Increased self-reported sensitivity to environmental stimuli and its effects on perception of air quality and well-being

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Abstract

Background: In previous studies, negative associations were found between increased environmental sensitivity and general well-being as well as positive perception of air quality. However, only a few studies with partly inconsistent results examined this relation under exposure. They tried to determine whether people with increased environmental sensitivity react to real environmental conditions with changes in current well-being and perception of air quality.

Methods: Pooled data from two single-blinded randomized controlled trials with different exposure levels were analyzed. Participants were exposed to different levels of volatile organic compounds (VOC) and carbon dioxide (CO_2) in the front part of a former in-service wide-body airplane inserted in a low-pressure chamber. Three exposure groups were created depending on the VOC/CO_2 levels: low, medium and high. Subjects repeatedly answered questions about their current mental well-being and about perception of air quality and odor intensity. Based on self-reported data the participants were classified into groups with low and higher environmental sensitivity. Data were evaluated using a 2 (environmental sensitivity) x 3 (exposure) ANCOVA with repeated measures.

Results: 503 individuals (221 females) participated (mean age: 42.8±14.5 years). Thereof, 166 individuals were assigned to the group with higher environmental sensitivity; they reported poorer psychological well-being regarding vitality ($F(1,466) = 16.42$, $p < .001$***, partial $\eta^2 = .034$) and vigilance ($F(1,467) = 7.82$, $p = .005$**, partial $\eta^2 = .016$) and rated the pleasantness of air quality ($F(1,476) = 7.55$, $p = .006$**, partial $\eta^2 = .016$) and air movement ($F(1,474) = 5.11$, $p = .024$*, partial $\eta^2 = .011$) worse than people in the low sensitivity group. Exposure levels showed no effects. No systematic differences between men and women were found. Increased environmental sensitivity shared common variance with negative affectivity, another person-related variable. Its explanatory power was higher for evaluations of the environment whereas no differences between the concepts in explaining current psychological well-being were found.

Conclusions: Even a slightly elevated level of environmental sensitivity led to worse ratings of the environment with no clear relation to the real environment. Consequently, environmental sensitivity should be considered as a confounding factor in environmental exposure studies. The independency from real exposure levels is in line with the results from previous studies showing that the differences in environmental ratings are probably also driven by psychological factors.

Keywords

Environmental sensitivity, Exposure study, Randomized controlled trial, Aircraft cabin air

Introduction

Individuals spend a large proportion of their time indoors (residence, factory, etc.) with some studies reporting up to 87% on average (Klepeis et al., 2001). The shift to an indoor lifestyle and the accompanying decreased outdoor exposure during the last decades has increased the prevalence of many allergies (Platts-Mills, 2015). For example, children growing up on farms developed fewer allergies due to exposure to germs (von Mutius and Vercelli, 2010). Moreover, people are more exposed to indoor air pollutants such as VOC (Lundberg, 1996) or (ultra)fine particulate matter (e.g., from traffic that can be found both outdoors and indoors, Christian et al., 2022). Poor indoor air quality can negatively affect physical and mental health and thus lead to poor quality of life, what is manifested in terms like idiopathic environmental intolerance (IEI), and multiple chemical sensitivity (MCS; Nordin, 2020; Viljoen and Thomas Neé Negrao, 2021), or just a slight, clinically not relevant increase of environmental sensitivity.

The evaluation of indoor air quality depends on different factors, for example sociodemographic and psychosocial (work) factors. Brauer and Mikkelsen (2010) found that psychosocial work factors were related to the perception of the indoor environment at individual level, but building characteristics were not associated with complaints about indoor environment. Workplace-level psychosocial risk factors could not explain this response heterogeneity whereas type of organization (e.g., office, hospital, school) explained some of the differences in perception. Cheung et al. (2022) showed for the work and private context that people with higher job and life satisfaction rated the indoor environmental quality as more satisfying than people with less job and life satisfaction. Furthermore, in the same study, Cheung et al. (2022) investigated the relationship between the Big Five personality traits (extraversion, agreeableness, conscientiousness, emotional stability, and openness to experience) and indoor environment. Agreeableness was associated with satisfaction with overall workspace environment, but otherwise the Big Five were not associated with evaluations of temperature, humidity, air movement, freshness of the air (stuffiness), or odors. Another study in the work context (Budie et al., 2019) included the Big Five in a path model to examine employee satisfaction with the work environment. Among these traits only agreeableness was positively associated with satisfaction with indoor climate. Individual factors like demographic variables also seem to influence the perception of indoor air environment: Women were found to be less satisfied with the thermal environment at times when ventilating and air conditioning is necessary (Choi et al., 2010); and Karjalainen (2007) found that women were less satisfied with indoor temperature, prefer warmer rooms and rated rooms as more uncomfortably hot or cold than men. In addition, subjects over 40 years rated thermal environment at times when ventilating and air conditioning is necessary as more satisfying than subjects under 40 years (Choi et al., 2010). In sum, individual factors seem to influence the perception of environment. However, up to now environmental sensitivity has not been researched as intensely as MCS or IEI. To approach the phenomenon of increased environmental sensitivity, we therefore first present findings on these clinically discussed phenomena.

MCS belongs to the broader definition of IEI, which additionally includes other environmental sensitivities such as electro(magnetic) sensitivity (Rossi and Pitidis, 2018). Present etiological explanations are not unanimous. On the one hand, there are biological theories, including toxicological or immunological theories that suggest an initially higher or longer exposure that is normally tolerated, as a cause (Bauer et al., 2008; Genius, 2010; Terr, 1987). According to consensus criteria (Bartha et al., 1999), symptoms are subsequently triggered and manifested by low doses and the appearance of symptoms depends on the presence of chemicals. Thus, MCS is defined as a chronic condition with reproducible recurring symptoms in response to different chemical substances in low doses (Bartha et al., 1999; Rossi and Pitidis, 2018). On the other hand, there are psychological theories, which assume a misattribution of symptoms to environmental stimuli leading to associative learning/conditioning (Siegel and Kreutzer, 1997). These theories "tend[s] to report the source of such disturbances to the psyche, as an endogenous self-induced cause and not as a consequence of excessive and abnormal reaction to an albeit reduced chemical exposure" (Rossi and Pitidis, 2018, p. 139). Other theories are based on a model in which both approaches are relevant. The development of MCS is seen as a multistage and very individual process with different factors: Exposure and vulnerability lead to a sensitive individual (Bauer et al., 2008). A learning approach is used by Van den Bergh et al. (2017) who proposed a biopsychosocial mechanism to explain IEI/MCS. The nocebo effect occurs when subjects associate an odor with symptoms by learning effect. When they perceive the harmless odor again, they expect symptoms independent und dissociated of the current exposure level. According to Van den Bergh et al. (2017) this nocebo/learning effect is stronger if subjects present a high negative affectivity (trait), that is, negative affectivity might act as a moderator. The authors reported several reasons for this relationship, for example, subjects with high negative affectivity are more attentive to the affective elements of a somatic experience and perceive sensory-perceptual elements as less intensive.

After developing environmental sensitivity, individuals exhibit symptoms for many years as shown in some long-term studies. One-, 5-, and 9-year follow up studies about IEI, MCS, and chemical intolerance confirmed their chronic condition, with some individuals reporting improvement in symptoms such as headache, pain, and fatigue, e.g., due to hospitalization, books, support groups (e.g., Bailer et al., 2007; Black, Okiishi, and Schlosser, 2000; Skovbjerg et al., 2015). In addition, it was found that negative affect such as anxiety or neuroticism increases the development and persistence of IEI (Bailer et al., 2007; Skovbjerg et al., 2015).

In general, there is significantly more data on people with independently observed/diagnosed MCS according to various criteria (e.g., from Cullen (1987) or Bartha et al. (1999)) than on people who self-report it in questionnaires. Prevalence of these "diagnosed" MCS cases increased from approximately 2.5% to 12.8% during the last 10 years until 2018, whereas self-reported MCS increased from approximately 11.1% to 25.9% (Driesen et al., 2020; Steinemann, 2018). It can be assumed that even more people show increased sensitivity to environmental stimuli below any clinical thresholds and that these numbers will continue to rise. Also, Van den Bergh et al. (2017) assumed that MCS is "the tip of an iceberg of highly prevalent self-reported chemical hypersensitivity among the general population" (p. 552). Almost all studies examining gender differences reported women to be more likely to have self-reported or observed MCS than men (e.g., Andersson et al., 2008; Berg et al., 2010; Hausteiner et al., 2005).

Besides physical symptoms such as headaches and fatigue, many affected people reported an increase in irritability, anxiety, depressed mood, as well as negative affectivity (Azuma et al., 2019; Bailer et al., 2006; Hausteiner et al., 2005; Papo et al., 2006). A few studies have determined that individuals with MCS showed poorer mental well-being than healthy control groups (Georgellis et al., 2003; Johnson and Colman, 2017). Johnson and Colman (2017) found this result only in men, whereas there was no difference in positive mental well-being between women with and without MCS. Georgellis et al. (2003) found no differences in this relation between men and women. However, these studies investigated only well-being in general and not current well-being in an actual exposure situation. Overall, studies about the relationship between environmental sensitivity and current well-being during exposure are lacking. Changes in current well-being during exposure could help to separate general psychological reactions from reactions to the actual environment.

Another factor that could be influenced by environmental sensitivity is the perception of air quality, but studies show contradictory results. Alobid et al. (2014) showed that individuals with MCS were less able to identify odors compared to a control group. Moreover, affected people reported "more odours as being intense and irritating and less fresh and pleasant" (Alobid et al., 2014, p. 3203). In other studies, individuals with MCS expressed stronger odor perceptions (van Thriel et al., 2008) or had unpleasant sensations in response to more odors (Ojima et al., 2002). In contrast, other studies found that affected individuals were just as capable of identifying odors and perceiving exposures (Georgellis et al., 2003; Ojima et al., 2002) as well as perceiving the intensity of odors as the control group (Andersson et al., 2014; Georgellis et al., 2003). In one study, no difference regarding reported unpleasantness of smell was found (Georgellis et al., 2003).

