Chemical Senses, 2018, Vol 43, 411–417
doi:10.1093/chemse/bjy028
Original Article
Advance Access Publication 15 May 2018

OXFORD

Original Article

Smelling Anxiety Chemosignals Impairs Clinical Performance of Dental Students

Preet Bano Singh[1], Alix Young[1], Synnøve Lind[1], Marie Cathinka Leegaard[1], Alessandra Capuozzo[2] and Valentina Parma[2,3,4]

[1]Institute of Clinical Dentistry, Faculty of Dentistry, University of Oslo, Oslo, Norway, [2]Department of Neuroscience Area, International School for Advanced Studies (SISSA), Trieste, Italy, [3]Department of Clinical Neuroscience, Karolinska Institutet, Stockholm, Sweden and [4]William James Research Center (WJCR), Instituto Superior de Psicologia Aplicada (ISPA), Lisbon, Portugal

Correspondence to be sent to: Valentina Parma, International School for Advanced Studies (SISSA), Via Bonomea, 265, 34136 Trieste (TS), Italy. e-mail: vparma@sissa.it

Editorial Decision 20 April 2018.

Abstract

Despite the fact that human body odors can transfer anxiety-related signals, the impact of such signals in real-life situations is scant. In this study, the effects of anxiety chemosignals on the performance of dental students operating on simulation units, wearing T-shirts imbued with human sweat and masked with eugenol were tested. A total of 24 fourth-year dental students (17 F) donated their body odors in two sessions (Anxiety and Rest). Twenty-four normosmic, sex- and age-matched test subjects who were third-year dental students performed 3 dental procedures while smelling masked anxiety body odors, masked rest body odors, or masker alone. The intensity and pleasantness ratings showed that the test subjects could not report perceptual differences between the odor conditions. When exposed to masked anxiety body odors, the test subjects' dental performance was significantly worse than when they were exposed to masked rest body odors and masker alone, indicating that their performance was modulated by exposure to the emotional tone of the odor. These findings call for a careful evaluation of the anxiety-inducing effects of body odors in performance-related tasks and provide the first ecological evaluation of human anxiety chemosignal communication.

Key words: anxiety body odor, chemosignals, dental performance, emotional contagion, expertise

Introduction

There is increasing empirical evidence showing that humans exchange messages through chemosignals (Lübke and Pause 2015). Besides transmitting stable features such as age, humans are also able to chemically convey transient information, such as emotional states (Semin and de Groot 2013). However, although there is only limited evidence on the ability to communicate positive emotions such as happiness (Chen and Haviland-Jones 2000; de Groot et al. 2015), there is much evidence showing that humans are able to encode and decode chemosensory messages of threat via their body odors (BOs) (Parma et al. 2017). Such threat communication can occur in the form of disgust (de Groot et al. 2012), aggression (Mutic et al. 2016), sadness (Flohr et al. 2017), fear (Ackerl et al. 2002; Chen et al. 2006; de Groot et al. 2012), and anxiety (Pause et al. 2004; Prehn et al. 2006; Mujica-Parodi et al. 2009; Pause et al. 2009; Prehn-Kristensen et al. 2009; Haegler et al. 2010; Albrecht et al. 2011; Zernecke et al. 2011; Rubin et al. 2012; Adolph et al. 2013; Dalton et al. 2013; Radulescu and Mujica-Parodi 2013; Wudarczyk et al. 2016). The majority of the research on human BO communication has focused on the transmission of fear-related/anxiety messages. Such messages are experimentally generated in situations where the individual vicariously perceives fear, as when watching horror movies (de Groot et al. 2012), or when the individual is actively taking part in a challenging situation perceived as threatening, for example, final exam (Pause et al. 2004) or high-rope course (Albrecht et al. 2011).

So far, the processing of chemosensory anxiety signals has been linked to the simulation of the state of anxiety in the receiver (de Groot et al. 2012), specifically in female recipients (Albrecht et al. 2011; Dalton et al. 2013; Radulescu and Mujica-Parodi 2013). This chemosensory processing has also been associated with reduced perception of positive emotions (Chen and Haviland-Jones 2000; Pause et al. 2004; Zernecke et al. 2011), with the enhancement of threat detection and response at the behavioral, physiological, and neural levels (Ackerl et al. 2002; Chen et al. 2006; Prehn et al. 2006; Pause et al. 2009; Haegler et al. 2010; Rubin et al. 2012; Adolph et al. 2013; Wudarczyk et al. 2016). Other studies have shown such processing associated with the modulation of social reactions in line with protective strategies and empathic concern (Mujica-Parodi et al. 2009; Prehn-Kristensen et al. 2009; Wudarczyk et al. 2016). Despite the variety of these laboratory-determined effects, anxiety communication occurs often in the absence of awareness (Lundström et al. 2008; Parma et al. 2017), preventing the recipient from being able to explicitly identify his/her own anxious state. The fact that the automatic contagion of anxiety chemosensory messages defies conscious awareness makes it even more difficult to assess when the communication of chemosensory messages of anxiety can impact real-life situations. This topic is still lacking research.

