Chem. Senses 36: 641–648, 2011
doi:10.1093/chemse/bjr028
Advance Access publication April 19, 2011

Affected by Smells? Environmental Chemical Responsivity Predicts Odor Perception

Stina Cornell Kärnekull[1], Fredrik U. Jönsson[1,2], Maria Larsson[1,2] and Jonas K. Olofsson[1,2]

[1]Department of Psychology, Stockholm University, Stockholm, Sweden and [2]Stockholm Brain Institute, Stockholm, Sweden

Correspondence to be sent to: Jonas K. Olofsson, Department of Psychology, Stockholm University, SE 10691, Stockholm, Sweden. e-mail: jonas.olofsson@psychology.su.se

Accepted March 14, 2011

Abstract

Strong negative reactions, physical symptoms, and behavioral disruptions due to environmental odors are common in the adult population. We investigated relationships among such environmental chemosensory responsivity (CR), personality traits, affective states, and odor perception. Study 1 showed that CR and neuroticism were positively correlated in a sample of young adults (*n* = 101), suggesting that persons high in neuroticism respond more negatively to environmental odors. Study 2 explored the relationships among CR, noise responsivity (NR), neuroticism, and odor perception (i.e., pleasantness and intensity) in a subset of participants (*n* = 40). High CR was associated with high NR. Regression analyses indicated that high CR predicted higher odor intensity ratings and low olfactory threshold (high sensitivity) predicted lower pleasantness ratings. However, neuroticism was not directly associated with odor ratings or thresholds. Overall, the results suggest that CR and odor thresholds predict perceptual ratings of odors and that high CR is associated with nonchemosensory affective traits.

Key words: affect, chemical sensitivity scale, neuroticism, olfaction, perception, personality

Introduction

The responsiveness of the chemical senses varies greatly across individuals, but little is known about psychological and sensory variables that potentially make the world smell different to different people. Individuals who are most responsive to environmental odors often become clinically recognized as suffering from multiple chemical sensitivity, also called idiopathic environmental intolerance (MCS/IEI). It is a relatively common clinical diagnosis in western populations, with prevalence rates ranging between 0.5 and 6.3% (Kreutzer et al. 1999; Caress and Steinemann 2004; Hausteiner et al. 2005). There is no consensus regarding the etiology of MCS/IEI, and diagnosed individuals might react to a wide range of everyday chemical compounds, such as petrol, perfume, or pesticides (Das-Munshi et al. 2006). The evoked symptoms are diverse and include headache, fatigue, respiratory symptoms, dizziness, and/or nausea (Labarge and McCaffrey 2000).

Whereas previous research often focused on extremely responsive individuals, such as clinically established MCS/IEI, the present study addresses psychological variables associated with environmental chemosensory responsivity (CR) and olfactory perception in a nonclinical student sample. Research suggests that strong negative responses to everyday chemosensory exposures are common. The estimated prevalence of high CR in the adult population varies from 9 to 33% due to different assessment procedures (Kreutzer et al. 1999; Caress and Steinemann 2004; Hausteiner et al. 2005; Johansson et al 2005). CR may be determined by asking individuals whether they consider themselves to be allergic or unusually responsive to everyday chemicals (Kreutzer et al. 1999; Caress and Steinemann 2004) or by asking if strong odors (e.g., perfume, cleaning agents, or flower scents) bother them (Johansson et al. 2005). Furthermore, odor responsivity can be investigated with respect to affective and behavioral consequences (Nordin et al. 2003). Clearly, a rather large group of people are often negatively affected by everyday odors without having an MCS/IEI diagnosis. Individuals with high CR report frequent problems related to working life, social life and recreation, and using public transportation (for a review of findings, see Nordin et al. 2010). Previous work showed that individuals with high CR often avoid situations where they might be exposed to strong odors (Nordin et al. 2010). In other words, CR might have significant behavioral and social consequences. The detrimental effects of high CR on quality of life make it of interest to further characterize CR in terms of its associated psychological variables and underlying mechanisms.

