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Olfactory perception is positively linked to anxiety in young adults

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Abstract. Olfactory abilities show a high degree of inter-individual variability and this could be partly related to personality differences. Here, in two studies, we tested a potential link between personality dimensions and olfactory perception. Sixty-eight (study 1) and a hundred and fifty-six (study 2) young adults completed the Big Five questionnaire and performed the Sniffin' Sticks test for assessing odour threshold, identification, and (in study 2) discrimination. In neither study did we find a significant link between personality dimensions and olfactory identification scores. However, in study 1, we found a significant positive correlation between the neuroticism dimension and olfactory sensitivity. This was mainly due to the anxiety and self-consciousness subscales, which load onto the neuroticism dimension. In a follow-up study, we again found a significant association between anxiety and odour perception, specifically in odour discrimination. Our results indicate that variability in anxiety could partly explain the high inter-individual variation in olfactory perception.

Keywords: Big Five, odour, olfactory identification, personality, Sniffin' Sticks, threshold, odour discrimination

1 Introduction

Humans use their sense of smell in various domains, particularly in food assessment (Sorensen et al 2003; Novakova et al 2012), avoiding dangerous chemicals (Stevenson 2010), and social interactions including mate choice (Havlicek et al 2008). Although olfactory abilities can be assessed in various ways, the most widely used measures involve the olfactory threshold (also referred to as olfactory sensitivity), odour discrimination, and odour identification. The olfactory threshold refers to the minimum concentration of a tested odorant that an individual is able to reliably differentiate from a blank sample. Odour discrimination is the ability to detect differences between odours and to identify which of a set of stimuli in comparable suprathreshold concentrations is different from the others. Finally, odour identification refers to correct verbal labeling of a given odour (for discussion about the veridicality of verbal labeling see Dubois and Rouby 2002). The major demographic predictor of all three abilities is age. As with many other sensory capacities, olfactory abilities, in general, decrease relatively constantly with age (Doty 1992). Further, results of twin studies suggest that, at least for some compounds, there is a relatively strong heritable component to threshold levels (Gross-Isseroff et al 1992). There is also a robust body of evidence indicating that, on average, women outperform their male counterparts in various odour tests (Brand and Millot 2001; Doty and Cameron 2009). However, even within each sex, there is also high inter-individual variability. Some of this variability could conceivably be related to the personality of the given individual.

The possibility that personality affects olfactory perception was first investigated more than 40 years ago by Koelega (1970). The work was theoretically grounded on Eysenck's three-dimensional personality model (extraversion, neuroticism, and psychoticism). According to this theory, extraverted individuals are marked by prevailing inhibitory processes and individuals scoring high on neuroticism by greater activity of the limbic system (Eysenck 1967). As olfaction is closely related to the limbic system, Koelega expected to find lower olfactory thresholds in neurotics and introverts. In a series of carefully controlled studies, he unexpectedly found lower thresholds in extraverts than in introverts, but no correlation with neuroticism. In a subsequent study by the same author, no general pattern between Eysenck's personality domains and sensitivity was observed (Koelega 1994). However, more recently, Pause et al (1998) reported a positive correlation between olfactory sensitivity and neuroticism in a group of men using the twelve-dimensional Freiburger Personality Inventory. Interestingly, it was recently shown that neuroticism score (assessed by the Big Five inventory) is positively associated with environmental chemosensory responsivity, but not with odour threshold (Cornell Kärnekull et al 2011).

Several other studies have tested the potential link between personality and odour identification. Odour identification was found to be positively related to a high level of neuroticism and openness to experience (Larsson et al 2000). In contrast, the same study found a negative correlation with impulsiveness and assertiveness. Furthermore, a positive relationship between an odour identification score and empathy (Mehrabian and Epstein Empathy Questionnaire) was reported (Spinella 2002).

The above-reviewed studies clearly indicate that a link between olfactory abilities and personality dimensions has not yet been conclusively established. One reason could be the highly variable number of personality measures used in previous studies. Recently, the most extensively used personality assessment tool has been the NEO-PI-R questionnaire, which is based on the Big Five personality model (eg McCrae and Costa 1997). It employs the following broad personality dimensions: neuroticism, extraversion, openness to experience, agreeableness, and conscientiousness. Each of the dimensions is further characterized by 6 subscales (Costa and McCrae 1997). Numerous studies carried out in various cultures and samples demonstrate the NEO-PI-R to be a suitable research tool for the assessment of inter-individual variability, including various aspects of perception (McCrae et al 1998; McCrae and Terracciano 2005; Schmitt et al 2007).