A common real-life situation in which people experience intense anxiety is related to dental treatment (Oosterink and De Jongh 2009). Dental anxiety is a well-documented phenomenon, with an average prevalence as determined in a range of population studies of around 20% (Wide Boman et al. 2013). Severe dental anxiety can be related to poor dental health (Ng and Leung 2008), reduced access to health services, increased risk of oral health diseases, and consequent worsening of untreated oral symptoms, all of which can reinforce the fear of dental procedures (Berggren and Meynert 1984). A variety of interventions have been used to reduce the negative effects of dental anxiety in patients (e.g., behavioral and cognitive behavioral therapy, pharmacological therapy, and sedation), although effective procedures are still being developed (Wide Boman et al. 2013). So far, only a few survey studies have evaluated the impact of patient anxiety on dental professionals (Moore and Brødsgaard 2000; Hakeberg et al. 2009; Brahm et al. 2013). Recent reports suggest that teaching on the topic of dental fear is included in pregraduation in certain countries, and that self-rated efficacy in handling patients with dental anxiety increases following postgraduate education in dental anxiety treatment (Brahm et al. 2013). However, greater experience of stress by the dental professional corresponds to a reduced ability to detect signs of anxiety in patients (Moore and Brødsgaard 2000). Whether or not the stress experienced by the dental professionals can also impact his/her ability to perform a dental procedure has not yet been explored. Human chemosignal communication of anxiety offers the possibility to evaluate whether or not, and to what degree, the undetected anxiety of a patient may affect the performance of dental procedures by the professional. Furthermore, such assessment allows the development of new training strategies with the goal of making dental professionals aware of how the patient's anxiety may unconsciously affect their performance.

To evaluate the role of chemosignals in dental performance, a group of dental students was exposed to simulation patients wearing T-shirts previously worn by individuals in an anxiety or rest situation while performing professional tasks. In line with the emotional contagion theory (Semin and de Groot 2013), it was expected that the dental students would feel more stressed during the exposure to masked anxiety body odor (ABO) and as a result the proficiency of their performance could be reduced compared to when they were performing tasks under the exposure of masked rest body odor (RBO) or the masker alone. It was also expected that the dental students would not be able to perceive differences between ABO, RBO, and no BO when masking was used for all odors, indicating that the chemosignal effect was operating beyond their conscious awareness.

Materials and methods

Study design and participants

This experimental study was performed at the Faculty of Dentistry, University of Oslo, during the period from September 2016 to May 2017. The sample size was determined via G*Power 3.1 (Faul et al. 2007) based on the average effect size (Hedges' g = 0.36) obtained in a recent meta-analysis on the effects of human fear chemosignals (de Groot and Smeets 2017). By including 22 participants, a power of ~95% is obtained with a significance level of 0.05. To ensure a final sample of that size, 24 BO donors and 24 test subjects were included in the study. All participants successfully completed the study and their results were included in the final analyses. All participants provided written informed consent to participate in the study and were explicitly informed that they could discontinue their participation in the study at any time, without any additional explanations or consequences. The research protocol was evaluated by the Norwegian Regional Committees for Medical and Health Research Ethics (REK Sør-øst 2016/1228) and not considered to require ethical approval. The study was compatible with the principles of the Declaration of Helsinki.

BO collection

Twenty-four students in their fourth-year of the Master degree in Dentistry, (17 F, age range 22–28 years, and mean age 23.7 ± 2.0 years) donated BO in two different situations: anxiety state and rest state. BO collection always took place on a Monday morning. Prior to the BO collection, the donors were asked to refrain from alcohol, cigarettes/snuff, spicy food, and certain food items for the whole weekend. In addition, they were asked to wash themselves regularly but refrain from using perfumed cosmetics such as soaps, deodorants, and shampoos on the upper part of the body for the whole weekend (Parma et al. 2017). The purpose of this strict weekend routine, prior to BO collection, was to avoid any contamination in the BO samples. Students were given clean white cotton T-shirts to wear under the clinic uniform before odor collection. ABO was collected during a 3-h clinical session, which is experienced by fourth-year students as rather stressful. RBO was collected during a 3-h lecture session, in which no test was administered. After the BO donation, T-shirts were immediately stored at −18 °C. Clean white T-shirts with no BO (CTRL) were also stored under the same conditions. One hour before the beginning of the experimental session, T-shirts exposed to the 3 different conditions (ABO, RBO, and CTRL) were masked with a common odor by pipetting 50 µL eugenol on to the T-shirts. Eugenol was chosen for two reasons. First, to enhance the ecological validity of the study, we chose an odor masker that is commonly found in a dental environment (e.g., Sarrami et al. 2002). Second, due to the high variability in the reported pleasantness of such odors, eugenol is rated on average as neither pleasant nor unpleasant (Alaoui-Ismaili et al. 1997), serving as an emotionally neutral odor masker. Students smelled the BO of same-sex donors. The odor conditions were given the following codes after the masker was added:

mABO, mRBO, and mCTRL for masked ABO, masked RBO, and masked control, respectively.