Both physiological and psychological mechanisms have been proposed to explain CR. It has been suggested that individuals with a diagnosis of MCS/IEI exhibit an immunological dysfunction, which explains their hypersensitivity to chemical compounds (Labarge and McCaffrey 2000). A psychological perspective emphasizes the role of cognitive influences, conditioning, and psychiatric disorders on MCS/IEI. Conditioning to chemical stimuli might occur by associating odors in the environment (conditioned stimuli [CS]) with physical reactions (unconditioned response) due to an initial overexposure to an odor (unconditioned stimulus [US]; Labarge and McCaffrey 2000). Also, Van den Bergh et al. (2001) suggested that a stress-induced hyperventilation might function as unconditioned stimuli and that the association between the US and CS is determined by a range of cognitive and emotional variables.

Research shows that individuals diagnosed with MCS/IEI score higher on depression, anxiety, and somatization measures than controls (Bailer et al. 2004; Papo et al. 2006). It is not clear to what extent these relationships may be generalized to a broader, nonclinical population of individuals reporting high CR (Bailer et al. 2004; Papo et al. 2006). Given the above reviewed findings targeting the MCS/IEI population, we hypothesized that in a nonclinical sample of participants, higher CR would be associated with higher negative affectivity and neuroticism. Negative affect and neuroticism are positively correlated (e.g., r = 0.50; Meyer and Shack 1989), such that highly neurotic persons are more susceptible to negative affective states than individuals scoring low on neuroticism (Larsen and Ketelaar 1991). These constructs differ in that negative affect appears to cover a broader range of negative moods (e.g., ashamed, guilty, hostile, and afraid) than the personality trait neuroticism. Thus, the 2 concepts may capture different aspects of negative emotionality (however, see Clark et al. 1994).

Although high-CR individuals, with or without MCS/IEI, have unusually strong reactions to environmental odors, available evidence indicates normal olfactory functions as assessed by standardized tests. For example, odor thresholds do not differ according to CR (Doty et al. 1988; Caccappolo et al. 2000; Nordin et al. 2005). Evidence is yet scarce regarding whether perceptual experiences of odors covary with CR in a nonclinical population. Although the mechanisms of CR remain unclear, such information would further our understanding of factors involved in high nonclinical CR. General perceptual changes can be assessed in a controlled laboratory setting to explain differences in CR. A previous study showed that MCS/IEI persons made lower hedonic evaluations of common odors than controls (Ojima et al. 2002). Nordin et al. (2005) presented pyridine in 3 different concentrations by means of an olfactometer to high-CR individuals and reported that the group rated pyridine to be more intense, less pleasant, and more irritating irrespective of concentration as compared with a control group. However, since pyridine is a distinct pungent and unpleasant odor, it is yet unknown whether this perceptual effect generalizes across a variety of olfactory experiences.

The present work comprises 2 studies with the main objectives to 1) investigate the relationships between self-reported CR, personality traits, and affective states and to 2) examine the relationships between perceptual evaluations of odors (intensity and pleasantness) and CR. We hypothesized that higher CR would be associated with higher negative affectivity and higher neuroticism as well as predict higher unpleasantness and higher intensity ratings of odors independently of olfactory threshold.

Study 1

Materials and methods

Participants

A questionnaire consisting of several scales was completed by 103 students at the Department of Psychology at Stockholm University. Two participants were excluded from the study due to reported anosmia, leaving a final sample of 101 participants (55 females, 46 males; age M = 27.01 years, standard deviation [SD] = 8.12). The respondents were given either course credits or a cinema ticket voucher as compensation for the participation. The study was carried out in accordance with the ethical principles of the Declaration of Helsinki.

Questionnaire

The questionnaire was composed of scales addressing olfaction, affect, and personality. CR was determined by the Chemical Sensitivity Scale (CSS; Nordin et al. 2003), personality by the Big Five Inventory (BFI; John et al. 1991) and affectivity by the Positive and Negative Affect Schedule (PANAS; Watson et al. 1988).

The chemical sensitivity scale

The CSS consists of 21 items relating to the individual's experiences of negative affective reactions and behavioral disruptions due to odorous and/or pungent chemical substances from the environment (e.g., "At movies, other persons' perfumes and after shaves disturb me"). The majority of the items are statements to which the respondents evaluate the degree of agreement or disagreement on a 6 point Likert scale (0 = agree strongly, 5 = disagree strongly).

Some of the items were reversed before an individual total score (of maximum 104 points) was calculated, where a high score correspond to high CR. The CSS was developed to be analogous to the Noise Sensitivity Scale (NSS; Weinstein 1978), which examines negative affective reactions and behavioral disruptions due to noise in the environment. The CSS was sensitive enough to differentiate asthmatic/allergic individuals from controls, and it was demonstrated that the scale had good test-retest reliability and that it generated approximately normally distributed scores (Nordin et al. 2003).