To sum up, few studies investigated the relationship between environmental sensitivity and perception of air quality and odor intensity under exposure. However, the results are contradictory. Furthermore, no studies explored the relationship between environmental sensitivity and current mental well-being under exposure. Studies that determined effects of environmental sensitivity in the normal population, that is, beyond clinical phenomena, in their everyday environment such as office buildings or aircraft are missing.

This study explores the effect of increased sensitivity to environmental stimuli on perception of air quality and well-being in different exposure conditions. For this purpose, people of a non-clinical population were exposed to different levels of CO_2 and VOC. The following hypotheses were tested:

H1) Regardless of the level of exposure, individuals with higher environmental sensitivity show worse current well-being than individuals with lower environmental sensitivity.

H2) Environmental sensitivity moderates the relationship between exposure and current well-being: individuals with higher environmental sensitivity show worse well-being at higher exposures than individuals with lower environmental sensitivity.

H3) Regardless of the level of exposure, individuals with higher environmental sensitivity perceive air quality worse than individuals with lower environmental sensitivity.

H4) Environmental sensitivity moderates the relationship between exposure and air quality perception: individuals with higher environmental sensitivity respond more strongly to higher exposures than individuals with lower environmental sensitivity.

Since the described clinical phenomena showed different prevalence in men and women, differential effects are considered. In addition, the increased negative affect found in some studies could also be explanatory. Therefore, it is also considered as a predictor and the findings are contrasted with the results of the analyses with increased environmental sensitivity.

Material and methods

Design and procedure

The presented analyses were conducted in the context of the European Union CleanSky 2 project ComAir ("Investigation of cabin ventilation strategies impact on aircraft cabin air quality and passengers' comfort and well-being through subject study in realistic aircraft environment") and the project CognitAir ("CO_2 and VOCs requirements for aircraft cabins based on cognitive performance, comfort responses and physiological changes depending on pressure level") which took place between November 2019 and January 2020 before the Sars-CoV-2 pandemic in the Flight Test Facility (FTF) at the Fraunhofer-Institute for Building Physics IBP in Holzkirchen, Germany. Both studies were single-blinded, randomized (stratified for age and sex of (business) flight passengers) controlled trials that achieved different cabin air qualities (see below) by different technical means (ventilation rates and CO_2/VOC dosing). Therefore, this is a reanalysis of two different studies. For the analyses presented in this paper, subjects from similar (in terms of air quality and study setting) exposure conditions of both studies were divided into three exposure groups (low, medium, and high exposure, see below). In the pooled data set, participants were also divided into two groups regarding low and higher environmental sensitivity, resulting in a 2 x 3 design. Each of the two projects showed sufficient power and sample size. Moreover, for the pooled data from both projects a sample size estimation for the 2 x 3 design was carried out. To detect small to medium sized effects (f = .15, η^2 = .022), a sample size of 489 subjects was required (based on ANCOVA, alpha-error of 5%, power of .85 ($1 - \beta$), 8 covariates).

Subjects in both studies were healthy adults recruited by a casting agency according to a set age/gender scheme to ensure that participants were representative of (business) air travelers. They received information about the project, procedure, and contact data for further inquiries in advance. People with pre-existing conditions (such as chronic respiratory, heart conditions, or severe anemia), potentially at risk, or who might cause problems during experiments (e.g., because of claustrophobia) were excluded. In addition, pregnant women, and potential outliers in health- and experiment-related measures, such as people who cannot sit for a while, were excluded. People with increased environmental sensitivity were not excluded, but also not specifically invited. We assumed that people with very high environmental sensitivity do not want to participate in an air quality study. Furthermore, the objective was to examine a normal population. A few days before the experiment, people reporting ongoing infectious conditions (e.g., seasonal cold) were excluded.

After welcoming the subjects at the Flight Test Facility, participants had the chance to ask questions about the study and exposure during a Q&A session before giving their signed informed consent. In addition, a final medical check was carried out by the study physicians to ensure that the participants could safely take part in the trials. After that, the participants were placed in the cabin in such a way that there was always an unoccupied seat or aisle between them to avoid disturbances. After boarding was completed, participants answered control questions as well as questions about environmental sensitivity during ascend. It took approximately 25 minutes to reach cruising altitude in terms of pressure condition and additional 30 minutes in CognitAir and – due to the slower generation of the different air qualities – 40 minutes in ComAir to reach fully controlled exposure. Subjects spent on average 4 hours in total in the mock-up (about 4:00 in CognitAir and 4:04 in ComAir) and completed a number of questionnaires during this time. Finally, participants deboarded and were debriefed; more details are described elsewhere (Norrefeldt et al., 2021). Both studies were approved by the Ethics Committee at the Faculty of Medicine, Ludwig-Maximilians-University, Munich (ComAir #19-256; CognitAir #19-350).

Exposure

The exposure took place in the FTF consisting of the front part of a former in-service wide-body airplane inserted in a low-pressure chamber, which can accommodate up to 80 passengers and generate different pressure levels. In the present study, the cabin was half occupied by 30 to 40 participants and pressure levels of 755 hPa equivalent to 8000 ft. cabin altitude were used. In the ComAir project, different air qualities were generated by different outdoor/recirculation airflow ratios. The higher the proportion of recirculation air rate, the higher the levels of CO_2 and VOC as participants' emissions became less diluted by outdoor air; more details are described elsewhere (Norrefeldt et al., 2021). The levels of air quality parameters follow mandatory requirements from the Federal Aviation Administration (FAA, 2019). In contrast, in the CognitAir project different air qualities were generated by dosing VOC and pure CO_2 into the cabin. To achieve different total volatile organic compound (TVOC) levels, a fixed mixture of 12 compounds such as Ethanol, Toluene, and Acetonitrile based on VOCs commonly found in aircrafts (Chen et al., 2021) were dosed in different amounts. For the present study, these different air qualities were allocated to low, medium, and high exposure based on TVOC and CO_2 (see table 1) following this procedure: Firstly, all relevant experimental sessions were sorted according to measured TVOC level and subsequently by CO_2 levels. Since allocation was based on TVOC, standard deviations for CO_2 are rather large. Secondly, differences between the ranked successive sessions were considered along with number of participants to achieve an equal distribution of subjects among the low, medium, and high exposure groups. Thus, the adjacent sessions for low and medium exposure differ only by 94 µg/m^3 TVOC, the ones for medium and high by 226 µg/m^3 TVOC (see Appendix B). The resulting three exposure levels show clear average differences in TVOC and CO_2. These clear differences are also shown by the three VOCs with the highest proportions across all exposure groups included as examples in table 1.

All other factors, such as pressure, temperature, lighting, or non-human noise, were kept as constant as possible. For more details about the measurement devices see appendix C.

Table 1

Characteristics of exposure levels.

	Low exposure	Medium exposure	High exposure
TVOC (µg/m^3), among others	598 (267)	1041 (149)	1616 (289)
Ethanol (µg/m^3)	100 (92)	169 (99)	557 (410)
Total propanol[a] (µg/m^3)	106 (80)	134 (35)	186 (147)
Acetone (µg/m^3)	30 (16)	45 (17)	67 (10)
CO_2 (ppm)	1958 (473)	2324 (660)	3363 (1206)
Pressure (hPa)	755 (0)	755 (0)	755 (0)
Temperature (°C)	22.7 (0.2)	23.0 (0.8)	22.6 (1.0)
Relative humidity (%)	14 (3)	15 (6)	14 (7)

Mean, standard deviation in brackets.

[a] Sum of 1-popanol and 2-propanol.

Measures

Sensitivity to environmental stimuli was measured by the chemical odor sensitivity scale by Kiesswetter et al. (1997). The questionnaire consists of eight items (e.g., *Strong smell of paint and smoke makes me dizzy*) on a five-point Likert scale (0 = *not applicable*, 4 = *highly applicable*) to measure how people subjectively react to environmental stimuli. The sum scale shows a good overall internal consistency (Cronbach's Alpha = .904).

To examine the effects of low and higher sensitivity to environmental stimuli, sum values on the chemical odor sensitivity scale had to be separated into two groups. Due to the generally rather low level of environmental sensitivity in the sample, the normally used cut-off could not be used, because otherwise most of the subjects would be assigned to the low environmental sensitivity group. To obtain a better cut-off point and a good ratio of numbers of subjects in both groups, tertiles of the sum value were calculated and the cut-off value was set after the first two tertiles. The lower two tertiles (range 0-7) are considered to present low environmental sensitivity, whereas the upper tertile (range 8-32) presents higher environmental sensitivity. Despite the overall very low values on the sum scale, we will use the terms low and higher environmental sensitivity due to better readability in the remainder of this paper.

Current well-being was assessed at the start (t1) and end (t2, approximately 130 minutes after start) of the controlled air regime (dosing/recirculation rate) on the Basler emotional state scale (Hobi, 1985). Using a bipolar seven-point rating scale, 16 adjectives capture the four subscales vitality (e.g., *tired* - *fresh*), intrapsychic equilibrium (e.g., *calm* - *nervous*), social extraversion (e.g., *talkative* - *secretive*), and vigilance (e.g., *inattentive* - *attentive*). All subscales showed an acceptable to good internal consistency (Cronbach's Alpha = .707-.890).

Perception of air quality was assessed by different scales. First, pleasantness of air quality, temperature, and air movement was measured in the middle (t1, approximately 70 minutes after start) and at the end (t2, approximately 130 minutes after start) of the controlled air regime (dosing/recirculation rate) on a five-point Likert scale (1 = *very unpleasant*, 5 = *very pleasant*). Pleasantness of air quality consists of the four items overall air quality, fresh air, humidity, and odors, whereas temperature and air movement consist of one item each. These items were adopted from the Ideal Cabin Environment (ICE) Questionnaire (Perera, 2010) and the Cost-effective Open-Plan Environments (COPE) project (Veitch et al., 2007). Second, participants rated the acceptability of air quality based on a two-part visual analogue scale from *clearly acceptable* to *just acceptable* and – after a small break of the scale – *just not acceptable* to *clearly not acceptable* right at t2 (Wargocki, 2001). To calculate this visual analogue scale, percentage of maximum possible score (POMP) was used (Cohen et al., 1999). Third, odor intensity was assessed by one item (*How would you assess the odor* *intensity in this flight?*) on a 5-point scale (1 = *no odor,* 5= *overwhelming odor*) right after exposure, too.