Dental performance under different odor conditions

Twenty-four students in their third-year of the Master degree in Dentistry (17 F, age range 20–41 years, mean age 24.8 ± 5.6 years) performed 3 dental procedures on 3 separate occasions, being stimulated on each occasion by a different odor condition (mRBO, mABO, mCTRL). Prior to the study commencement, the subjects' medical and olfactory status were recorded using a screening questionnaire. None of the subjects reported any history of neurologic (including head trauma) endocrine, respiratory, or psychiatric conditions or autoimmune diseases, and none of them had knowingly been exposed to toxins. The female participants were asked about the date of the beginning of their last menstrual cycle. Based on that and on the test date, the length of their menstrual cycle was calculated. The length of the cycle was then standardized to a 28-day cycle. Considering that the menstrual cycle varies greatly between women and that this variability particularly depends on variations in the length of the follicular phase, the follicular phase of each female participant was adjusted with respect to the length of her normal menstrual cycle, whereas the luteal phase was kept constant at 14 days (as in Parma et al. (2012)). For further details on the procedure, please refer to Garver-Apgar et al. (2008). The majority of women included were not on hormonal contraception ($N = 11$).

As is often the case for dental training, the preclinical practical education of the dental students in Oslo is conducted on simulation units (DSEclinical 5198, KAVO Dental GmbH). Students are taught standards of treatment, operability, ergonomics, and hygiene. A dental simulation unit is composed of a patient simulator (phantom head and upper abdomen, Figure 1), dentist chair, dentist unit with rotatory instruments, and swivel table for dental hand instruments. The dental task consisted of 3 operative preparations in teeth in the lower jaw: tooth 34 mesial-occlusal, minibox; tooth 35 mesial-occlusal, one-sided box; and tooth 46 mesial-occlusal-distal, double-sided box. Each of these dental procedures was performed by each student 3 times, with the phantom patient wearing a different T-shirt each time (mABO, mRBO, or mCTRL T-shirts). To avoid the fact that the subjective difficulty of the task (from easiest to most challenging: tooth 34, tooth 35, and tooth 46) could confound the olfactory effect on the dental performance, each odor condition–dental task association was counterbalanced across participants. Perceptual odor and task difficulty ratings were retrieved from the subjects after each session. The standard of dental performance for each task was scored (score ranged from 0 [poor] to 50 [excellent]) separately by 3 judges who then agreed on a final rating for each task. For each task the judges were blinded to the participant ID and the experimental exposure condition.

Data analysis

All dependent and independent variables are reported in the Results section. No observations required exclusion. Data were analyzed using R (version 3.3.2 [2016-10-31]). Following normality testing of variables performed by visual inspection of a *qqp* plot and Levene test, linear mixed model (LMM) analyses using the nlme package were performed. The participant's ID was included as a random factor in all models. Post hoc contrasts were explored by means of the lsmeans package. The level of significance was set at $\alpha = 0.05$. To select the best model to balance good fit of the data and parsimony, the criterion of lowest Akaike information criterion (AIC) and Bayesian information criterion (BIC) on the performance score variable was used. An evaluation of all the models that were run is presented in Supplementary Materials. The results are based on the model (Dependent variable ~ Odor Condition * Task Difficulty + Odor pleasantness, random = ~1|Subject). To assess whether nonsignificant P values were the result of inconclusive data or due to a true lack of difference between conditions (Dienes et al. 2016), Bayes factors (BFs) were computed by means of the software package JASP (Love et al. 2015). Instead of capturing the probability of the data distribution, the BF_{01} determines how well the data are predicted by the null hypothesis (in this case, no difference in performance between odor conditions) compared to the alternative hypothesis (difference in performance between odor conditions). The BF_{10} determines how well the data are predicted by the alternative hypothesis as opposed to the null hypothesis. If the BF is close to 1, then the evidence is inconclusive, meaning that both the null hypothesis and the alternative hypothesis explain the data equally well. Commonly $3 < BF < 10$ is considered moderate evidence, $10 < BF < 30$ is considered strong evidence, whereas $BF > 30$ indicates very strong evidence (Dienes et al. 2016).

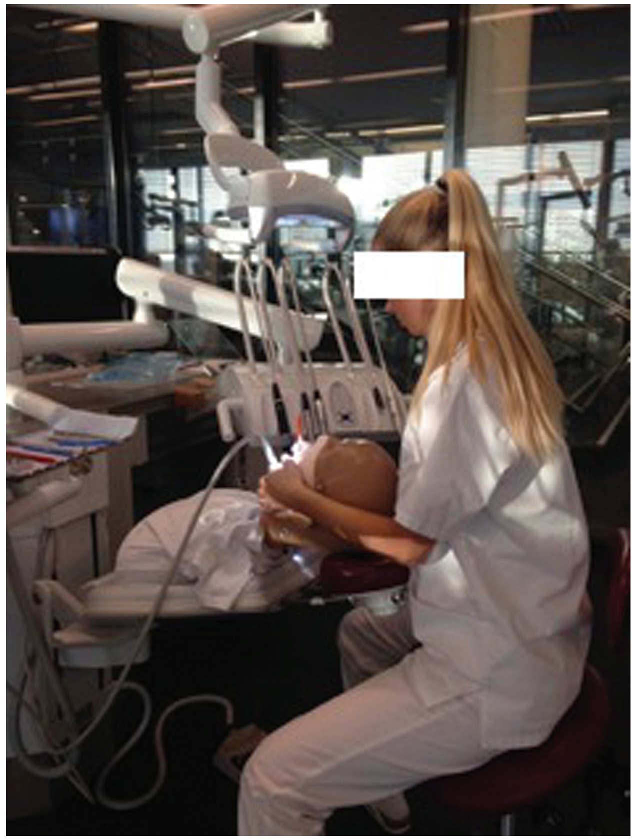

Figure 1. Experimental setting showing a performance test subject preparing a tooth in a phantom patient clothed with an odor-impregnated T-shirt.