The Big Five Inventory

The scale contains 44 items to measure the 5 personality dimensions of openness, conscientiousness, extraversion, agreeableness, and neuroticism. Ratings are made on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree) of how well the statements correspond to the individual's personality. Neuroticism, which was of primary interest in the current study, subsumes traits such as being tense, moody, and anxious. This personality dimension is negatively correlated with extraversion, which in turn is characterized by being talkative, assertive, and energetic (John and Srivastava 1999). Neuroticism and extraversion are considered to be the most fundamental personality traits (Draycott and Kline 1995). The BFI is frequently used in personality research settings, and previous work has reported a high reliability for this scale (John and Srivastava 1999).

The positive and negative affect schedule

This schedule consists of 20 items that measure to what extent the respondent has experienced positive and negative mood states during the last weeks. The ratings are made on a 5-point Likert scales (1 = very slightly or not at all, 5 = very much) for 10 positive affects (enthusiastic, interested, determined, excited, inspired, alert, strong, proud, active, and attentive) and 10 negative affects (scared, afraid, upset, distressed, jittery, nervous, ashamed, guilty, irritable, and hostile). An individual mean score for positive and negative affectivity is calculated, respectively. A previous evaluation showed a sufficiently high reliability for the scale (Watson et al. 1988).

Procedure

The participants were informed that the aim of the survey was to investigate their personal relations to odors in everyday life. Completion of the questionnaires took about 35 min. Participants were also informed that they might be contacted within the following weeks regarding participation in a follow-up study focusing on perceptual evaluations for a variety of odors.

Results and discussion

The Cronbach alpha reliability (r) was computed for the relevant scales and showed reliability estimates that were consistently high and comparable with those reported previously. The CSS yielded an r of 0.87; BFI yielded r:s ranging from 0.70 to 0.84 across the 5 factors; PANAS yielded 0.86 for negative affect and 0.77 for positive affect.

The level of CR in this sample ranged from 19 to 98 (CSS score M = 57.11, SD = 13.59). The objective of the survey was to investigate the relationships between CR, affective states, and personality traits. We hypothesized that CR would correlate positively to both negative affectivity and neuroticism. A Pearson correlation analysis was performed for the CSS, BFI personality traits, and PANAS affective states. As shown in Table 1, moderate positive correlations were found between CR and neuroticism and between neuroticism and negative affect. Furthermore, extraversion was positively correlated with positive affect and negatively with neuroticism. However, CR did not correlate reliably with negative affect. The personality variables extraversion, agreeableness, conscientiousness, and openness were uncorrelated with CR and are not discussed further.

The observed positive relationship between CR and neuroticism favors the notion that personality is related to nonclinical CR. Although no causal inferences may be drawn from the observed correlation, it is of interest to note from

Table 1 Intercorrelations among variables

Variables	1	2	3	4	5	6	7	8
1. Chemical responsivity	—							
2. Neuroticism	0.36**	—						
3. Extraversion	−0.05	−0.28**	—					
4. Agreeableness	−0.16	−0.37**	0.14	—				
5. Conscientiousness	0.16	−0.22*	0.20*	0.22*	—			
6. Openness	0.03	0.02	0.07	−0.06	−0.00	—		
7. Positive affect	0.13	−0.12	0.24*	0.01	0.32**	0.16	—	
8. Negative affect	0.09	0.54**	−0.09	0.40**	0.22*	−0.03	−0.05	—

*$P < 0.05$, **$P < 0.01$.

previous work that high neuroticism appears to be involved across a variety of heightened sensory sensitivities. For example, highly neurotic persons tend to be more sensitive to loud noise, unpleasant visual stimuli, and pain (Harkins et al. 1989; Wilson et al. 2000; Thomas and Jones 1982). This may reflect a general tendency of generating negative emotions to environmental stimuli. Furthermore, it has been proposed that neuroticism is related to a lower activation threshold in the limbic system, which may underlie enhanced negative emotions in high-neurotic persons (Rusting and Larsen 1997).