As ratings of current well-being and air quality can be influenced by a variety of other factors, the following control variables were considered. Health on day of trial was measured by one item (*Taking everything into consideration, how would you describe your health today?*) on a five-point Likert scale (1 = *poor*, 5 = *excellent*) based on McDowell (2010), whereas the physical and mental health status in the past four weeks was assessed by the Short-Form-8-Health Survey (SF-8) by 8 items (e.g., *During the past 4 weeks, how much did physical health problems limit your physical activities (such as walking or climbing stairs)?*) on different four-, five- or six-point scales with higher values showing worse health (Ware et al., 2001; German version Ellert et al., 2005). This scale shows a good internal consistency (Cronbach's Alpha = .815). Moreover, subjects were asked if they currently smoke on a four-point scale (1 = *I've never smoked before*, 4 = *yes, daily*; Gößwald et al., 2012) and how they would rate the quality of their sleep the night before the trial on a four-point Likert scale (1 = very *poor*, 4 = *very good*; Robert-Koch-Institut, 2008). Negative affectivity was measured by the shortened negative subscale of the Positive and Negative Affect Schedule (PANAS) by 5 items (e.g., *afraid*) on a five-point Likert scale (1 = *not at all*, 5 = *extremely*; Watson et al., 1988). This scale shows an acceptable internal consistency (Cronbach's Alpha = .754). Like environmental sensitivity, negative affectivity was separated into tertiles for the sensitivity analysis. The lower two tertiles (range 1-1.4) are considered to present low negative affectivity, whereas the upper tertile (range 1.6-5) presents higher negative affectivity.

Statistical analyses

To test for comparability of exposure and environmental sensitivity groups, non-parametric tests for independent samples (Mann-Whitney U tests) were used for two groups. To compare three groups, Kruskal-Wallis tests were used. Due to nominal scaling, differences in sex and smoking were calculated by using the Chi² test. As method of choice for experimental designs, hypotheses were tested using two-way ANCOVA with repeated measures and Bonferroni adjustment for post hoc comparisons. Furthermore, main and interaction effects were considered to explore how participants with low versus higher environmental sensitivity react to different exposure levels. Covariates were centered to correctly represent the within-subjects effects (Schneider et al., 2015). Crude models were additionally computed.

In addition, sensitivity analyses for sex and negative affectivity were performed. To explore the differences between men and women with increased sensitivity, all analyses were performed separately for both sexes. To test if the results were indeed predicted by environmental sensitivity and not by a more general person-related variable, the controlled models were also computed with negative affectivity.

P-values below .05 were considered significant and *p*-values below .10 as a trend. In addition, effect sizes were reported as partial η^2 for ANOVAs. In line with Ellis (2010), based on Cohen (1992), we considered effect sizes of $\eta^2 \geq .01$ as small effects, of $\eta^2 \geq .06$ as medium-sized effects, and of $\eta^2 \geq .14$ as big effects. Effect sizes reported as *r* above .10 were considered as small, above .30 as medium and above .50 as large (Cohen, 1992). All statistical analyses were performed using SPSS 26.

Results

Sample characteristics

The sample consisted of 503 participants (221 females, 282 males) with a mean age of 42.8 years (*SD* = 14.5, range 18-77 years) and rather high educational level (45.9% with qualification for university entrance/A level, 0.6% left school without graduation). During on-site screening, five participants were screened out before exposure started because of pre-existing conditions, a surgery a few months ago and a too late appearance. Two female participants left the chamber during exposure (one medium/one high exposure condition) because of nausea and headache; transient symptoms were later confirmed by the onsite physician as almost surely not being related to the air-related exposure. Three subjects had to be excluded due to missing values regarding the chemical odor sensitivity scale. Therefore, 500 subjects were used in all further calculations. 334 individuals were allocated to the group with low environmental sensitivity and 166 individuals to the group with higher environmental sensitivity. These two groups were evenly distributed across the three exposure levels ($\chi^2(2) = 3.03$, $p = .220$) and randomization to exposure group was mostly successful (see Table 2). The participants did not differ with regard to age, BMI, or smoking behavior. However, combinations of exposure and environmental sensitivity group showed some differences. In general, more women reported higher environmental sensitivity. This effect was driven by significant differences in low and medium exposures levels and a – albeit not significant - different proportion in the high exposure group. In low and medium exposure levels, generally more women were in the higher than in the low environmental sensitivity group resulting in significant differences. If the proportion of men and women in the two sensitivity groups was similar, no significant differences between the sexes could be found as shown in the high exposure group. People with higher sensitivity to environmental stimuli showed poorer self-assessed health on day of trial, as well as poorer physical and mental health during the past four weeks. Furthermore, participants with higher sensitivity showed higher negative affectivity than participants with low sensitivity. This effect was mainly driven by a significant difference in the low exposure condition. With regard to differences between the exposure groups, a significant difference in sleep quality before trial was determined. Participants in the medium exposure group reported poorer sleep quality before trial than people in the low or high exposure group. All sample characteristics in the three different exposure levels as well as the two environmental sensitivity groups are presented in table 2. In consideration of the differences, sex, negative affectivity, physical and mental health, health on day of trial, and sleep quality before trial were included as control variables in the model. As the air quality levels were produced differently in the two projects, this was also controlled for by using a binary variable. In addition, results were controlled regarding age. Moreover, crude models were calculated and can be found in the appendix (table A.2 and A.3).

To ensure that environmental sensitivity is an independent construct, correlations with the relevant control variables were analyzed. Environmental sensitivity correlated positively with sex (r = .277***), negative affectivity (r = .215***), and lower physical and mental health (r = .246***). That is higher values in environmental sensitivity were associated with poorer physical and mental health. In addition, a negative correlation with health on day of trial (r = -.142***) was detected. All correlations with environmental sensitivity showed low effect sizes (Cohen, 1992) with less than 8% shared variance (see appendix, table A.1).

Table 2

Characteristics of the study population.

	Low exposure			Medium exposure			High exposure				
	Low ES (M (SD))	Higher ES (M (SD))	Difference between ES (p-value)	Low ES (M (SD))	Higher ES (M (SD))	Difference between ES (p-value)	Low ES (M (SD))	Higher ES (M (SD))	Difference between ES (p-value)	Overall difference between ES (p-value)	Overall difference between exposure (p-value)
Sex			.002**[b]			.002**[b]			.306[b]	<.001***[b]	.899[b]
male	60	21		73	24		76	26			
female	31	33		42	37		52	25			
Age	43.99 (16.18)	41.91 (14.27)	.318[a]	40.35 (14.89)	44.23 (13.09)	.063[a]	43.11 (13.68)	43.88 (13.61)	.635[a]	.437[a]	.419[c]
BMI	24.44 (3.99)	23.95 (4.43)	.216[a]	24.88 (6.01)	24.61 (4.02)	.844[a]	24.94 (5.09)	24.89 (4.53)	.752[a]	.732[a]	.798[c]
Smoking			.848[b]			.200[b]			.097[b]	.384[b]	.292[b]
I've never smoked before	45	30		49	25		63	17			
no, not anymore	18	11		24	21		36	18			
yes, occasionally	20	9		25	9		8	8			
yes, daily	8	4		17	6		21	8			
Environmental sensitivity sum score	2.81 (2.37)	12.70 (5.16)	<.001***[a]	2.79 (2.19)	13.21 (4.98)	<.001***[a]	2.41 (2.22)	14.55 (5.33)	<.001***[a]	<.001***[a]	.170 [c]
Negative affectivity	1.25 (0.37)	1.50 (0.45)	<.001***[a]	1.39 (0.41)	1.52 (0.56)	.334[a]	1.44 (0.51)	1.55 (0.59)	.322[a]	.002**[a]	.066[c]
Physical and mental health	14.12 (4.01)	16.59 (4.62)	.002**[a]	15.12 (4.46)	16.64 (4.49)	.035*[a]	14.98 (4.53)	17.20 (5.05)	.008**[a]	<.001***[a]	.465[c]
Health on day of trial	4.26 (0.85)	4.00 (0.58)	.003**[a]	4.09 (0.70)	4.02 (0.72)	.510[a]	4.13 (0.64)	3.84 (0.62)	.004**[a]	<.001***[a]	.099[c]
Sleep quality before trial	2.92 (0.73)	2.72 (0.60)	.051[a]	2.57 (0.76)	2.59 (0.80)	.695[a]	2.88 (0.66)	2.90 (0.70)	.810[a]	.452[a]	<.001***[c]

*p ≤ .05; **p ≤ .01; ***p ≤ .001; ES = environmental sensitivity, M = Mean, SD = Standard deviation.

[a] Mann-Whitney U test for group comparisons.

[b] Chi² test for group comparisons.

[c] Kruskal-Wallis test for group comparisons.

Well-being

For intrapsychic equilibrium, analyses of variance showed two interaction trends regarding environmental sensitivity and measurement time ($F(2,466) = 2.66$, $p = .071^{+}$, partial $\eta^2 = .011$) as well as environmental sensitivity and exposure level ($F(2,466) = 2.47$, $p = .086^{+}$, partial $\eta^2 = .010$; see table 3 and figure 1). Intrapsychic equilibrium decreased less over time for subjects with low environmental sensitivity than for those with higher environmental sensitivity. People with low environmental sensitivity indicated a lower intrapsychic equilibrium in the medium exposure level whereas people with higher environmental sensitivity reported the highest intrapsychic equilibrium in this condition. However, differences were very small.