Based on previous findings and characteristics of personality domains, we predict more acute olfactory perception in individuals scoring high on neuroticism and conscientiousness, but no significant link with other Big Five domains. Neurotic individuals are characterised by greater irritability and high vigilance, which might be associated with lower sensory thresholds. On the other hand, conscientiousness is characterised by high self-control, orderliness, and perfectionism. Further, conscientiousness and some of its facets (C4: Achievement Striving and C5: Self-Discipline) tends to predict verbal fluency (Jensen-Campbell et al 2002; Sutin et al 2011). Consequently, one might predict a positive link with ability in odour identification, which also involves verbal fluency (Larsson et al 2005). In addition, we might expect that variation in relative dominance, although it is not included in the Big Five model as a separate dimension, might be of particular relevance. Recently, there has been a growing body of evidence that people are responsive (eg in the form of a startle response), to affective body odours (eg Pause et al 2009). This might be particularly true for individuals low in dominance, as they are more sensitive to potentially socially threatening situations.

Here we tested these predictions regarding possible links between inter-individual variation in olfactory acuity (using measures of odour sensitivity and identification) and personality domains. We controlled for a potential age-related decline in olfactory performance by using a sample of young adults.

2 Study 1

2.1 *Method*

2.1.1 *Participants.* The research sample consisted of 71 students (41 female and 30 male; mean age (SD) = 18.0 (±0.81) years; range 17–22 years) attending two mixed-sex Prague (Czech Republic) high schools. Two men did not complete a personality test and one woman did not finish an odour threshold test, thus leaving 68 participants for the main analysis. All participants were assured about confidential data treatment and none was paid for their participation. All work and data treatment were carried out in accordance with the Declaration of Helsinki.

2.1.2 *Questionnaires.* First, the participants were asked to complete a basic demographic questionnaire which consisted of item concerning age, sex, health problems related to olfaction (cold, allergy, and a history of head injuries) and, for women, their menstrual cycle phase.

Personality profile was assessed using the Czech version of the NEO Personality Inventory (NEO-PI-R) (Hřebíčková 2004). This personality test consists of 240 items loading onto the 5 broad personality dimensions (neuroticism, extraversion, openness to experience, agreeableness, and conscientiousness). Each dimension is loaded by 48 items and can be further separated into 6 subscales (facets); each loaded by 8 items. Participants are asked to assess how well each statement describes themselves using a 5-point Likert scale. The raw scores are computed as a sum of values (0–4) loading onto the individual dimensions (theoretical range 0–192) or facets (theoretical range 0–32), with relevant items reverse-scored (Hřebíčková 2004). The NEO-PI-R does not include dominance as a separate dimension, thus this characteristic was assessed by the 11-item questionnaire from the international personality item pool (Goldberg et al 1999). For descriptive statistics see table 1.

2.1.3 *Olfactory threshold test.* Olfactory threshold/sensitivity was tested using the extended Sniffin' Sticks test. This is a widely used clinical and research tool, which consists of 16 dilution steps of 2-phenylethanol (Hummel et al 1997). Pen-like odour dispensing devices are presented in triplets comprised of one target containing the specific concentration of the chemical and two blanks. The testing starts at the lowest concentration (dilution step 16) and proceeds with every other higher one, prompting a random-order repetition after a correct guess, until the tested individual succeeds in identifying the odorised pen twice in a row, which marks the starting point. The odorised pen in the next presented triplet is one of the nearest lower concentration, which continues to further decrease until the tested individual fails to identify the odorised pen, marking a turning point. The process is then reversed and the nearest higher concentration is presented, further increasing until two correct identifications in a row are attained. The testing is finished after 7 reversals are reached and the threshold is computed as the mean dilution steps value of the last 4 reversals; higher scores signify lower thresholds (ie higher sensitivity). The mean value in our sample was 9.3 (range 2.5–15.75).

2.1.4 *Identification test.* We used a modified version of the extended identification Sniffin' Sticks test which consists of 16 odours commonly known within the European context. The Sniffin' Sticks test presents odours in the form of pen-like dispensing devices; in our study, we used the same set of odorants kept in brown glass jars. One drop (10 μl) of each tested chemical was applied onto a cotton pad which was subsequently deposited in a glass jar. Fresh samples were prepared for each testing session. The chemicals were commercially available essential oils or manufactured odour composites. 4 verbal labels, identical to those used in the Sniffin' Sticks test, were presented for each tested compound. The overall score is simply the number of correct answers. The mean value in our sample was 12.4 (range 9–15).

2.1.5 *Procedure.* All tests were performed during school time in groups of up to 15 students and were carried out by MV and her assistant. The researcher first introduced the procedure, assured the participants that all the data would be treated anonymously and confidentially, and asked them to only provide honest answers. Then they completed the questionnaires and were individually invited to take the odour tests which were performed in another classroom. The order of the threshold and identification tests within the session was randomised. The complete session took, for most individuals, between 60 and 75 min.