Results

Odor intensity, odor pleasantness, and subjective stress perceived in the three odor conditions were similar

As depicted in Figure 2, LMMs of intensity ratings revealed no significant perceived differences between the 3 odor conditions ($F[2, 43] = 0.60$, $P = 0.552$; mABO mean = 26.17, standard error [SE] = 4.05; mRBO mean = 25.04, SE = 4.05; mCTRL mean = 21.98, SE = 4.05), no significant effect of task difficulty ($F[1, 43] = 2.00$, $P = 0.164$), and no significant interaction ($F[2, 43] = 0.125$, $P = 0.882$). A tendency toward a main effect of condition was observed in the pleasantness ratings (F[2, 43] = 3.15, P = 0.053; mABO mean = 0.04; SE = 0.39; mRBO mean = 0.29; SE = 0.39; mCTRL mean = 0.98; SE = 0.39), and specifically when considering the reduced pleasantness for the mABO compared to the mCTRL. Significant main effect of neither the task difficulty (F[1, 43] = 0.116, P = 0.735) nor the interaction was retrieved (F[2, 43] = 2.50, P = 0.093). No perceived difference across odor conditions was revealed in the subjective stress ratings (F[2, 43] = 1.26, P = 0.307; mABO mean = 5.18; SE = 0.54; mRBO mean = 5.25; SE = 0.54; mCTRL mean = 5.41; SE = 0.54). However, a significant main effect of the task difficulty is evident (F[1, 43] = 12.80, P = 0.002), in that the more difficult the task was perceived, the more stressed the recipient reported to be. No interaction with odor condition was however retrieved (F[1, 43] = 0.81, P = 0.46). The details of the LLMs are shown in Table 1.

ABO selectively reduced the quality of the dental performance

As shown in Table 1 and Figure 3, LMMs revealed that the performance score varied according to the odor condition (F[2, 43] = 8.145, P = 0.001). The test subjects received a significantly lower performance score while operating under exposure to mABO compared to mRBO and mCTRL (mABO mean = 28.37, SE = 1.41; mRBO mean = 33.06, SE = 1.41; mCTRL mean = 34.82, SE = 1.40). There was no significant difference in performance score when test subjects were exposed to mRBO versus mCTRL. The greater the difficulty of the task, the lower the score obtained (F[1, 43] = 11.62, P = 0.001). No interaction between odor condition and task difficulty emerged in the analysis (F[2, 43] = 0.04, P = 0.96). Table 2 and Figure 3 show the results of the LMMs on dental performance scores.

mRBO and masker only had a similar impact on dental performance

Bayesian statistics were applied to evaluate the likelihood of finding evidence of a true difference performance under the different odor conditions. Initially, we ran a Bayesian analysis of covariance to evaluate whether the odor pleasantness would significantly modify the evidence for differences among the odor conditions. As reported in Table 3, there is evidence for the null hypothesis of an effect of odor pleasantness on the dental performance (BF_{01} = 3.046). Furthermore, the model assessing the role of condition and odor pleasantness in influencing the dental performance provides a greater level of evidence for the null hypothesis than the model considering the role of condition as the only factor. Therefore, in the exploration of the main effect of the role of condition, we dropped the odor pleasantness variable.

The Cauchy prior distributions shown in Figure 4 indicated that there was strong to very strong evidence for a difference (direction unspecified) between the mABO and mRBO performance scores ($9.65 < BF_{10} < 12.91$) and between the mABO and mCTRL performance scores ($79.16 < BF_{10} < 92.04$). An anecdotal-to-moderate difference in performance was revealed between mRBO and mCTRL odor conditions ($1.98 < BF_{01} < 3.47$).

Dental performance was only marginally influenced by odor pleasantness and in women by menstrual cycle phase

To account for possible confounding variables, two additional models were tested, adding one covariate to the selected model. In the first model, we assessed whether the odor effect can be dependent simply on the pleasantness of the odor and not on its emotional connotation. Regardless of the model, including odor pleasantness