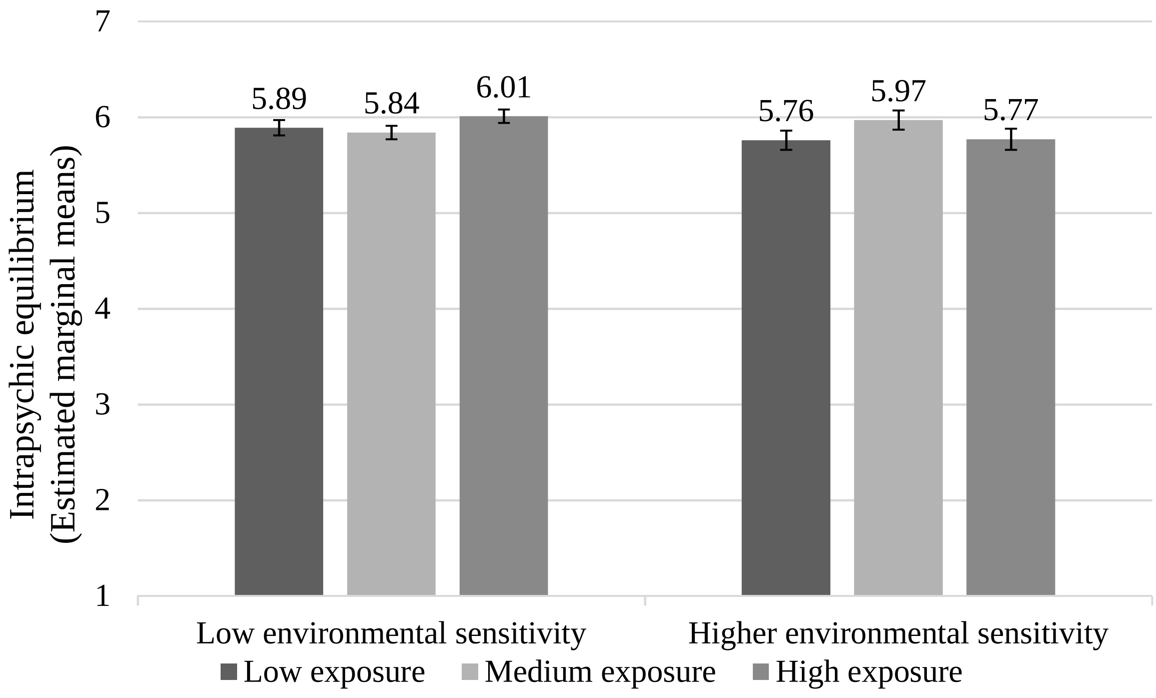

Fig. 1. Interaction effect of intrapsychic equilibrium.

For two subscales of current well-being a main effect of environmental sensitivity was found: People with higher sensitivity to environmental stimuli exhibited lower current well-being regarding vitality ($F(1,466) = 16.42$, $p < .001$***, partial $\eta^2 = .034$) and vigilance ($F(1,467) = 7.82$, $p = .005$**, partial $\eta^2 = .016$) during exposure. No main effect of exposure could be found. Moreover, no significant differences in post hoc comparisons were identified.

Therefore, the detected effects are not attributable to exposure. Assessment of vitality intrapsychic equilibrium, and vigilance decreased significantly over time in all groups irrespective of exposure or environmental sensitivity. Compared to the controlled model, main effects of environmental sensitivity were additionally found in the crude model for intrapsychic equilibrium and social extraversion (see appendix, table A.2).

Table 3

Effect of increased sensitivity to environmental stimuli on current well-being.

	Time	Low exposure		Medium exposure		High exposure		MT		ES		Exposure		MT*ES		MT* Exposure		ES* Exposure	
		EMM	SE	EMM	SE	EMM	SE	F	p	F	p	F	p	F	p	F	p	F	p
Vitality (1-7)[a]																			
Low ES	t1	4.72	0.10	4.61	0.08	4.69	0.08	16.45	**<.001*** **	16.42	**<.001*** **	0.43	.653	0.04	.839	1.58	.206	0.56	.573
	t2	4.61	0.10	4.52	0.09	4.41	0.08												
High ES	t1	4.30	0.13	4.42	0.12	4.34	0.14												
	t2	4.02	0.13	4.27	0.12	4.06	0.14												
Intrapsychic equilibrium (1-7)[b]																			
Low ES	t1	6.00	0.09	5.95	0.08	6.14	0.07	*29.64*	**<.001*** **	1.32	.252	0.43	.649	2.66	.071+	0.41	.523	2.47	.086+
	t2	5.80	0.09	5.74	0.08	5.88	0.08												
High ES	t1	5.92	0.12	5.95	0.10	5.90	0.12												
	t2	5.60	0.12	6.00	0.12	5.63	0.13												
Social extraversion (1-7)[c]																			
Low ES	t1	3.70	0.13	3.64	0.12	3.77	0.11	0.58	.445	1.40	.237	0.74	.476	0.22	.639	0.79	.455	1.54	.215
	t2	3.80	0.13	3.58	0.12	3.69	0.11												
High ES	t1	3.68	0.17	3.73	0.16	3.35	0.19												
	t2	3.66	0.17	3.62	0.16	3.31	0.19												
Vigilance (1-7)[d]																			
Low ES	t1	5.00	0.11	4.96	0.10	4.96	0.09	*45.87*	**<.001*** **	7.82	**.005** **	0.07	.937	0.42	.517	1.41	.244	0.06	.938
	t2	4.69	0.12	4.65	0.10	4.63	0.10												
High ES	t1	4.76	0.15	4.60	0.13	4.74	0.16												
	t2	4.38	0.16	4.45	0.14	4.23	0.17												

Two-way ANCOVA with repeated measures, models controlled for centered variables age, sex, study sample, negative affectivity, physical and mental health, health on day of trial, and sleep quality before trial; in brackets: min-max; ES = Environmental sensitivity, MT = Measurement time, EMM = Estimated marginal mean, SE = Standard error, F = F-value, italic if partial $\eta^2 \geq .06$; p = level of significance: +p ≤ .10; *p ≤ .05; **p ≤ .01; ***p ≤ .001; t1 = start of controlled air regime (dosing/recirculation rate), t2 = end of controlled air regime (dosing/recirculation rate).

[a] Higher values = higher vitality. [b] Higher values = higher intrapsychic equilibrium. [c] Higher values = higher social extraversion. [d] Higher values = higher vigilance.

Perception of air quality

As shown in table 4, no interaction effects or main effects of exposure were found regarding perception of air quality. Individuals with higher environmental sensitivity rated the pleasantness of air quality ($F(1,476) = 7.55$, $p = .006$**, partial $\eta^2 = .016$) and air movement ($F(1,474) = 5.11$, $p = .024$*, partial $\eta^2 = .011$) worse than individuals with low environmental sensitivity. They were also prone to perceive odors more intensively ($F(1,485) = 2.76$, $p = .097^{+}$, partial $\eta^2 = .006$). Pleasantness of air quality and air movement decreased significantly over time in all groups irrespective of exposure or environmental sensitivity. Besides these main effects of environmental sensitivity found in the controlled model, the crude models showed main effect trends of environmental sensitivity for pleasantness of temperature and acceptability and one trend for an exposure main effect – subjects with higher environmental sensitivity tended to rate the temperature as less pleasant and acceptable; moreover, subjects in the high exposure condition tended to rate the temperature as less pleasant as subjects in the low exposure condition (see appendix, table A.3).

Table 4

Effect of increased sensitivity to environmental stimuli on perception of air quality.

	Time	Low exposure		Medium exposure		High exposure		MT		ES		Exposure		MT*ES		MT* Exposure		ES* Exposure	
		EMM	SE	EMM	SE	EMM	SE	F	p	F	p	F	p	F	p	F	p	F	p
Pleasantness of air quality (1-5)[a]																			
Low ES	t1	3.57	0.08	3.61	0.07	3.66	0.06	7.10	**.008****	7.55	**.006****	0.33	.719	0.09	.770	1.08	.342	0.73	.480
	t2	3.41	0.08	3.56	0.07	3.64	0.07												
High ES	t1	3.40	0.10	3.41	0.90	3.45	0.10												
	t2	3.39	0.10	3.42	0.10	3.27	0.11												
Pleasantness of temperature (1-5)[a]																			
Low ES	t1	3.32	0.12	3.32	0.10	3.39	0.10	1.71	.192	2.00	.159	0.34	.711	0.42	.520	0.17	.842	0.35	.708
	t2	3.38	0.12	3.31	0.11	3.26	0.10												
High ES	t1	3.29	0.15	3.29	0.14	3.09	0.16												
	t2	3.17	0.16	3.22	0.14	3.05	0.17												
Pleasantness of air movement (1-5)[a]																			
Low ES	t1	3.59	0.10	3.63	0.08	3.69	0.08	6.70	**.008****	5.11	**.024***	0.15	.859	0.38	.538	0.33	.721	0.57	.566
	t2	3.49	0.10	3.61	0.09	3.57	0.08												
High ES	t1	3.49	0.12	3.52	0.11	3.43	0.13												
	t2	3.43	0.13	3.37	0.12	3.24	0.14												
Acceptability (0-100)[b]																			
Low ES		80.72	1.69	82.63	1.52	83.71	1.44			1.10	.297	0.15	.862					2.15	.118
High ES		83.08	2.19	80.91	2.07	78.09	2.36												
Odor intensity (1-5)[c]																			
Low ES		1.63	0.09	1.63	0.08	1.56	0.07			2.76	.097^{+}	0.50	.610					0.39	.679
High ES		1.67	0.11	1.82	0.10	1.72	0.12												

Two-way ANCOVA (with repeated measures), models controlled for centered variables age, sex, study sample, negative affectivity, physical and mental health, health on day of trial, and sleep quality before trial; in brackets: min-max; ES = Environmental sensitivity, MT = Measurement time, EMM = Estimated marginal mean, SE = Standard error, F = F-value, italic if partial $\eta^2 \geq .06$; p = level of significance: +p ≤ .10; *p ≤ .05; **p ≤ .01; ***p ≤ .001; t1 = middle of controlled air regime (dosing/recirculation rate), t2 = end of controlled air regime (dosing/recirculation rate).