The current results showed no relationship between negative affectivity and CR. Even though negative affectivity and neuroticism were positively correlated, it is important to stress the differences between the 2 scales. The PANAS measures a wider range of negative affects, such as shame, fear, nervousness, and hostility, whereas the measure of neuroticism in the BFI emphasizes negative affects in the sense of being tense and anxious. Given that high CR, as operationalized here, reflects that the individual is negatively affected by chemosensory exposure, the current results show a specific association between CR and neuroticism that did not generalize to general negative affectivity. It is unclear whether these results, obtained with questionnaire data, also predict odor perception in a laboratory setting. In order to investigate whether CR, neuroticism, and olfactory detection sensitivity were related to odor perception, we conducted a follow-up behavioral experiment that is reported below.

Study 2

The study used CR, odor thresholds, and the personality dimension neuroticism to predict perceptual ratings of odor intensity and hedonics in a sample of healthy young participants, who were recruited randomly from the Study 1 sample. Furthermore, to investigate whether neuroticism correlated with environmental responsivity across sensory modalities, the NSS was included. Previous research has shown positive correlations between neuroticism and noise responsivity (NR), although results are mixed (e.g., Thomas and Jones 1982; Dornic and Ekehammar 1990; Campbell 1992). Multiple regression analyses were used to partition the variance from each predictor variable and compute their statistical relations to the variance in mean ratings of intensity and hedonics across a set of odors. Due to a limited sample size, we selected only a small set of independent variables for the multiple regression analysis (Tabachnick and Fidell 2007). The independent variables were motivated by the results of Study 1 indicating a relationship between neuroticism and CR.

We hypothesized that neuroticism and/or CR would predict higher intensity and unpleasantness ratings. Strong odors are more often perceived as more unpleasant, and we therefore expected a similar pattern of results for these 2 perceptual dimensions. Because neuroticism shared common variance with CR, it is important to partition the contributions from these variables to odor perception. An odor threshold assessment was included to control for potential effects of basic olfactory sensitivity in the sample and to screen for anosmia. In addition, questionnaires concerning 1) NR and 2) perceived physical symptoms were administered with the purpose of investigating their potential links to CR and to evaluate whether any physical symptoms would be elicited by the olfactory test. NR was expected to correlate highly with CR and moderately with neuroticism (Nordin et al. 2003). The degree of physical symptoms was expected to be positively correlated with CR.

Materials and methods

Participants

From the pool of 101 respondents in Study 1, 40 healthy participants were randomly selected for participation in Study 2. The sample comprised 21 females and 19 males (age M = 26.97 years, SD = 8.54). The level of CR (CSS score M = 56.80, SD = 13.68) did not differ from that of other participants in Study 1 (CSS score M = 57.31, SD = 13.63), as determined by an independent sample *t*-test, $t_{99} = -0.18$, $P = 0.85$. Participants were given course credits or 2 cinema ticket vouchers as compensation. The study was carried out in accordance with the ethical principles of the Declaration of Helsinki.

Questionnaire of perceived physical symptoms

This questionnaire measures to what extent the participant experiences a variety of physical and inner states at the moment. The ratings are made on a 5-point scale (1 = very slightly or not at all, 5 = very much) for 13 symptoms (fatigue, headache, nausea, trouble breathing through the nose, irritated nose, trouble breathing through the mouth, concentration difficulties, drowsiness, confusion, irritated eyes, tired eyes, irritated throat, and bad taste in mouth). In order to investigate if the presentation of odors produced physical symptoms in the participants, this scale was handed out before and after the exposure. The items were similar to those used in previous studies (Nordin et al. 2005; Laudien et al. 2007).

The noise sensitivity scale

The NSS (Weinstein 1978) is analogous to the CSS and consists of 21 items that measure the individual's experiences of negative affective reactions and behavioral disruptions due to noise in the environment (NR).

Assessment of odor threshold

Odor threshold was determined by exposing the participants to pairs of odorous pen-like sticks (Sniffin' Sticks; Hummel et al. 1997) with increasing concentration levels of *n*-butanol (total 16 concentrations). The procedure began at the lowest concentration level (pen 16). Each pair contained one odorous and one odorless stick. The sticks were presented approximately 2 cm under the nose of the participants every 15–20 s. The participants were instructed to report which one of the sticks that contained an odor while blindfolded with a sleeping mask. If they failed, a new pair of sticks with a higher concentration level was presented, without any feedback given. If 4 correct decisions were made in a row, that concentration level represented the individual's odor threshold.