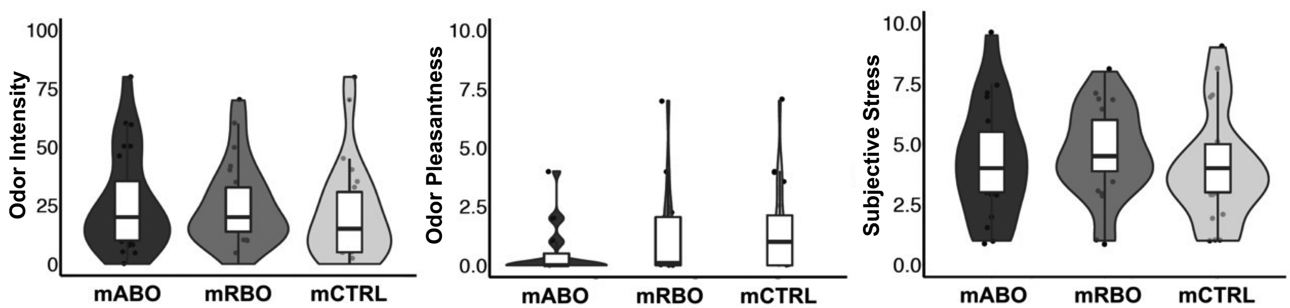

Figure 2. Odor intensity, odor pleasantness, and subjective stress ratings of the masked anxiety (mABO) chemosignal, masked rest (mRBO) chemosignal, and the control condition (mCTRL, masker only). Each dot represents a test subject's rating, the boxplots depict the median and the interquartile range of the ratings per condition, and the colored areas represent the probability density of each odor condition spanning throughout the rating scale.

Table 1. Results of the LMMs on odor perceptual ratings for the 3 different dependent variables (odor intensity, odor pleasantness, and subjective stress)

Dependent variable	Contrast	Estimate	SE	df	*t* ratio	*P* value
Odor intensity	mABO–mRBO	−8.55	20.08	43	−0.43	0.67
	mABO–mCTRL	−0.64	16.41	43	−0.04	0.97
	mRBO–mCTRL	7.91	20.90	43	1.18	0.25
Odor pleasantness	mABO–mRBO	−1.53	2.10	43	−0.73	0.13
	mABO–mCTRL	−2.68	1.72	43	−1.66	0.10
	mRBO–mCTRL	−1.15	2.18	43	−0.53	0.60
Subjective stress	mABO–mRBO	−4.25	3.04	43	−1.21	0.24
	mABO–mCTRL	1.80	3.09	43	0.58	0.57
	mRBO–mCTRL	−2.45	3.14	43	−1.27	0.22

Note: The *P* values reported are adjusted with the Tukey method for comparing a family of 3 estimates.

appears to be better than not including it (AIC = 465.88 vs. 467.98, L-Ratio = 4.10, *P* value = 0.04), although odor pleasantness only tended to have a significant main effect on the dental performance ($F[1, 42] = 3.95$, $P = 0.053$). In the second model, we evaluated whether the menstrual cycle phase could have impacted on the effect of the odor condition over dental performance. A main effect of the menstrual cycle phase did not reach significance, although a tendency can be noted ($F[1, 24] = 3.64$, $P = 0.068$).

Discussion

Analysis of the performance scores determined by 3 judges blinded to the odor conditions confirmed the emotional contagion theory (Semin and de Groot 2013), as the quality of the dental students' performance was significantly reduced when they were exposed to mABO. Bayesian analyses (Dienes et al. 2016) indicated strong to very strong evidence that the performance of the dental students was modulated by the exposure to the emotional tone conveyed by the ABO. Interestingly, no significant difference was observed in the students' dental performance when exposure to mRBO was compared to exposure to the masker alone. From a Bayesian perspective, this evidence is therefore inconclusive, suggesting that the null hypothesis (no difference in the performance scores based on the odor condition) and the alternative hypothesis (difference in the performance scores based on the odor condition) can equally well explain the data. Interestingly, these effects do not seem to be influenced by differences in the odor pleasantness of the 3 odor conditions.

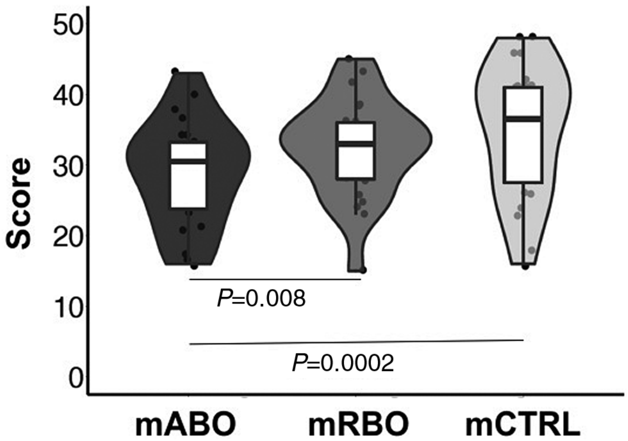

Figure 3. The score for the dental performance (range 0–50) obtained under the 3 different olfactory conditions. The boxplot depicts the interquartile range, whereas the colored area represents the probability density of each odor condition at different values. Significant *P* values are indicated within the figure.

Importantly, and in line with previous data (Parma et al. 2017), the emotional connotation of the BO does not emerge in the explicit perceptual evaluations considered (e.g., odor intensity and pleasantness), suggesting that this type of BO message may not require conscious awareness to be processed. This is in line with the prioritized processing associated with other evolutionary relevant signals, such as visual signals of threats (Morris et al. 1999), and in this situation, it is extended to the emotional evaluation of chemosignals related to BO messages. To confirm this aspect, and the unconscious nature of these effects, discrimination tests among the different odor conditions should be performed.

