Perspect 94:25–30

Smeets MAM, Dalton PH (2005) Evaluating the human response to chemicals: odor, irritation and non-sensory factors. Environ Toxicol Pharmacol 19:581–588

Stenlund T, Lidén E, Andersson K, Garvill J, Nordin S (2009) Annoyance and health symptoms and their influencing factors: a population-based air pollution intervention study. Public Health 123:339–345

Stevenson RJ (2010) An initial evaluation of the functions of human olfaction. Chem Senses 35:3–20

van Thriel C, Kiesswetter E, Blaszkewicz M, Golka K, Seeber A (2003) Neurobehavioral effects during experimental exposure to 1-octanol and isopropanol. Scand J Work Environ Health 29:143–151

van Thriel C, Kiesswetter E, Schäper M, Blaszkewicz M, Golka K, Juran S, Kleinbeck S, Seeber A (2007) From neurotoxic to chemosensory effects: new insights on acute solvent neurotoxicity exemplified by acute effects of 2-ethylhexanol. NeuroToxicol 28:347–355

Zigmond AS, Snaith RP (1983) The hospital anxiety and depression scale. Acta Psychiatr Scand 67:361–370

Österberg K, Orbaek P, Karlson B, Akesson B, Bergendorf U (2003) Annoyance and performance during the experimental chemical challenge of subjects with multiple chemical sensitivity. Scand J Work Environ Health 29:40–50

Österberg K, Persson R, Karlson B, Orbaek P (2004) Annoyance and performance of three environmentally intolerant groups during experimental challenge with chemical odors. Scand J Work Environ Health 30:486–496