2.1.6 *Statistical analysis.* First, we checked whether the continuous variables were approximately normally distributed, by use of Shapiro–Wilk's W tests. Results of the odour identification test (SW-W = 0.95; $N = 69$; $p = 0.005$) and personality dimension agreeableness (SW-W = 0.95; $N = 69$; $p = 0.005$) showed significant deviation from normality (negative skew) and therefore we used more conservative non-parametric tests for further analysis. Sex differences in the olfactory tests were thus analysed by Mann–Whitney U tests. As we had specific predictions about the association between the olfactory tests and personality dimensions, we performed separate Kendall correlation analyses instead of employing a multivariate regression analysis. Descriptive statistics and a correlational matrix of the personality dimensions are shown in table 1.

2.2 *Results*

First, we performed a correlation analysis between personality dimensions and individual measures of olfactory threshold (assessed as dilution steps, ie greater dilution step number signifies higher sensitivity/lower threshold) and identification. Contrary to prediction, we found no relationship between olfactory threshold and either conscientiousness or dominance. However, we did find the predicted relationship (Kendall's tau = 0.17; $N = 68$; $p = 0.04$) between neuroticism and threshold scores (ie more neurotic individuals tended to be more sensitive) (table 1). To find out whether this link was sex-specific, we analysed the male and female samples separately. In men, the correlation between neuroticism and olfactory sensitivity approached the formal level of significance (Kendall's tau = 0.26; $N = 28$; $p = 0.055$); however, it was not significant in the case of women (Kendall's tau = 0.16; $N = 40$; $p = 0.14$) (figure 1). Further, we performed analyses of the threshold values and all 6 subscales loading onto neuroticism to test whether the correlation between the olfactory threshold and neuroticism in men was due to one or more subscales. We found a significant correlation between olfactory sensitivity and both the N1 subscale (anxiety) (Kendall's tau = 0.31; $N = 28$; $p = 0.02$) and the N4 subscale (self-consciousness) (Kendall's tau = 0.27; $N = 28$; $p = 0.05$). To check that the sex-specific correlation between odour sensitivity and neuroticism was not due to sex differences in variance in neuroticism, we performed the Levene test for equality of variance. The results showed no significant difference ($p = 0.30$), indicating comparable variances in women and men.

As predicted, we also found no significant correlation between olfactory threshold and extraversion, openness, and agreeableness. Furthermore, analysis of the odour identification test and personality dimensions showed no significant correlations.

Finally, we analysed sex differences in the olfactory tests. We found no significant difference between men and women in either the threshold (Mann–Whitney U = 527; $N = 68$; $p = 0.68$) or identification test (Mann–Whitney U = 543; $N = 69$; $p = 0.70$). Interestingly, there was also no significant correlation between the threshold and identification tests.

Table 1. Descriptive statistics (mean, SD) and correlation matrix (Kendall's tau) of Big Five dimensions, dominance, odour identification and threshold tests in study 1.

Measure		Measure							
		neuroticism	extraversion	openness	agreeableness	conscientiousness	dominance	odour thresholds	odour identification
	Mean	104.8	111.2	120.2	110.3	100.6	37.1	9.3	12.4
	SD	24.8	23.3	19.3	24.4	27.1	9.3	2.3	1.6
Neuroticism	tau		–0.121	0.273**	0.008	–0.262**	0.133	0.172*	0.037
	p		0.147	0.001	0.926	0.002	0.114	0.043	0.680
	N		69	69	69	69	69	68	69
Extraversion	tau			–0.025	0.015	–0.062	–0.153	–0.081	0.005
	p			0.764	0.860	0.459	0.068	0.342	0.958
	N			69	69	69	69	68	69
Openness	tau				0.239**	–0.245**	0.176	–0.083	0.073
	p				0.004	0.003	0.037	0.326	0.410
	N				69	69	69	68	69
Agreeableness	tau					0.039	0.460**	–0.042	0.014
	p					0.641	<0.001	0.622	0.878
	N					69	69	68	69
Conscientiousness	tau						0.041	0.030	0.047
	p						0.626	0.722	0.594
	N						69	68	69
Dominance	tau							0.096	0.025
	p							0.276	0.764
	N							71	70
Odour thresholds	tau								–0.084
	p								0.349
	N								70

Note. * and ** signify that correlation is significant at the 0.05 and 0.01 level, respectively (two-tailed).