Masking the BOs can be considered a relatively new procedure in research on human chemosignals, although it has been used in studies on the effects of steroidal compounds (e.g., Saxton et al. 2008). As it happens in our daily experience, BOs are often covered by other fragrances, and constitute body-common odor mixtures (Lenochová et al. 2012). Our experimental data show that the constitution of such mixtures does not limit the transmission of emotional information via BOs.

With specific reference to masking in the dental context, previous studies have investigated the role of common odors in modulating dental anxiety in patients waiting for a procedure (e.g., Lehrner et al. 2005; Kritsidima et al. 2010). Assuming that their BO would signal stress as in the present case, it may be surprising that those data reveal a significant relaxation effect due to the presence of a common odor (i.e., orange, lavender). However, a few methodological differences can explain why these results appear contradictory. First, the anxiety ratings considered were those of the patients themselves rather than of a third party, as in our study, in which we take the perspective of the dental students. Although we agree that anxiety sweat should have nevertheless been present in the waiting room, it is to date unclear which are the effects of an emotional BO on oneself and how these would

Table 2. Results of the LMMs on dental performance scores

Dependent variable	Contrast	Estimate	SE	df	*t* ratio	*P* value
Score	mABO–mRBO	−4.77	1.55	43	−3.08	**0.010**
	mABO–mCTRL	−6.06	1.51	43	−4.27	**0.0003**
	mRBO–mCTRL	−1.68	1.53	43	−1.10	0.52

Note: Results of the LMMs on the score obtained as evaluation of the dental performance in interaction with the perceived task difficulty with the test subject as a random factor. The *P* values reported are adjusted with the Tukey method for comparing a family of 3 estimates. In bold, the P values indicate significant values at a threshold of alpha = 0.05.

Table 3. Model comparisons based on Bayesian statistics to evaluate the effect of odor pleasantness as a covariate

Model comparison—score					
Models	P(M)	P(M|data)	BF_M	BF_{01}	% Error
Null model (incl. subject)	0.250	0.012	0.037	1.000	
Condition	0.250	0.661	5.862	0.018	0.767
Odor pleasantness	0.250	0.004	0.012	3.046	2.306
Condition + odor pleasantness	0.250	0.323	1.428	0.037	3.175

Note. All models include subject. P(M), prior model probabilities; P(M|data), posterior model probabilities; BF_M, change from prior to posterior model odds; BF_{01}, Bayes factor for each model against the null model.

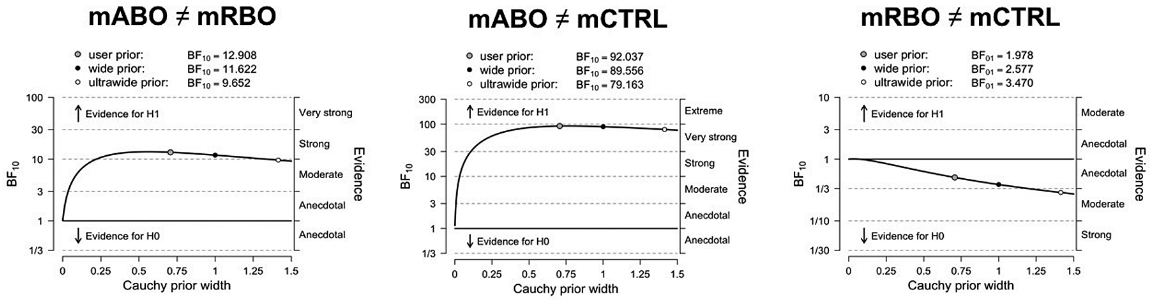

Figure 4. Cauchy prior distributions based on which evidence for true differences among the conditions are established. BF_{10} = evidence for the alternative hypothesis over the null hypothesis; BF_{01} = evidence for the null hypothesis over the alternative hypothesis.

selectively impact anxiety ratings. Second, the relative quantity of ABO and odor masker cannot be controlled for in-the-waiting-room setting (e.g., Lehrner et al. 2005; Kritsidima et al. 2010), where sitting close to or far away from the odor delivery device can have introduced differences in the reports. This problem is not relevant in the present study, in which the quantity of the odor masker was carefully controlled across participants, although the BO production was not. Third, and perhaps more importantly, the comparison in the cited studies was performed between two conditions: a common odor (orange or lavender) and no odor. Assuming that the ABO was present in both conditions equally, the comparison that can be drawn here is whether the presence of the masker odor would have changed the emotional tone of the ABO. Instead, here we aimed at understanding, irrespective of the induction that the masker odor may produce on the recipients (which is monitored in the control condition), whether there are differences in the way the ABO and RBO affected dental performance.

It may be argued that the poorer dental performance of the students may have been due to a general state of anxiety that can be expected to be experienced by students who are tested on the tasks they were given (Elani et al. 2014). If that were true, significant differences in the performance scores obtained during the 3 olfactory conditions would not be evident. In addition, the present results cannot be attributed to differences between BO and common odors (Lundström et al. 2008). If that were the case, the same dental performance would have been observed in all odor conditions, which did not occur. Therefore, the most plausible explanation for these results is that the mABO—even when not consciously perceived—transmitted an anxiety message to the dental students (Semin and de Groot 2013). In line with a heightened stress response due to the presence of potentially threatening signals, the students' overall performance on the dental tasks suffered, as would also be expected if in line with other types of test anxiety (Eysenck et al. 2007). However, their ability to attribute such anxiety to the BO did not emerge in the subjective stress ratings. Instead, it was attributed to the perceived task difficulty. As postulated by the Attentional Control Theory (Eysenck et al. 2007), anxiety can promote attentional shifts from goal-directed to stimulus-driven information. These shifts may thereby increase the attentional resources toward threat-related perceptual stimuli, while sacrificing the resources devoted to the performance of the task, in this case the dental procedure. As a result, task efficiency tends to decrease, and performance drops are often reported (Eysenck et al. 2007), as was the case in this study.