[a] Higher values = higher pleasantness of air quality, temperature, and air movement, respectively. [b] Higher values = higher acceptability of air quality. [c] Higher values = overwhelming odor.

Sensitivity analysis

Sex

Since the sex distribution differs in low and higher environmental sensitivity groups and previous studies suggest differences between men and women, a sensitivity analysis was performed. This is to test whether males and females with higher environmental sensitivity react differently to the exposures. For current well-being, differences between men and women were only found for intrapsychic equilibrium while the three other subscales showed comparable patterns for both sexes. Men with low environmental sensitivity showed higher intrapsychic equilibrium than men with higher environmental sensitivity ($F(1, 267) = 7.07$, $p = .008$**, partial $\eta^2 = .001$; see appendix, table A.4). In contrast, for women an interaction effect of repeated measure and exposure for intrapsychic equilibrium was found ($F(2,206) = 4.87$, $p = .009$**, partial $\eta^2 = .045$; see appendix, table A.5). During first measurement, women in the medium exposure group indicated the lowest intrapsychic equilibrium whereas women during second measurement in the medium exposure group indicated the highest intrapsychic equilibrium.

Perceptions of air quality showed a number of differences between men and women. Men with low environmental sensitivity rated the air quality as more pleasant than men with higher environmental sensitivity ($F(1, 271) = 7.02$, $p = .009$**, partial $\eta^2 = .025$; see appendix, table A.6), while no differences were seen for women. Moreover, for men, but not for women, an interaction effect of repeated measurement and environmental sensitivity was found for pleasantness of air quality ($F(1, 271) = 4.42$, $p = .036$*, partial $\eta^2 = .016$). Men with low environmental sensitivity perceived increasing pleasantness of air quality whereas men with higher environmental sensitivity showed the opposite pattern. Overall, men with low environmental sensitivity perceived the air quality as better than the men with high environmental sensitivity. In contrast, for women but not for men main effects of environmental sensitivity were found for pleasantness of temperature ($F(1,210) = 7.66$, $p = .006$**, partial $\eta^2 = .035$) and air movement ($F(1, 211) = 6.81$, $p = .010$**, partial $\eta^2 = .031$) which were rated better by women in the low environmental sensitivity group than by women in the higher environmental sensitivity group (see appendix, table A.7). In addition, main effects of exposure for pleasantness of temperature ($F(2,210) = 3.30$, $p = .039$*, partial $\eta^2 = .030$) and air movement ($F(2,210) = 3.40$, $p = .035$*, partial $\eta^2 = .031$) driven by the medium exposure group were found for women but not for men. Overall, no systematic differences between men and women could be found.

Negative affectivity

As literature showed a strong association between negative affectivity and environmental sensitivity, negative affectivity instead of environmental sensitivity was used as main factor. In contrast to environmental sensitivity, negative affectivity indicated a main effect for intrapsychic equilibrium: Subjects with low negative affectivity reported a higher intrapsychic equilibrium ($F(1,466) = 4.27$, $p = .043$*, partial $\eta^2 = .009$). They also tended to report higher social extraversion and higher vitality (see appendix, table A.8). In contrast to environmental sensitivity, no main effects of negative affectivity could be found for vigilance. For none of the variables regarding perception of air quality main effects of negative affectivity or interactions were found (see appendix, table A.9).

Discussion

This study explored the effects of low-level environmental sensitivity during acute exposure to different air quality levels. Some differences between individuals with low and higher sensitivity to environmental stimuli regarding current well-being and perception of air quality could be observed. Regardless of the level of exposure, individuals with higher environmental sensitivity showed less vitality and vigilance than individuals with lower environmental sensitivity. In addition, and also regardless of the level of exposure, individuals with higher environmental sensitivity perceived the temperature and air movement as less pleasant than individuals with lower environmental sensitivity. Thus, these results support hypothesis 1 and 3, although the differences are rather small. A moderating role of environmental sensitivity for the effects of exposure on current well-being or perception of air quality could not be demonstrated: Individuals with higher environmental sensitivity did not show a stronger reaction to higher exposure levels compared to individuals with lower environmental sensitivity. Hypothesis 2 and 4 must therefore be rejected. In addition and contrary to what is reported in literature, sensitivity analyses showed no systematic differences between men and women but only few scattered effects. For example, men, but not women, with low environmental sensitivity rated the air quality as more pleasant. Moreover, they perceived increasing pleasantness of air quality whereas men with higher environmental sensitivity showed the opposite pattern. This suggests that the response of men with higher environmental sensitivity exacerbates during exposure, whereas it improves for individuals with low environmental sensitivity. Sensitivity analyses regarding person-related variables (in comparison with environmental sensitivity) indicated that for current well-being environmental sensitivity showed stronger effects, but negative affectivity showed more main effects at 10% error level; thus, showing no clear superiority of one concept over the other. This result is similar to results from Cheung et al. (2022) about the Big Five in terms of the very small effects of person-related variables. Overall, for prediction of environmental perception environmental sensitivity is more suitable than other person-related variables.co Results suggest that even a small increase in environmental sensitivity leads to effects. It can be assumed that environmental sensitivity is a relevant factor regarding the evaluation of the environment, but not regarding the evaluation of the current well-being. Depending on the study aim, it seems recommendable to use one of the two variables. Environmental sensitivity could be included in research as a control variable when the environment is assessed or when assessments are used in an exposure study. Otherwise, the results might be biased. Even though environmental sensitivity showed only small effects, it can have an impact as presented in the present trial.

Although we investigated a just slightly elevated level of environmental sensitivity in this study, the results are in line with MCS related results from previous studies. We did not find differences in the evaluation of odor intensity which is in line with Andersson et al. (2014). In addition, we could not find any differences regarding pleasantness of temperature, or acceptability between individuals with low and higher environmental sensitivity. However, our results suggest that people with higher environmental sensitivity perceive air quality and air movement as less pleasant. Similarly, Alobid et al. (2014) and Ojima et al. (2002) found differences regarding the pleasantness of odor between subjects with MCS and the control groups. This differential results regarding the evaluation of aspects of air quality might in part be due to different assessment methods but also show that people are indeed capable to differentiate between the (intended) underlying constructs of pleasantness, acceptability and satisfaction. To sum up, we cannot confirm that people react differently at different exposure levels or that reactions increase at higher exposures. It seems that no clear reference to real environment exists, but that it is more likely to be a psychological phenomenon. This supports psychological theories about the etiology of increased environmental sensitivity. Different from assumptions from toxicological theories (e.g., Genius, 2010; Terr, 1987), the reactions are less likely to be triggered by exposure, but rather an endogenous self-induced effect (Rossi and Pitidis, 2018) or a learning effect (Van den Bergh et al., 2017). These results are also supported by Bornschein et al. (2008): Twenty individuals with MCS and 17 controls were exposed to a solvent mixture or clean air in six random-order sessions (double-blind). Individuals with MCS did not differ regarding sensitivity, specificity, and efficiency from controls, that is, they were no more able to differentiate between real and placebo conditions than controls. Thus, no direct relation to the real environmental conditions could be found either.

Most studies found that more women are affected by MCS (e.g., Andersson et al., 2008; Berg et al., 2010; Hausteiner et al., 2005) and we also see this in our study population, even for only slightly elevated levels of environmental sensitivity. Furthermore, it could be demonstrated that individuals with increased environmental sensitivity report a poorer general well-being (Georgellis et al., 2003; Johnson and Colman, 2017) as well as a poorer current well-being. Compared to Johnson and Colman (2017), no systematic sex differences in well-being between individuals with low and higher environmental sensitivity were detected.

As a subscale of current well-being, vigilance showed lower values for individuals with higher environmental sensitivity. Other studies also found that the attention of people with MCS or IEI is impaired (e.g., Bornschein et al., 2007; Ziem and McTamney, 1997). Bornschein et al. (2007) assumed that people with IEI are only selectively attentive because they are mainly occupied with their physical sensations. Witthöft et al. (2006) also found this selective attention for people with IEI in their study. In an emotional stroop test, interference indices and recognition performance for IEI-trigger-related words were lower than for symptom-related words (Witthöft et al., 2006).

Since the air quality levels were produced differently in the two projects from which the data was pooled, a bias cannot be ruled out. A general difference (independent of exposure level) between the studies was found for pleasantness of temperature and air movement; the study that let the VOC and CO_2 naturally develop by reducing fresh air supply showed better ratings than the study where both were dosed into the supply air. To control for this, we added the projects as control variable in all analyses. Another difficulty could be temperature and humidity in the middle exposure. Although in general rather comparable, in the middle exposure both were highest on average, and it cannot be ruled out that these also had an effect. Especially since the standard deviations of the different exposure levels must be noted and the relative humidity – as an uncontrolled environmental factor – was very low. However, Grün et al. (2012) determined that low humidity is not related to perceived symptoms.

Nevertheless, no effects were found between low and high exposure level regarding air quality. In addition, exposure levels could bias the results due to the classification into three conditions. Especially the allocation of CO_2 needs improvements due to the focus on VOC. As already described in the introduction, odor is important regarding environmental sensitivity. Thus, we decided to focus on VOCs. However, the levels of TVOC might have been too low to cause effects and categorization of conditions was quite arbitrary so that group differences were rather small and “poor” air quality ratings were still good. Due to the relatively low TVOC levels, it is possible that some subjects did not detect the odors and therefore did not react. Many studies on MCS used detectable odors such as mandarin, perfume, lavender oil, acetone, butanol, or methanol (e.g., Hillert et al., 2007; Azuma et al., 2013). Compared to control groups, patients with MCS process odors differently (Hillert et al., 2007; Azuma et al., 2013). Among other things, Azuma et al. (2013) report that this difference is caused by changes in the regional cerebral blood flow (rCBF) in the prefrontal cortex. In their study, there was initially no increase in rCBF when non-odorant was presented, but over time rCBF increased during non-odorant condition. That is, patients with MCS were no longer able to distinguish between non-odorant and odor condition (Azuma et al., 2013) and responded independent of the exposure level. To examine in the present study whether and which odors the subjects perceived, they were asked by an open question to describe the odor if they perceived one. Common responses from 223 subjects were musty, metallic, neutral, fresh, or sweaty odor. However, some subjects smelled aftershave, perfume, floral odor, mandarin, tobacco smoke, disinfectant, or exhaust fumes which were also mentioned in the studies by Hillert et al. (2007) and Azuma et al. (2013). Therefore, it can be assumed that there were detectable odors despite the low exposure level.