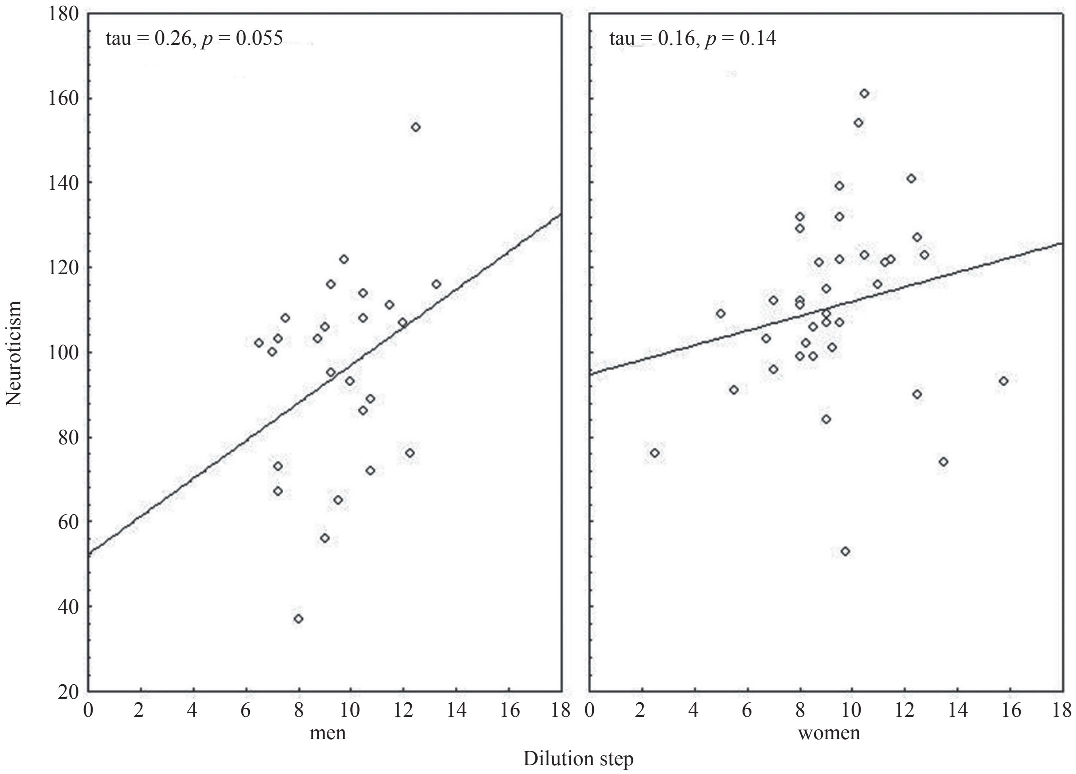

Figure 1. Correlation (Kendall's tau) of 2-phenylethanol dilution steps and neuroticism scores in men (left) and women (right) in study 1. Note that higher values in the dilution step signify lower threshold values.

3 Study 2

The aim of study 2 was to further investigate the trend toward a sex-specific association between neuroticism and olfactory threshold found in study 1. The data presented here were primarily collected for the purpose of a study of the relationship between sexual orientation and olfactory abilities (Nováková et al, submitted). However, the variables that are of interest here (personality traits) were only controlled for and not included in any of the hypotheses. Thus, not only is the present sample categorised according to sex but also with regard to sexual orientation.

3.1 *Method*

3.1.1 *Participants.* A total of 156 university students or alumni (67 female and 89 male; mean age (SD) = 24.2 (± 4.1) years; range 19–35 years) participated in the study. Participants were recruited by means of snowball sampling from students attending both undergraduate and graduate courses lectured by LN and JV, by announcing in the lectures that a study on olfactory perception was to be carried out for which participants were needed, and members of the university's student homosexual association, who received an invitation e-mail by JV. Thus, the majority of participants were current students or alumni of 11 faculties of Charles University (the ratio of graduate students/alumni to undergraduates being 3 : 4). The sample was further subdivided according to participants' self-described sexual orientation, which was indicated on a 7-point Kinsey scale, anchored on either end, with 0 labelled "heterosexual" and 6 labelled "homosexual". We subdivided the sample into the *heterosexual* (ratings of "0" or "1"; $N = 73$; 41 males) and the *non-heterosexual group* (ratings "2" to "6"; $N = 83$; 48 males). To avoid vastly unequal group sizes, data analysis was carried out primarily on these two groups and further verified with participants regrouped to the *heterosexual* and the *homosexual group* (ratings “5” or “6”; $N = 60$; 42 males). This is, however, not reported as the respective results did not differ in any significant way.

Although all participants reported good respiratory health, one case had to be excluded owing to a low olfactory score indicative of moderate hyposmia (for details see olfactory measures below). All women were regularly cycling and reported a usual menstrual cycle length of 24–32 days, were not using hormonal contraceptives, and menstrual cycle phase at the time of testing was random across participants. All participants signed written consent and received financial reimbursement of CZK 300 (approximately USD 15).