Odor stimuli

A total of 32 odors comprised the perceptual evaluation test set. The odor items were selected such that half of the set should represent familiar everyday odors (e.g., vanilla) and the other half unfamiliar odors. We assumed that the odors would vary greatly with respect to hedonics, and there is usually a positive relationship between familiarity and pleasantness ratings (e.g., Sulmont et al. 2002). The 32 odors were divided in 2 sets, each consisting of 8 unfamiliar and 8 familiar odors. Within each set, the odors were presented according to 5 randomized lists. Each participant was randomly assigned to an odor set and lists. The odors were prepared in 160-mL opaque glass jars by injecting 10 mL on a cotton pad that in turn was covered by another pad. The odors are listed in Table 2.

Procedure

The participants were tested individually in a well-ventilated room. First, the participants completed the NSS and the physical symptoms questionnaires. Next, odor threshold was assessed. Then, the participants were presented with 1 of the 2 sets of 16 odors (sets were balanced across high and low CR) and evaluated them with regards to intensity and pleasantness. The experimenter held the odor jars approximately 5 cm under the participant's nose, and one sniff was allowed for each odor. To minimize effects of olfactory adaptation, an interstimulus interval of at least 20 s elapsed between each presentation. For each odor, ratings were performed for intensity (1 = not intense at all, 7 = very intense) and pleasantness (1 = very unpleasant, 7 = very pleasant). As a final task, subjects were requested to once again complete the questionnaire of physical symptoms. The session took approximately 30 min.

Results

The Cronbach alpha reliability (r) was computed for the scales used in Study 2 and showed high reliability scores for the questionnaire of perceived physical symptoms ($r = 0.76$ before and 0.82 after odor exposure), as well as for the NSS ($r = 0.87$).

A correlation analysis was performed to investigate the relationships among the key variables. As shown in Table 3, neuroticism was unrelated to both the hedonic and intensity ratings (Ps > 0.20). NR was positively correlated with CR, neuroticism, and intensity ratings of the odors. There was a marginally significant positive correlation between CR and intensity ratings ($P = 0.06$). To determine the unique influence of the key variables for the perception of intensity and hedonics, 2 linear regressions were performed. The analyses included odor threshold, CR, and neuroticism as predictor variables. Because NR was not of theoretical interest as a predictor of odor ratings, NR was not included in the regression analysis. As shown in Table 4, odor threshold significantly predicted hedonic ratings such that individuals with a high sensitivity rated odors as less pleasant. Intensity ratings were predicted by CR, such that individuals with higher CR rated odors as more intense compared with individuals with lower CR (Table 4). Furthermore, Pearson correlation analyses showed that CR was unrelated to the degree of physical symptoms, summed across all symptoms ($r_{38} = 0.12$, $P = 0.46$), as well as with odor threshold ($r_{38} = -0.18$, $P = 0.26$).

To investigate whether the relationship between CR and intensity ratings was influenced by odor hedonics, the odors were divided into one pleasant and one unpleasant odor set by means of a median split. Although the complete odor set showed a normal distribution of pleasantness ratings that ranged from 2.33 to 6.00 across odors (M = 4.06, SD = 1.02), the "pleasant odors" ranged from 4.19 to 6.00 (M = 4.91, SD = 0.61) and the "unpleasant odors" ranged from 2.33 to 4.00 (M = 3.20, SD = 0.47). The 2 odor sets differed significantly in average pleasantness ratings ($t_{30} = -8.84$, $P < 0.001$), as indicated by an independent samples t-test. Based on the individual CSS scores, the sample was split into 2 groups: low and high CR. The CSS scores ranged from 35 to 57 in the low-CR group (CSS M = 45.50, SD = 7.42) and from 58 to 88 in the low-CR group (CSS M = 68.10, SD = 7.78). An independent samples t-test showed a significant difference in CSS scores between the groups ($t_{38} = -9.40$, $P < 0.001$). The high-CR group included 13 females and 7 males (age M = 29.05, SD = 10.90), and the low-CR group comprised 8 females and 12 males (age M = 24.84, SD = 4.21). A 2 (CR group: high, low) × 2 (odor set: pleasant, unpleasant) mixed analysis of variance on odor intensity ratings showed significant main effects for CR group ($F_{1,38} = 6.75$, $P < 0.01$), and odor set ($F_{1,38} = 5.64$, $P = 0.02$) indicating that high CR and odor unpleasantness were associated with higher intensity ratings. However, the interaction between odor set and CR group was not significant ($F_{1,38} = 0.03$, $P = 0.87$).