The results of this study support the idea that the chemosensory transmission of anxiety is based on an emotional contagion mechanism, as previously revealed by behavioral, physiological, and neurophysiological studies (de Groot and Smeets 2017). The current findings represent the first empirical account showing that the ABO, even when masked by other fragrances, as often is the case in real-life situations when sweat signals are masked by deodorants or other fragranced products, may impair the performance of naive smellers and have significant consequences. However, these results cannot explain whether or not this is dependent on the level of performance expertise of the dental students. Considering that continuous practice is shown to reduce the need for attentional resources in an individual when performing a certain task (Brown and Carr 1989), novices may be more affected by the negative effects of the ABO than experienced professionals who may have less need to dedicate attentional resources to task execution (Nibbeling et al. 2012). Further studies should also clarify whether being on hormonal contraception plays a role on these effects.

In summary, the present findings call for a careful evaluation of the anxiety-inducing effects of ABO on dental professionals, as their professional performance may be unconsciously influenced by the anxiety experienced by their patients. Even if such an impairment is mainly confined to inexperienced dental students, and expert professionals are not shown to be influenced to any great degree by the body-odor-mediated emotional contagion, these results support the possibility of using human chemosignals during dental training. Novices can be taught to become aware of and address this otherwise unnoticeable negative effect of patient anxiety on their dental performance. Furthermore, this study represents a unique ecological evaluation of the effects of anxiety chemosignal communication in humans, showing for the first time the extent to which chemosignal communication can influence real-life situations and impact performance in a relevant setting. The results highlight the relevance of BO communication in human day-to-day experience and reveal practical consequences of such unconscious forms of communication.

Supplementary material

Supplementary material can be found at http://www.chemse.oxfordjournals.org/.

Funding

No funding to disclose.

Conflict of interest

The authors declared no conflicts of interest with respect to the authorship or the publication of this article.

Acknowledgements

The authors express their sincere appreciation to Dr Inger Hattestad Henriksen for clinical guidance in scoring the dental work performed by the test students. We would also like to thank the third- and fourth-year dental students who

participated in this study. The data and experimental materials are available on request.

References

Ackerl K, Atzmueller M, Grammer K. 2002. The scent of fear. *Neuro Endocrinol Lett*. 23:79–84.

Adolph D, Meister L, Pause BM. 2013. Context counts! Social anxiety modulates the processing of fearful faces in the context of chemosensory anxiety signals. *Front Hum Neurosci*. 7:283.

Alaoui-Ismaïli O, Robin O, Rada H, Dittmar A, Vernet-Maury E. 1997. Basic emotions evoked by odorants: comparison between autonomic responses and self-evaluation. *Physiol Behav*. 62:713–720.

Albrecht J, Demmel M, Schöpf V, Kleemann AM, Kopietz R, May J, Schreder T, Zernecke R, Brückmann H, Wiesmann M. 2011. Smelling chemosensory signals of males in anxious versus nonanxious condition increases state anxiety of female subjects. *Chem Senses*. 36:19–27.

Berggren U, Meynert G. 1984. Dental fear and avoidance: causes, symptoms, and consequences. *J Am Dent Assoc*. 109:247–251.

Brahm CO, Lundgren J, Carlsson SG, Nilsson P, Hultqvist J, Hägglin C. 2013. Dentists' skills with fearful patients: education and treatment. *Eur J Oral Sci*. 121:283–291.

Brown TL, Carr TH. 1989. Automaticity in skill acquisition: mechanisms for reducing interference in concurrent performance. *J Exp Psychol*. 15:686–700.

Chen D, Haviland-Jones J. 2000. Human olfactory communication of emotion. *Percept Mot Skills*. 91:771–781.

Chen D, Katdare A, Lucas N. 2006. Chemosignals of fear enhance cognitive performance in humans. *Chem Senses*. 31:415–423.

Dalton P, Mauté C, Jaén C, Wilson T. 2013. Chemosignals of stress influence social judgments. *PLoS One*. 8:e77144.

de Groot JHB, Smeets MAM. 2017. Human fear chemosignaling: evidence from a meta-analysis. *Chem Senses*. 42:663–673.

de Groot JH, Smeets MA, Kaldewaij A, Duijndam MJ, Semin GR. 2012. Chemosignals communicate human emotions. *Psychol Sci*. 23:1417–1424.

de Groot JH, Smeets MA, Rowson MJ, Bulsing PJ, Blonk CG, Wilkinson JE, Semin GR. 2015. A sniff of happiness. *Psychol Sci*. 26:684–700.