3.1.2 *Questionnaires.* For each participant, additional data on sex, education, socioeconomic status, religious beliefs, smoking history, environmental pollution, and olfaction-related health issues and, in women, menstrual cycle phase, were obtained by means of a basic demographic questionnaire. To reduce the time demand on participants, personality profile was assessed with the Czech version of the NEO-Five Factor Inventory (NEO-FFI, Hřebíčková and Urbánek 2001), which is a short version of the Revised NEO Personality Inventory (NEO-PI-R) consisting of 60 items, thereby providing a brief, comprehensive measure of the 5 personality dimensions mentioned earlier. Here, each dimension is loaded by 12 items and can be further divided into 2 to 3 facets, each loaded by 3 to 8 items. Administration and scoring of the NEO-FFI are identical to that of the NEO-PI-R. Correlations between the NEO-FFI and the NEO-PI-R domains were ranging from 0.92 and 0.77 (Costa and McCrae 1992).

3.1.3 *Olfactory measures.* All olfactory measures (olfactory threshold/sensitivity, identification, and discrimination) were obtained using the Sniffin’ Sticks test (Burghart Messtechnik GmbH). Olfactory sensitivity was assessed as specified above, only in this particular Sniffin’ Sticks set, n-butanol served as a stimulus. Nevertheless, a significant correlation between thresholds for n-butanol and 2-phenylethanol has been found (Croy et al 2009). Identification testing was performed following the exact standard procedure this time (Hummel 2004), identical to that described in study 1, only actually employing the pen-like odour dispensing devices. The Sniffin’ Sticks test of odour discrimination is comprised of 16 triplets of “pens” containing odorants in suprathreshold concentrations, of which two are identical. The discrimination task consists in (correct) identification of the odd one. The score is the total number of correct identifications. The sum of the three subtest scores is expressed as the threshold-discrimination-identification (TDI) score (Wolfensberger et al 2000). There were 11 instances of hyposmia in the sample: 10 mild (TDI score of 25–30) and 1 moderate (TDI score of 20–25), predominantly affecting heterosexual men ($N = 7$). The case of moderate hyposmia is excluded from the analysis as more consequential factors than a mere momentary lapse in current olfactory performance are likely to be involved (Hummel et al 2007; Kobal et al 2000).

3.1.4 *Procedure.* Individual, one-per-person testing sessions were conducted by LN in the morning or early afternoon (by 3 pm) in a well-ventilated room. Individuals were instructed to only attend if in good respiratory health, and asked to refrain from smoking or consumption of odorous foods at least 2 h prior to participation, as well as to forego applying perfume. The researcher first introduced the procedure, assured the participant the data would be subject to confidential treatment, and provided financial recompense for participation. Within the olfactory testing part of the session, olfactory sensitivity/odour threshold was tested first, followed by discrimination and identification with a 3 min break after each test to prevent olfactory adaptation, as suggested by Hummel (2004). In addition to the questionnaires mentioned above, for the purposes of the study the data were primarily collected for, there were others that were completed by the participants, namely the Czech versions of the Childhood Gender Nonconformity scale (CGN, Bailey et al 1995), Continuous Gender Identity scale (CGI, Bailey et al 1995), Empathy Quotient (EQ, Baron-Cohen and Wheelwright 2004), the Odor Awareness scale (Smeets et al 2008), and a survey on olfactory-related behaviours from early childhood to present. For this reason the entire session took, in most individuals, 75 to 90 min.

3.1.5 *Statistical analysis.* The assumption of univariate normality for each dependent variable was checked, as suggested by Field (2005, page 593) with multiple Shapiro–Wilk's W tests which showed departure from normality in nearly all variables (for descriptive statistics, see table 2). The assumptions of homogeneity of variances (Levene's test) and homogeneity of covariances (Box's M test) were met for all of the dependent variables. Nevertheless, a MANCOVA is considered to be robust to violations of multivariate normality (as well as to violations of homogeneity of variance/covariance matrices) if N of the largest group is no more than about 1.5 times the N of the smallest group (Field 2005), which was met in the heterosexual–nonheterosexual approach to group categorisation. Prior to performing a MANCOVA, homogeneity of slopes was first checked via the homogeneity-of-slopes model which yielded no significant results, suggesting that a traditional MANCOVA could be performed.

In the multivariate multi-way (multi-factor) between-group design the three olfactory scores (threshold, discrimination, identification) were entered as dependent variables, sex and sexual orientation as categorical factors, and age as a continuous predictor (covariate).

To follow up, separate ANCOVAs on the individual olfactory measures were performed. We ran nonparametric Kendall correlations between age and olfactory measures or personality dimensions to explore the possible associations. Finally, Kendall correlation analyses, or, where appropriate, partial correlation analyses controlling for age, between olfactory measures, and personality dimensions were performed for the total sample, sex, sexual orientation, and each of the 4 groups (non/heterosexual fe/males). All analyses were carried out with Statistica 8.0 (Statsoft, Inc.).