Another limitation relates to the dichotomization of the chemical odor sensitivity scale to focus on group differences between low and higher environmental sensitivity, as it resulted in a loss of information. Levels of environmental sensitivity were also very low in the sample.

However, it can be assumed that people with a very high environmental sensitivity do not participate in air quality assessment studies as they have been informed about the topic in advance. Nevertheless, we did not specifically exclude these people. In general, effect sizes demonstrated rather small, but significant effects. Based on our sample size estimation, power was sufficient, and we are fairly sure that the effects are reliable. However, further research is necessary. Furthermore, an expectation bias could distort the results because the subjects knew that different levels of air conditions existed but not in which condition they participated. A focus of the participants on this information could influence the actual valuation.

Conclusion

This study explored the effect of slightly higher levels of sensitivity to environmental stimuli on perception of air quality and well-being in randomized and controlled exposure trials during different exposure conditions. Although self-reported environmental sensitivity was only slightly elevated, participants showed poorer well-being and worse perception of quality during exposure but independent of exposure level. Differential effects were found for women and men, but no systematic pattern emerged. Accordingly, general expectations and previous findings on environmental sensitivity between the sexes could not be confirmed. It is expected that environmental sensitivity will also influence other variables and that the number of affected people will continue to increase. For example, Steinemann (2018) mentioned an increase of self-reported and diagnosed MCS over the last years even though no explanations are given, whereas Platt-Mills (2015) reports a shift to indoor lifestyle as one reason for the aspect of increasing prevalence of many allergies over the last decades. Therefore, environmental sensitivity beyond clinical phenomena should be further investigated. In addition, there should be further studies that confirm the psychological etiology and investigate the associations with other person-related variables.

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Appendix A

Table A.1
Intercorrelations.

	1	2	3	4	5	6	7	8
1. Sex (1 = male, 2 = female)								
2. Age	**-.088***							
3. BMI	**-.363*** **	**.274*** **						
4. Smoking (1 = I've never smoked before, 4 = yes, daily)	**-.164*** **	-.027	**.110***					
5. Negative affectivity[a]	.051	-.007	-.054	.079				
6. Physical and mental health[b]	**.084**	-.059	-.033	**.155*** **	**.480*** **			
7. Health on day of trial[c]	**-.104***	.013	.011	**-.163*** **	**-.173*** **	**-.326*** **		
8. Sleep quality before trial[d]	.052	-.050	-.040	**-.106***	**-.101***	**-.099***	**.096***	
9. Environmental sensitivity[e]	**.227*** **	.055	-.055	-.046	**.215*** **	**.246*** **	**-.142*** **	-.004

Pearson-correlations except for sex and smoking. *p ≤ .05; **p ≤ .01; ***p ≤ .001.
[a] Higher values = higher negative affectivity. [b] Higher values = worse health status. [c] Higher values = better current health. [d] Higher values = better sleep quality. [e] Higher values = higher environmental sensitivity.

Table A.2

Crude model: Effect of increased sensitivity to environmental stimuli on current well-being.

	Time	Low exposure		Medium exposure		High exposure		MT		ES		Exposure		MT*ES		MT* Exposure		ES* Exposure	
		M	SE	M	SE	M	SE	F	p	F	p	F	p	F	p	F	p	F	p
Vitality (1-7)[a]																			
Low ES	t1	4.89	0.10	4.58	0.09	4.74	0.09	15.85	**<.001*** **	*34.85*	**<.001*** **	0.42	.656	0.00	.960	1.14	.322	2.41	.091
	t2	4.77	0.11	4.47	0.10	4.48	0.09												
High ES	t1	4.11	0.14	4.31	0.13	4.20	0.14												
	t2	4.02	0.15	4.16	0.13	3.97	0.15												
Intrapsychic equilibrium (1-7)[b]																			
Low ES	t1	6.16	0.09	5.92	0.08	6.18	0.08	*31.74*	**<.001*** **	9.28	**.002** **	0.01	.990	0.73	.395	3.51	**.031* **	3.76	**.024* **
	t2	5.90	0.09	5.72	0.08	5.92	0.08												
High ES	t1	5.83	0.12	5.84	0.11	5.79	0.12												
	t2	5.50	0.12	5.90	0.12	5.54	0.13												
Social extraversion (1-7)[c]																			
Low ES	t1	3.84	0.13	3.63	0.12	3.78	0.11	0.76	.384	6.80	**.009** **	1.55	.214	1.27	.260	0.85	.430	1.87	.155
	t2	3.98	0.13	3.58	0.12	3.72	0.11												
High ES	t1	3.59	0.18	3.66	0.16	3.26	0.18												
	t2	3.53	0.18	3.53	0.16	3.19	0.18												
Vigilance (1-7)[d]																			
Low ES	t1	5.01	0.12	4.91	0.10	4.98	0.10	*47.11*	**<.001*** **	16.81	**<.001*** **	0.58	.563	0.51	.477	1.13	.324	0.38	.683
	t2	4.88	0.12	4.61	0.11	4.66	0.11												
High ES	t1	4.68	0.16	4.54	0.14	4.61	0.16												
	t2	4.26	0.16	4.39	0.15	4.16	0.17												

Two-way ANOVA with repeated measures, models not controlled; in brackets: min-max; ES = Environmental sensitivity, MT = Measurement time, M = Mean, SE = Standard error, F = F-value, italic if partial $\eta^2 \geq .06$; p = level of significance: +p ≤ .10; *p ≤ .05; **p ≤ .01; ***p ≤ .001; t1 = start of controlled air regime (dosing/recirculation rate), t2 = end of controlled air regime (dosing/recirculation rate).

[a] Higher values = higher vitality. [b] Higher values = higher intrapsychic equilibrium. [c] Higher values = higher social extraversion. [d] Higher values = higher vigilance.

Table A.3

Crude model: Effect of increased sensitivity to environmental stimuli on perception of air quality.

	Time	Low exposure		Medium exposure		High exposure		MT		ES		Exposure		MT*ES		MT* Exposure		ES* Exposure	
		M	SE	M	SE	M	SE	F	p	F	p	F	p	F	p	F	p	F	p
Pleasantness of air quality (1-5)[a]																			
Low ES	t1	3.62	0.07	3.56	0.07	3.68	0.06	5.19	**.023***	7.70	**.004****	0.13	.881	0.13	.722	0.75	.471	0.78	.460
	t2	3.48	0.08	3.52	0.07	3.65	0.07												
High ES	t1	3.40	0.10	3.42	0.90	3.44	0.10												
	t2	3.41	0.10	3.42	0.10	3.28	0.11												
Pleasantness of temperature (1-5)[a]																			
Low ES	t1	3.46	0.12	3.31	0.10	3.35	0.10	1.15	.284	3.81	.051[+]	2.97	.052[+]	0.05	.828	0.82	.443	1.00	.369
	t2	3.51	0.12	3.32	0.11	3.19	0.10												
High ES	t1	3.31	0.15	3.31	0.14	2.94	0.16												
	t2	3.25	0.16	3.28	0.15	2.88	0.16												
Pleasantness of air movement (1-5)[a]																			
Low ES	t1	3.70	0.10	3.57	0.09	3.66	0.08	7.47	**.007****	6.14	**.014***	1.39	.251	0.71	.401	0.07	.933	1.24	.290
	t2	3.59	0.10	3.57	0.09	3.55	0.08												
High ES	t1	3.56	0.13	3.57	0.12	3.30	0.13												
	t2	3.46	0.13	3.39	0.12	3.16	0.13												
Acceptability (0-100)[b]																			
Low ES		82.06	1.64	82.53	1.49	83.82	1.42			3.05	.081[+]	0.38	.685					1.67	.189
High ES		82.50	2.15	80.51	2.04	77.45	2.24												
Odor intensity (1-5)[b]																			
Low ES		1.59	0.08	1.62	0.07	1.54	0.07			5.78	**.017***	0.70	.498					0.24	.784
High ES		1.70	0.11	1.85	0.10	1.75	0.11												

Two-way ANOVA (with repeated measures), models not controlled; in brackets: min-max; ES = Environmental sensitivity, MT = Measurement time, M = Mean, SE = Standard error, F = F-value, italic if partial $\eta^2 \geq .06$; p = level of significance: +$p \leq .10$; *$p \leq .05$; **$p \leq .01$; ***$p \leq .001$; t1 = middle of controlled air regime (dosing/recirculation rate), t2 = end of controlled air regime (dosing/recirculation rate).

[a] Higher values = higher pleasantness of air quality, temperature, and air movement, respectively. [b] Higher values = higher acceptability of air quality. [c] Higher values = overwhelming odor.

Table A.4

Effect of increased sensitivity to environmental stimuli on current well-being: sensitivity analysis for men.