General discussion

Our main aim was to investigate whether variation in CR is related to personality, affective states, and/or the perception of olfactory stimuli in young healthy participants. Overall, the results indicated that persons who scored high in CR also scored high in neuroticism, and NR, and perceived odors presented to them in a laboratory setting as more intense than persons scoring low on CR. Overall, unpleasant odors were perceived as more intense. Previous findings show that a negative odor name causes higher intensity ratings and lower pleasantness ratings in young healthy subjects (Djordjevic et al. 2008). However, the observation that odor intensity differed

Table 2 Test set of odors used in study 2

Name	Intensity (M, SD)	Pleasantness (M, SD)
2-Heptanone	5.37 (1.50)	3.11 (1.37)
2-Phenyl ethyl ethyl ether (PEE)[a]	5.24 (1.37)	3.14 (1.28)
2-Phenylethyl pentyl ether (PPE)[a]	4.89 (1.45)	2.63 (1.46)
3.7-Dimethyloctanenitrile (DON)[a]	4.58 (1.43)	3.42 (1.22)
Anise[b]	4.63 (1.57)	4.79 (1.81)
Bitter almond[b]	5.05 (1.16)	3.76 (1.51)
Bornyl acetate (BOR)[a]	5.10 (1.37)	4.00 (1.38)
Calone (7- Methyl (2H, 4H)-1.5, benzo-dioxepin-3-one) (CAL-25)	3.63 (1.80)	4.47 (1.43)
Caraway[b]	4.52 (1.57)	3.05 (1.43)
Cedarwood[b]	4.68 (1.34)	4.21 (1.55)
Chocolate[b]	4.95 (1.16)	5.33 (1.28)
Cinnamon[b]	6.63 (0.90)	2.53 (1.84)
Citrowanil (2-ethenyl-2-methyl benzene-propanal) (CIW)[a]	4.43 (1.12)	4.24 (1.34)
Clove[b]	4.89 (1.52)	3.16 (1.64)
Dec-9-en-1-ol (DEO)[a]	3.74 (1.73)	3.84 (0.96)
Elderflower[b]	5.14 (1.31)	5.52 (1.33)
Eucalyptus[b]	6.29 (0.78)	4.48 (1.36)
Heptanal	5.00 (1.30)	2.33 (1.06)
Heptyl acetate	5.00 (1.15)	4.79 (1.62)
Juniper Berry[b]	5.00 (1.25)	4.26 (1.59)
Lemon[b]	5.32 (0.75)	6.00 (0.67)
Lilac[b]	5.24 (1.34)	5.67 (1.11)
Menthyl acetate (19)[a]	4.14 (1.53)	4.48 (1.21)
Methyl benzoate (MBE)[a]	5.38 (1.36)	3.62 (1.56)
Octanol	4.48 (1.44)	3.00 (1.48)
Pine needle[b]	5.19 (1.17)	3.52 (1.03)
Plicatone (1.4-Methano-7-methyl-(2H)-octahydro naphtalene-6-one) (PLI-44)[a]	4.62 (1.07)	4.19 (1.03)
Rose[b]	4.47 (1.50)	5.42 (1.22)
Tridec-2-enenitrile (TDN)[a]	5.42 (1.22)	3.05 (1.72)
Vanilla[b]	4.48 (1.21)	5.67 (1.15)
Violet[b]	4.53 (1.43)	5.11 (1.15)
α pinene (hydrocarbon)	4.84 (1.42)	3.05 (1.43)

[a]Donated by the Department of Organic Chemistry at Stockholm University.
[b]Purchased from Essencefabriken, Stockholm.

but pleasantness was similar across the 2 CR groups suggests that the higher intensity perception among high CR individuals was not primarily driven by an altered hedonic perception in this group. Rather, we speculate that the intensified chemosensory perception in high CR individuals are mainly experienced as unpleasant in everyday life situations (e.g., in the movie theater) where the exposures are unpredictable, sustained, and difficult to control. Furthermore, the regression analysis revealed that persons who exhibited high olfactory sensitivity, as determined by an olfactory threshold test, also perceived the presented odors as less pleasant than persons who were less sensitive.