3.2 *Results*

The MANCOVA on olfactory measures revealed no sex differences but a significant effect of the covariate age ($F_{3,148} = 3.73$; $p = 0.013$). Follow-up ANCOVAs revealed this effect was relevant for identification ($F_{1,150} = 8.92$; $p = 0.003$). A Kendall correlation analysis between the covariate age and identification revealed a positive association (Kendall's tau = 0.15; $N = 155$; $p < 0.01$), that is, the older the participant the better the identification score he or she tended to exhibit. Again, we also found no significant correlation between the threshold and identification or discrimination score.

To look for the possible association between individual olfactory measures and personality dimensions, a partial correlation analysis was run for identification (in which age was controlled for), and Kendall correlation analyses were performed for discrimination and sensitivity. For the complete overview of the correlation matrix, see table 2. No association was found between neuroticism and olfactory measures for sex, sexual orientation, or any of the 4 groups (non/heterosexual fe/male) analysed separately.

Although the neuroticism dimension was not significantly associated with any of the olfactory measures, results of the previous study indicate that the association could be limited to some of the components of the neuroticism, namely anxiety. Thus, the analyses were run in the same fashion for the 3 individual components of neuroticism.

Table 2. Descriptive statistics (mean, SD) and correlation matrix of Big Five dimensions and olfactory measures in study 2 ($N = 155$). Please note that Kendall's nonparametric correlations are reported for all associations but those involving identification, in which age was controlled for and thus partial correlations were employed instead.

Measure		neuroticism	extraversion	openness	agreeableness	conscientiousness	odour thresholds	odour discrimination	odour identification
	Mean	20.0	32.2	27.4	30.6	30.0	8.3	13.3	13.7
	SD	8.5	8.8	7.0	7.1	8.8	2.3	1.7	1.4
Extraversion	tau	–0.325***							
	p	0.000							
Openness	tau	0.051	0.012						
	p	0.345	0.829						
Agreeableness	tau	–0.033	0.092	0.088					
	p	0.547	0.090	0.105					
Conscientiousness	tau	–0.294***	0.298***	–0.114*	0.026				
	p	0.000	0.000	0.036	0.636				
Odour threshold	tau	–0.018	–0.081	–0.101	–0.061	–0.017			
	p	0.733	0.133	0.063	0.261	0.750			
Odour discrimination	tau	0.068	0.005	0.019	0.041	–0.061	0.083		
	p	0.209	0.927	0.723	0.449	0.263	0.124		
Odour identification	*r*	0.010	0.165*	0.050	0.060	–0.001	0.047	0.068	
	p	0.903	0.041	0.540	0.459	0.986	0.566	0.405	

Note. *, **, and *** signify that correlation is significant at the 0.05, 0.01, and 0.001 level, respectively (two-tailed).

A positive association was found between the olfactory measure of discrimination and the anxiety component of neuroticism (Kendall's tau = 0.12; $N = 155$; $p = 0.03$; figure 2; see also table 3). For explorative purposes, we further tested whether the association was similarly valid for heterosexual and non-heterosexual individuals separately. The association between discrimination and anxiety was true for heterosexual individuals (Kendall's tau = 0.17; $N = 72$; $p = 0.03$) but not for non-heterosexual ones. This association was not specific to either sex or any of the 4 groups (non/heterosexual fe/male).

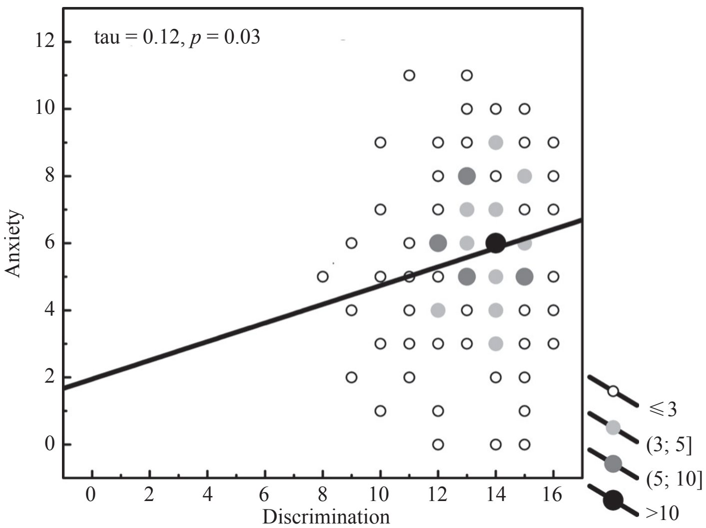

Figure 2. Correlation (Kendall's tau) of the Sniffin' Sticks discrimination score and anxiety scores in the total sample in study 2.

Table 3. Correlation matrix of the three neuroticism facets and olfactory measures in study 2 ($N = 155$). Please note that Kendall's nonparametric correlations are reported for all associations but those involving identification, in which age was controlled for and thus partial correlations were employed instead.