	Time	Low exposure		Medium exposure		High exposure		MT		ES		Exposure		MT*ES		MT* Exposure		ES* Exposure	
		EMM	SE	EMM	SE	EMM	SE	F	p	F	p	F	p	F	p	F	p	F	p
Vitality (1-7)[a]																			
Low ES	t1	4.92	0.12	4.66	0.11	4.90	0.11	3.25	.073+	14.61	**<.001*** **	0.34	.710	0.13	.715	2.12	.122	0.57	.566
	t2	4.85	0.13	4.55	0.12	4.55	0.11												
High ES	t1	4.21	0.22	4.47	0.19	4.35	0.12												
	t2	4.34	0.23	4.16	0.20	4.15	0.20												
Intrapsychic equilibrium (1-7)[b]																			
Low ES	t1	6.17	0.10	5.98	0.09	6.26	0.09	3.35	.068+	7.07	**.008** **	0.08	.923	2.86	.092+	1.28	.280	1.93	.148
	t2	5.86	0.11	5.69	0.10	5.96	0.10												
High ES	t1	5.63	0.18	5.88	0.16	5.82	0.15												
	t2	5.71	0.20	5.78	0.18	5.47	0.17												
Social extraversion (1-7)[c]																			
Low ES	t1	3.87	0.16	3.74	0.14	3.80	0.14	0.30	.584	2.03	.155	1.40	.248	1.02	.314	2.36	.097+	1.66	.193
	t2	4.13	0.16	3.71	0.14	3.80	0.14												
High ES	t1	3.68	0.28	4.03	0.25	3.21	0.24												
	t2	3.70	0.28	3.72	0.25	3.35	0.24												
Vigilance (1-7)[d]																			
Low ES	t1	5.01	0.13	4.95	0.12	5.19	0.12	1.20	.275	8.62	**.004** **	0.28	.759	0.09	.765	0.68	.506	0.03	.974
	t2	4.84	0.15	4.70	0.13	4.74	0.13												
High ES	t1	4.62	0.24	4.65	0.21	4.75	0.20												
	t2	4.36	0.26	4.29	0.23	4.39	0.22												

Two-way ANCOVA with repeated measures, models controlled for age, sex, study sample, environmental sensitivity, physical and mental health, health on day of trial, and sleep quality before trial; in brackets: min-max; ES = Environmental sensitivity, MT = Measurement time, EMM = Estimated marginal mean, SE = Standard error, F = F-value, italic if partial $\eta^2 \geq .06$; p = level of significance: +p ≤ .10; *p ≤ .05; **p ≤ .01; ***p ≤ .001; t1 = start of controlled air regime (dosing/recirculation rate), t2 = end of controlled air regime (dosing/recirculation rate).

[a] Higher values = higher vitality. [b] Higher values = higher intrapsychic equilibrium. [c] Higher values = higher social extraversion. [d] Higher values = higher vigilance.

Table A.5

Effect of increased sensitivity to environmental stimuli on current well-being: sensitivity analysis for women.

	Time	Low exposure		Medium exposure		High exposure		MT		ES		Exposure		MT*ES		MT* Exposure		ES* Exposure	
		EMM	SE	EMM	SE	EMM	SE	F	p	F	p	F	p	F	p	F	p	F	p
Vitality (1-7)[a]																			
Low ES	t1	4.74	0.18	4.58	0.15	4.47	0.14	0.23	.636	*17.98*	**<.001*** **	0.82	.442	0.03	.864	0.55	.577	0.33	.721
	t2	4.54	0.18	4.47	0.15	4.33	0.14												
High ES	t1	4.09	0.17	4.14	0.16	4.01	0.21												
	t2	3.89	0.17	4.09	0.16	3.74	0.21												
Intrapsychic equilibrium (1-7)[b]																			
Low ES	t1	6.04	0.17	5.87	0.14	6.08	0.13	1.86	.174	2.10	.148	0.01	.994	0.37	.546	4.87	**.009*** *	0.86	.426
	t2	5.96	0.17	5.80	0.15	5.85	0.13												
High ES	t1	5.95	0.16	5.77	0.15	5.84	0.20												
	t2	5.39	0.17	5.96	0.15	5.63	0.20												
Social extraversion (1-7)[c]																			
Low ES	t1	3.68	0.23	3.54	0.20	3.77	0.18	0.02	.900	2.72	.101	0.22	.800	0.16	.691	0.47	.627	0.45	.641
	t2	3.57	0.22	3.46	0.19	3.66	0.18												
High ES	t1	3.52	0.22	3.35	0.21	3.37	0.28												
	t2	3.41	0.22	3.31	0.20	3.07	0.27												
Vigilance (1-7)[d]																			
Low ES	t1	5.05	0.20	5.00	0.17	4.70	0.16	0.66	.419	8.76	**.003*** *	0.74	.477	0.46	.499	0.81	.448	0.02	.981
	t2	4.77	0.21	4.60	0.18	4.58	0.16												
High ES	t1	4.70	0.20	4.35	0.18	4.52	0.24												
	t2	4.20	0.20	4.33	0.19	4.97	0.25												

Two-way ANCOVA with repeated measures, models controlled for age, sex, study sample, environmental sensitivity, physical and mental health, health on day of trial, and sleep quality before trial; in brackets: min-max; ES = Environmental sensitivity, MT = Measurement time, EMM = Estimated marginal mean, SE = Standard error, F = F-value, italic if partial $\eta^2 \geq .06$; p = level of significance: +p ≤ .10; *p ≤ .05; **p ≤ .01; ***p ≤ .001; t1 = start of controlled air regime (dosing/recirculation rate), t2 = end of controlled air regime (dosing/recirculation rate).

[a] Higher values = higher vitality. [b] Higher values = higher intrapsychic equilibrium. [c] Higher values = higher social extraversion. [d] Higher values = higher vigilance.

Table A.6

Effect of increased sensitivity to environmental stimuli on perception of air quality: sensitivity analysis for men.

	Time	Low exposure		Medium exposure		High exposure		MT		ES		Exposure		MT*ES		MT* Exposure		ES* Exposure	
		EMM	SE	EMM	SE	EMM	SE	F	p	F	p	F	p	F	p	F	p	F	p
Pleasantness of air quality (1-5)[a]																			
Low ES	t1	3.63	0.08	3.54	0.07	3.67	0.07	1.55	.214	7.02	**.009****	2.30	.102	4.42	**.036***	2.64	.073^{+}	0.76	.470
	t2	3.50	0.09	3.43	0.08	3.64	0.08												
High ES	t1	3.34	0.14	3.13	0.13	3.47	0.13												
	t2	3.65	0.16	3.20	0.15	3.26	0.14												
Pleasantness of temperature (1-5)[a]																			
Low ES	t1	3.41	0.14	3.31	0.13	3.41	0.13	1.37	.242	0.00	.953	1.38	.254	0.81	.368	1.44	.239	0.42	.659
	t2	3.43	0.14	3.29	0.13	3.35	0.12												
High ES	t1	3.56	0.24	3.30	0.22	3.40	0.22												
	t2	3.50	0.24	2.92	0.22	3.47	0.22												
Pleasantness of air movement (1-5)[a]																			
Low ES	t1	3.62	0.12	3.41	0.10	3.69	0.10	0.19	.665	2.16	.143	2.38	.094^{+}	0.25	.620	0.45	.641	0.02	.982
	t2	3.53	0.12	3.40	0.11	3.63	0.10												
High ES	t1	3.42	0.20	3.36	0.18	3.45	0.18												
	t2	3.44	0.20	3.06	0.18	3.50	0.18												
Acceptability (0-100)[b]																			
Low ES		82.12	1.94	81.17	1.79	85.11	1.77			0.93	.397	1.75	.098^{+}					2.14	.120
High ES		83.89	3.35	77.78	3.05	76.22	3.01												
Odor intensity (1-5)[c]																			
Low ES		1.51	0.10	1.58	0.09	1.59	0.09			3.36	.068^{+}	0.14	.871					0.03	.976
High ES		1.73	0.17	1.79	0.16	1.76	0.15												

Two-way ANCOVA (with repeated measures), models controlled for age, sex, study sample, environmental sensitivity, physical and mental health, health on day of trial, and sleep quality before trial; in brackets: min-max; ES = Environmental sensitivity, MT = Measurement time, EMM = Estimated marginal mean, SE = Standard error, F = F-value, italic if partial $\eta^2 \geq .06$; p = level of significance: $+p \leq .10$; $*p \leq .05$; $**p \leq .01$; $***p \leq .001$; t1 = middle of controlled air regime (dosing/recirculation rate), t2 = end of controlled air regime (dosing/recirculation rate).

[a] Higher values = higher pleasantness of air quality, temperature, and air movement, respectively. [b] Higher values = higher acceptability of air quality. [c] Higher values = overwhelming odor.

Table A.7

Effect of increased sensitivity to environmental stimuli on perception of air quality: sensitivity analysis for women.

	Time	Low exposure		Medium exposure		High exposure		MT		ES		Exposure		MT*ES		MT* Exposure		ES* Exposure	
		EMM	SE	EMM	SE	EMM	SE	F	p	F	p	F	p	F	p	F	p	F	p
Pleasantness of air quality (1-5)[a]																			
Low ES	t1	3.55	0.14	3.66	0.12	3.68	0.11	0.21	.650	3.44	.065^{+}	1.46	.235	0.79	.377	1.98	.140	0.34	.713
	t2	3.39	0.15	3.73	0.12	3.68	0.11												
High ES	t1	3.45	0.13	3.57	0.13	3.42	0.16												
	t2	3.27	0.14	3.53	0.13	3.33	0.16												
Pleasantness of temperature (1-5)[a]																			
Low ES	t1	3.36	0.20	3.39	0.17	3.39	0.15	1.00	.318	7.66	**.006****	3.30	**0.39***	0.21	.644	1.78	.171	1.53	.220
	t2	3.37	0.20	3.44	0.17	3.14	0.16												
High ES	t1	3.06	0.19	3.22	0.18	2.60	0.20												
	t2	2.96	0.20	3.38	0.18	2.52	0.23												
Pleasantness of air movement (1-5)[a]																			
Low ES	t1	3.62	0.16	3.89	0.14	3.73	0.13	1.66	.200	6.81	**.010****	3.40	**.035***	0.54	.461	1.37	.258	1.09	.339
	t2	3.54	0.17	3.90	0.15	3.51	0.13												
High ES	t1	3.57	0.16	3.61	0.15	3.27	0.19												
	t2	3.42	0.17	3.53	0.16	3.96	0.20												
Acceptability (0-100)[b]																			
Low ES		80.83	3.05	85.16	2.60	82.46	2.38			0.63	.428	0.51	.602					0.26	.771
High ES		81.36	2.91	81.86	2.83	79.58	3.52												
Odor intensity (1-5)[c]																			
Low ES		1.77	0.14	1.70	0.12	1.45	0.11			1.46	.229	1.17	.311					0.91	.404
High ES		1.70	0.14	1.89	0.13	1.73	0.16												

Two-way ANCOVA (with repeated measures), models controlled for age, sex, study sample, environmental sensitivity, physical and mental health, health on day of trial, and sleep quality before trial; in brackets: min-max; ES = Environmental sensitivity, MT = Measurement time, EMM = Estimated marginal mean, SE = Standard error, F = F-value, italic if partial $\eta^2 \geq .06$; p = level of significance: +p ≤ .10; *p ≤ .05; **p ≤ .01; ***p ≤ .001; t1 = middle of controlled air regime (dosing/recirculation rate), t2 = end of controlled air regime (dosing/recirculation rate).