Table 3 Intercorrelations among variables

Variables	1	2	3	4	5	6
1. Chemical responsivity	—					
2. NR	0.76**	—				
3. Odor threshold	−0.18	−0.18	—			
4. Pleasantness	−0.09	−0.04	−0.29	—		
5. Intensity	0.30	0.32*	0.17	−0.31	—	
6. Neuroticism	0.46**	0.49**	−0.14	−0.16	−0.03	—

*$P < 0.05$, **$P < 0.01$.

Table 4 Multiple regression models for predicting perceived odor hedonics and odor intensity

	Odor hedonics		Odor intensity	
	β	*P*	β	*P*
1. Odor threshold	−0.33	0.05*	0.22	0.17
2. Chemical responsivity	−0.06	0.72	0.43	0.02*
3. Neuroticism	−0.17	0.33	−0.20	0.26

*$P < 0.05$.

As noted above, Nordin et al. (2005) reported that high-CR persons perceived pyridine as more intense, less pleasant, and more irritating than controls. The current study replicated and extended this observation by showing that intensity assessments are affected by CR also with a larger set of odors. However, in contrast to Nordin et al. (2005), our results indicated that CR was unrelated to perceived odor hedonics; this outcome discrepancy may be related to a more extreme variation in CR scores and a strong correlation between the perceived intensity and unpleasantness of pyridine in their study. It is possible that odor pleasantness ratings obtained in laboratory settings are mainly affected in extremely responsive individuals, such as clinically diagnosed MCS/IEI patients or when odorous air is injected into the nasal cavities of the subjects by means of a dynamic olfactometer, reducing the control of the participant over the stimulus delivery (Ojima et al. 2002; Nordin et al. 2005). Overall, the present and previous findings suggest that perceived olfactory hedonics and physical symptoms are affected primarily in individuals who experience a very high CR, whereas olfactory intensity is altered also in moderately high CR.

The results pertaining to personality indicated that neuroticism was positively and significantly correlated with CR, although the degree of neuroticism was unrelated to perceived olfactory intensity, hedonics, and odor thresholds. Evidence is mixed regarding the relationship between personality and olfactory threshold. In contrast to Koelega (1970) and the results from the current study, Pause et al. (1998) found a positive association between neuroticism and olfactory threshold. However, we are aware of no plausible psychobiological account to explain why olfactory threshold sensitivity should be heightened in highly neurotic individuals. The present results are also congruent with previous studies indicating no relationship between CR and olfactory threshold (Doty et al. 1988; Caccappolo et al. 2000; Nordin et al. 2005). A previous study showed that patients with high environmental responsivity to odors showed increased odor-evoked activity in anterior cingulate when compared with a control group (Hillert et al. 2007). This was interpreted as a top-down regulation of odor perception. The combined evidence suggests that emotional and/or cognitive factors, rather than sensory factors, underlie variation in CR.

The results also showed that NR was positively correlated to both CR and neuroticism, indicating that these traits covary in the population. Although not of primary interest in our study, we note that similarly to CR, NR was associated with odor intensity. This result further emphasizes the relationship among emotional responsiveness and the auditory and chemosensory modalities (Nordin et al. 2003).

The question why some people are more reactive than others to odorous chemicals in the environment requires further attention. It is very likely that complex interactions among personality factors and unique experiences are involved in developing chemical responsivity (Bell et al. 1993). Prevalence of CR increases from adolescence to adulthood and is correlated with NR and anxiety in adolescence, suggesting that modality-general and personality-related variables are important in the development of CR (Andersson et al. 2008). Among elderly, individuals with high CR reported having experienced higher life stress in early life (<40 years), suggesting that emotionally vulnerable individuals are prone to develop CR during this period (Bell et al. 1992). Longitudinal studies that span this critical period might provide a better understanding regarding the dynamic development of high environmental odor responsivity.

In summary, the current study shows that CR predicts ratings of intensity across both pleasant and unpleasant odors in a sample of young healthy adults. Also, a high degree of neuroticism was associated with a high CR and NR, suggesting that CR is but one aspect of a much broader phenotype.

Funding

The study was supported by a research grant from the Stockholm Brain Institute.

Acknowledgements

We thank the Department of Organic Chemistry, Stockholm University, for generously donating odors used in Study 2, and Claes Palm for excellent assistance in data collection.

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