Measure		Measure		
		anxiety	depression	self-reproach
Odour threshold	tau	0.047	–0.001	–0.036
	p	0.384	0.992	0.502
Odour discrimination	tau	0.121*	0.050	0.043
	p	0.025	0.351	0.428
Odour identification	*r*	–0.016	0.035	–0.012
	p	0.847	0.665	0.879

Note. * signifies that correlation is significant at the 0.05 level (2-tailed).

4 Discussion

Initially, we predicted a positive link between olfactory sensitivity and neuroticism, a negative link between sensitivity and dominance, and a positive link between odour identification and conscientiousness. The results of study 1 supported only the association between sensitivity and neuroticism. Further analysis found that this was driven by the anxiety and self-consciousness subscales. The specific association between anxiety and olfactory abilities, namely odour discrimination, was confirmed in study 2.

These findings are consistent with several previous studies. In a sample of men, Pause et al (1998) found neuroticism to be the only personality dimension associated with olfactory sensitivity. More recently, it has been shown that individuals scoring high in neuroticism report elevated environmental chemical sensitivity, suggesting a higher level of odour irritability (Cornell Kärnekull et al 2011), and exhibit high trigeminal sensitivity (but not olfactory sensitivity) (Croy et al 2011). In contrast, three other studies failed to find a link between olfactory sensitivity and neuroticism (Koelega 1970, 1994; Croy et al 2011) and one earlier study found the opposite pattern: women scoring high on the anxiety scale had higher thresholds (were less sensitive) than less anxious ones (Rovee et al 1973; although these authors selected individuals with the highest scores of anxiety, which could explain their opposite results).

What might contribute to such discrepancies? First, each of the studies used a different measure to assess personality traits. However, the discrepancy cannot be accounted for entirely by the use of different measures alone, since neuroticism scores, as measured by Eysenck's, Freiburger's, BFI, NEO-FFI, or NEO-PI-R inventories, are highly correlated (Borkenau and Ostendorf 1989; Larstone et al 2002; McCrae and Costa 1985). Another reason could be that different chemical compounds were used to assess threshold levels. There is some evidence that olfactory thresholds of various compounds can show a relatively high intra-individual variability (Stevens and O'Connell 1991). In turn, sensitivity only to some chemicals might be associated with the given personality dimension. Indeed, personality studies which employed several odorants for threshold assessment (Koelega 1970, 1994; Pause et al 1998) usually found a correlation with some compounds and not with others. In contrast, other threshold studies showed a relatively high intercorrelation between odorants (Cain and Gent 1991). In our research we used 2-phenylethanol (study 1) and n-butanol (study 2), which are generally considered to be good markers of general olfactory sensitivity (Hummel et al 1997). This is further supported by the finding that thresholds for both compounds are highly correlated (Croy et al 2009). Here, the neuroticism dimension, which was found to be positively correlated with olfactory threshold in study 1, was not associated with any of the olfactory measures as an entire dimension in study 2. Only one of its components, namely the anxiety facet, was positively correlated with odour discrimination. A plausible explanation for the present pattern of findings may be the fact that different measures were used to assess both neuroticism and olfactory threshold in the two studies. Furthermore, the fact that no correlation was found between the olfactory threshold and odour discrimination in study 2 prevents direct comparison of the discrepant findings in the respective studies. Nevertheless, because odour threshold in a given individual may exhibit substantial fluctuation over time (Pause et al 1998; Stevens et al 1988), one would expect that, of the two olfactory measures, we would be more likely to find an association between anxiety and odour discrimination, as was the case in study 2.

Interestingly, when men and women were analysed separately, the association between neuroticism and the olfactory threshold in study 1 approached significance in men only. A similar sex-specific pattern was observed by Chen and Dalton (2005). They found that neurotic men, but not women, perceived emotionally valenced odours faster than neutral ones. It is difficult to compare our findings with the above-mentioned studies as Pause et al (1998) examined men only and Cornell Kärnekull et al (2011) and Croy et al (2011) did not test for sex differences. We tested whether this finding could be due to sex differences in variance on the neuroticism dimension, but our results suggest this is not the case. However, as the results of study 2 did not confirm the sex-specific effect, we urge caution in interpreting these findings.

Our results showed no link between personality dimensions and the odour identification score obtained using a forced-choice (cued) paradigm. In contrast, Larsson et al (2000) found in a large sample of ageing participants (mean age = 65 years) that high neuroticism, low impulsivity, and high assertiveness were significant predictors of high odour identification rates even when controlling for age, demographic characteristics, and cognitive abilities. The authors used a mix of free and forced-choice identification. Such a difference in the form of the identification task might result in differences in the link between personality and odour identification. Free identification is known to be much more difficult, and thus there is more variation in the scores (De Wijk and Cain 1994). Further, our participants were young adults (mean age = 18 years in study 1 and 24.2 years in study 2), and they tended to correctly identify the majority of the odours (mean = 12.4, maximum 16 in study 1; and mean = 13.7, maximum 16 in study 2). Thus, it is conceivable that the negative findings in our study could be due to a ceiling effect; if so, a more comprehensive odour identification test (eg free choice, one employing more stimuli and/or distractors) should be used for this age group. Alternatively, the link between personality and odour identification may be expressed only later in life when variability in odour identification increases.