[a] Higher values = higher pleasantness of air quality, temperature, and air movement, respectively. [b] Higher values = higher acceptability of air quality. [c] Higher values = overwhelming odor.

Table A.8

Effect of negative affectivity on current well-being.

	Time	Low exposure		Medium exposure		High exposure		MT		NA		Exposure		MT*NA		MT* Exposure		NA* Exposure	
		EMM	SE	EMM	SE	EMM	SE	F	p	F	p	F	p	F	p	F	p	F	p
Vitality (1-7)[a]																			
Low NA	t1	4.64	0.09	4.56	0.08	4.65	0.09	2.78	.096^{+}	3.21	.074^{+}	0.21	.807	0.06	.801	0.93	.397	0.97	.379
	t2	4.57	0.10	4.46	0.09	4.34	0.09												
High NA	t1	4.43	0.15	4.53	0.12	4.44	0.12												
	t2	4.22	0.16	4.38	0.13	4.25	0.13												
Intrapsychic equilibrium (1-7)[b]																			
Low NA	t1	5.98	0.08	6.01	0.07	6.18	0.08	1.03	.310	4.27	**.043***	0.10	.902	0.00	.996	3.52	**.030***	0.97	.379
	t2	5.80	0.09	5.82	0.08	5.88	0.08												
High NA	t1	6.05	0.13	5.82	0.11	5.81	0.11												
	t2	5.53	0.15	5.83	0.12	5.65	0.12												
Social extraversion (1-7)[c]																			
Low NA	t1	3.83	0.12	3.65	0.12	3.72	0.12	1.28	.259	3.50	.062^{+}	0.06	.945	1.85	.158	0.60	.551	0.09	.770
	t2	3.92	0.12	3.61	0.11	3.61	0.12												
High NA	t1	3.35	0.21	3.70	0.17	3.49	0.17												
	t2	3.32	0.20	3.56	0.17	3.51	0.17												
Vigilance (1-7)[d]																			
Low NA	t1	4.85	0.11	4.87	0.10	5.00	0.10	0.34	.561	1.09	.297	0.10	.907	0.13	.723	0.82	.443	0.49	.611
	t2	4.65	0.11	4.56	0.10	4.55	0.11												
High NA	t1	4.91	0.18	4.76	0.14	4.66	0.14												
	t2	4.41	0.19	4.64	0.15	4.43	0.15												

Two-way ANCOVA with repeated measures, models controlled for age, sex, study sample, environmental sensitivity, physical and mental health, health on day of trial, and sleep quality before trial; in brackets: min-max; NA = Negative affectivity, MT = Measurement time, EMM = Estimated marginal mean, SE = Standard error, F = F-value, italic if partial $\eta^2 \geq .06$; p = level of significance: +p ≤ .10; *p ≤ .05; **p ≤ .01; ***p ≤ .001; t1 = start of controlled air regime (dosing/recirculation rate), t2 = end of controlled air regime (dosing/recirculation rate).

[a] Higher values = higher vitality. [b] Higher values = higher intrapsychic equilibrium. [c] Higher values = higher social extraversion. [d] Higher values = higher vigilance.

Table A.9

Effect of negative affectivity on perception of air quality.

	Time	Low exposure		Medium exposure		High exposure		MT		NA		Exposure		MT*NA		MT* Exposure		NA* Exposure	
		EMM	SE	EMM	SE	EMM	SE	F	p	F	p	F	p	F	p	F	p	F	p
Pleasantness of air quality (1-5)[a]																			
Low NA	t1	3.50	0.70	3.51	0.07	3.61	0.07	0.38	.539	0.46	.500	0.63	.534	0.46	.498	0.97	.382	0.81	.448
	t2	3.38	0.08	3.50	0.07	3.55	0.07												
High NA	t1	3.55	0.11	3.61	0.09	3.56	0.09												
	t2	3.45	0.12	3.64	0.10	3.51	0.10												
Pleasantness of temperature (1-5)[a]																			
Low NA	t1	3.38	0.11	3.32	0.10	3.25	0.10	0.16	.686	0.29	.591	0.07	.929	0.03	.872	1.15	.318	0.94	.393
	t2	3.37	0.11	3.27	0.10	3.20	0.11												
High NA	t1	3.11	0.19	3.27	0.15	3.41	0.15												
	t2	3.12	0.19	3.31	0.15	3.20	0.15												
Pleasantness of air movement (1-5)[a]																			
Low NA	t1	3.51	0.09	3.60	0.08	3.62	0.08	0.04	.838	0.23	.631	0.14	.872	0.09	.764	0.61	.546	0.30	.742
	t2	3.47	0.09	3.49	0.09	3.50	0.09												
High NA	t1	3.67	0.15	3.61	0.12	3.60	0.12												
	t2	3.49	0.15	3.62	0.13	3.42	0.13												
Acceptability (0-100)[b]																			
Low NA		80.66	1.58	81.32	1.50	82.92	1.52			0.43	.514	0.11	.901					1.43	.514
High NA		84.32	2.59	83.54	2.19	80.46	2.17												
Odor intensity (1-5)[c]																			
Low NA		1.67	0.80	1.70	0.08	1.61	0.08			0.33	.563	0.37	.693					0.09	.914
High NA		1.58	0.13	1.65	0.11	1.60	0.11												

Two-way ANCOVA (with repeated measures), models controlled for age, sex, study sample, environmental sensitivity, physical and mental health, health on day of trial, and sleep quality before trial; in brackets: min-max; NA = Negative affectivity, MT = Measurement time, EMM = Estimated marginal mean, SE = Standard error, F = F-value, italic if partial $\eta^2 \geq .06$; p = level of significance: +p ≤ .10; *p ≤ .05; **p ≤ .01; ***p ≤ .001; t1 = middle of controlled air regime (dosing/recirculation rate), t2 = end of controlled air regime (dosing/recirculation rate).

[a] Higher values = higher pleasantness of air quality, temperature, and air movement, respectively. [b] Higher values = higher acceptability of air quality. [c] Higher values = overwhelming odor.

Appendix B

Exposure characteristics in included experimental sessions and allocation to exposure levels.

Exposure level	Project	TVOC (µg/m³)	CO_2 (ppm)	Pressure (hPa)	Temperature (°C)	Relative humidity (%)	Fresh air rate (m³/h)	Recirc air rate (m³/h)	N
Low	ComAir1	203	1683	755	22.4	13.5	790	629	39
Low	ComAir2	624	1981	755	22.7	16.6	483	903	35
Low	CognitAir1	761	2615	755	23.0	10.0	1325	200	38
Low	ComAir3	770	1555	755	22.7	16.1	738	616	34
Medium	CognitAir2	864	1295	755	22.8	9.0	1328	200	30
Medium	ComAir4	892	2020	755	23.6	16.8	547	903	39
Medium	CognitAir3	1139	2746	755	21.7	10.0	1359	207	37
Medium	ComAir5	1152	2744	755	23.2	21.5	281	1109	37
Medium	ComAir6	1156	2813	755	23.5	19.1	253	1100	34
High	CognitAir4	1382	4101	755	22.3	9.0	1331	199	36
High	ComAir7	1417	4150	755	23.6	21.3	175	1181	36
High	CognitAir5	1556	3952	755	21.3	9.0	1325	202	33
High	ComAir8	1620	3322	755	23.6	22.6	157	1200	35
High	CognitAir6	2103	1289	755	22.3	10.0	1343	204	40

Mean during entire exposure.

Appendix C

In the ComAir project, different air qualities were generated by changing the fresh air / recirculation air ventilation rate for the cabin at four different levels, whereas in the CognitAir project either no VOCs were added or they were added at two concentration levels (medium, high). In both studies, VOCs were measured by mass spectrometry. For ComAir, VOCs were measured by gas chromatography – mass spectrometry (GC-MS, Shimadzu QP2010 SE) as well as carbonyl-compounds (aldehydes, ketones) by high performance liquid chromatography with diode array detector (HPLC-DAD, Agilent 1260 Infinity) after pumped sampling on Tenax TA ® adsorbent tubes (ISO 16000-6) and DNPH cartridges (ISO 16000-3), respectively. For CognitAir, real-time VOCs were analyzed by a selected ion flow tube mass spectrometer (Voice 200 ultra SIFT-MS). 22 VOCs were simultaneously quantified in gaseous sample from the air circulation system of the A310 fuselage in the FTF every seven seconds. The sum of the 22 VOCs results in the TVOC concentration. To quantify the dosed VOCs, samples were taken from the cabin air feed. In addition, VOCs were measured from air drawn from the cabin air return duct to ensure that fully homogenous sample was taken, to reduce the influence of emissions of subjects close to the sampling locations and to assess the TVOC concentration which subjects were exposed to. Moreover, the SIFT-MS was calibrated before each trail.

In both projects, CO_2 was measured by Vaisala GMW20, temperature by four-wire PT100 thermocouples, and humidity by Rotronic HygroClip HC2-C05 sensors.