Previously, researchers have tended to interpret associations between olfactory abilities and personality in terms of common underlying biological machinery (Larsson et al 2000; Pause et al 1998). In connection with Eysenck's personality model it was proposed that the activity of the limbic system (eg amygdala) is the underlying brain substrate. The limbic system is known to play a crucial role in odour processing (Zatorre et al 1992; Dade et al 1998) and is also expected to be more activated in neurotic individuals (Eysenck 1998). Furthermore, behavioural genetics studies show a relatively large heritable component in both neuroticism (McCrae et al 2000) and olfactory perception (Gross-Isseroff et al 1992; Knaapila et al 2007). This is also supported by a recent study which found an association between genetic polymorphism in olfactory receptor genes and hypersensitivity to isovaleric acid (Menashe et al 2007). However, the correlational nature of our study (and the same applies to all previous studies on this subject) does not permit conclusions about causality. It is, for instance, plausible that highly neurotic individuals, because of their higher irritability, engage in a greater number of olfactory-related activities, which can in turn result in their higher sensitivity. Future studies should therefore also control for olfactory-related activities. Alternatively, this issue should be addressed in young children where the effect of such activities might be relatively limited.

Interestingly, in both studies there was no significant difference between men and women in threshold values, discrimination, and identification scores. There is a relatively robust body of evidence that women tend to outperform men in various olfactory-related tests (for reviews see Brand and Millot 2001; Doty and Cameron 2009) and report a greater significance ascribed to olfaction (Havlicek et al 2008). On the other hand, sex differences tend to be smallest in young adults (Doty 1992) and have been reported to be restricted to the fertile phase of the menstrual cycle (Navarrete-Palacios et al 2003). Regarding study 1, one might argue that our sample size was not large enough to detect the relatively subtle effect typical for this age category; however, this argument could hardly explain a similar pattern observed in study 2.

As a subsidiary finding, both the comparison of identification scores in study 1 and study 2 (Mann–Whitney U = 2914.5; $N = 224$; $p < 0.0001$), and the effect of age on identification found in study 2, indicate that in the studied age group, older participants tend to exhibit higher identification scores. This is in line with the results of Yousem et al (1999) who report an increase in odour identification score as a function of age, measured by the University of Pennsylvania smell identification test (UPSIT, Doty et al 1984b), in a subgroup of participants in their mid-twenties. However, reports do not tend to be unanimous on this, as, for instance, the authors of the UPSIT themselves found a plateau in odour identification scores for this age cohort (Doty et al 1984a).

We further found no correlation between identification and threshold levels in either of the studies. One may find this surprising, as it is thought that both functions overlap to some extent. Clearly, if one's threshold is very high, it can affect identification ability which is tested with suprathreshold concentrations. Moreover, neuroimaging studies show that odour processing is organised in a hierarchical fashion, and thus different olfactory tasks partly involve specific neural substrates (Royet et al 2001). For instance, both odour detection and discrimination tasks activate areas including the orbitofrontal cortex, thalamus, insula, and piriform cortex; however, areas such as the prefrontal cortex and hippocampus are activated only during odour discrimination (Savic et al 2000). Further, odour identification is heavily dependent on verbal abilities, while sensitivity measures are not (Finkel et al 2001). Consistent with this, most previous studies found only a moderate correlation between threshold values and odour identification scores ($r = 0.18$ in Lehrner et al 1999; $r = 0.24$ in Segal et al 1995). Furthermore, correlational measures vary greatly across study samples, and performance-heterogeneous samples (such as those using a population of the elderly) tend to result in higher correlations. The lack of a significant correlation in our study could perhaps be attributed to the performance-homogeneity of our samples and/or the above-mentioned ceiling effect in the odour identification test.

In summary, the results of our two studies indicate that olfactory perception is associated with a specific personality factor, anxiety. Highly anxious individuals show elevated olfactory perception. We also found some evidence that this effect might be limited to or stronger in men, but further data are needed to confirm this finding. Thus, considering similar findings in previous studies, there is an emerging pattern suggesting that neuroticism, or at least its subscale anxiety, is related to various aspects of olfactory perception. However, we cannot currently distinguish between whether the observed patterns are due to shared underlying biological processes or due to olfactory-linked activities and experience. Future studies should therefore also employ a measure of olfactory awareness and experience to explore these possible connections with neuroticism/anxiety. This, in turn, might improve our understanding of marked individual differences in olfactory perception.

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