Dienes Z, Lush P, Semmens-Wheeler R, Parkinson J, Scott R, Naish P. 2016. Hypnosis as self-deception; meditation as self-insight. In: Raz A, Lifshitz M, editors. *Hypnosis and meditation: toward an integrative science of conscious planes*. Oxford: Oxford University Press. p. 107–128.

Elani HW, Allison PJ, Kumar RA, Mancini L, Lambrou A, Bedos C. 2014. A systematic review of stress in dental students. *J Dent Educ*. 78:226–242.

Eysenck MW, Derakshan N, Santos R, Calvo MG. 2007. Anxiety and cognitive performance: attentional control theory. *Emotion*. 7:336–353.

Faul F, Erdfelder E, Lang AG, Buchner A. 2007. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods*. 39:175–191.

Flohr EL, Erwin E, Croy I, Hummel T. 2017. Sad man's nose: emotion induction and olfactory perception. *Emotion*. 17:369–378.

Garver-Apgar CE, Gangestad SW, Thornhill R. 2008. Hormonal correlates of women's mid-cycle preference for the scent of symmetry. *Evol Hum Behav*. 29:223–232.

Haegler K, Zernecke R, Kleemann AM, Albrecht J, Pollatos O, Brückmann H, Wiesmann M. 2010. No fear no risk! Human risk behavior is affected by chemosensory anxiety signals. *Neuropsychologia*. 48:3901–3908.

Hakeberg M, Klingberg G, Noren JRG, Berggren U. 2009. Swedish dentists' perceptions of their patients. *Acta Odontol Scand*. 50:245–252.

Kritsidima M, Newton T, Asimakopoulou K. 2010. The effects of lavender scent on dental patient anxiety levels: a cluster randomised-controlled trial. *Community Dent Oral Epidemiol*. 38:83–87.

Lehrner J, Marwinski G, Lehr S, Johren P, Deecke L. 2005. Ambient odors of orange and lavender reduce anxiety and improve mood in a dental office. *Physiol Behav*. 86:92–95.

Lenochová P, Vohnoutová P, Roberts SC, Oberzaucher E, Grammer K, Havlíček J. 2012. Psychology of fragrance use: perception of individual odor and perfume blends reveals a mechanism for idiosyncratic effects on fragrance choice. *PLoS One*. 7:e33810.

Love J, Selker R, Marsman M, Jamil T, Dropmann D. 2015. *JASP (version 0.7) [computer software]*. Amsterdam, The Netherlands: JASP Project.

Lübke KT, Pause BM. 2015. Always follow your nose: the functional significance of social chemosignals in human reproduction and survival. *Horm Behav*. 68:134–144.

Lundström JN, Boyle JA, Zatorre RJ, Jones-Gotman M. 2008. Functional neuronal processing of body odors differs from that of similar common odors. *Cereb Cortex*. 18:1466–1474.

Moore R, Brødsgaard I. 2000. Dentists' perceived stress and its relation to perceptions about anxious patients. *Community Dent Oral Epidemiol*. 29:73–80.

Morris JS, Ohman A, Dolan RJ. 1999. A subcortical pathway to the right amygdala mediating "unseen" fear. *Proc Natl Acad Sci USA*. 96:1680–1685.

Mujica-Parodi LR, Strey HH, Frederick B, Savoy R, Cox D, Botanov Y, Tolkunov D, Rubin D, Weber J. 2009. Chemosensory cues to conspecific emotional stress activate amygdala in humans. *PLoS One*. 4:e6415.

Mutic S, Parma V, Brünner YF, Freiherr J. 2016. You smell dangerous: communicating fight responses through human chemosignals of aggression. *Chem Senses*. 41:35–43.

Ng SK, Leung WK. 2008. A community study on the relationship of dental anxiety with oral health status and oral health-related quality of life. *Community Dent Oral Epidemiol*. 36:347–356.

Nibbeling N, Oudejans RR, Daanen HA. 2012. Effects of anxiety, a cognitive secondary task, and expertise on gaze behavior and performance in a far aiming task. *Psychol Sport Exerc*. 13:427–435.

Oosterink FM, de Jongh A, Hoogstraten J. 2009. Prevalence of dental fear and phobia relative to other fear and phobia subtypes. *Eur J Oral Sci*. 117:135–143.

Parma V, Gordon AR, Cecchetto C, Cavazzana A, Lundström JN, Olsson MJ. 2017. Processing of human body odors. In: Buettner A, editors. *Springer handbook of odor*. 3rd ed. Switzerland: Cham: Springer International Publishing. Vol. 123. p. 127–128.

Parma V, Tirindelli R, Bisazza A, Massaccesi S, Castiello U. 2012. Subliminally perceived odours modulate female intrasexual competition: an eye movement study. *PLoS One*. 7:e30645.

Pause BM, Adolph D, Prehn-Kristensen A, Ferstl R. 2009. Startle response potentiation to chemosensory anxiety signals in socially anxious individuals. *Int J Psychophysiol*. 74:88–92.

Pause BM, Ohrt A, Prehn A, Ferstl R. 2004. Positive emotional priming of facial affect perception in females is diminished by chemosensory anxiety signals. *Chem Senses*. 29:797–805.

Prehn A, Ohrt A, Sojka B, Ferstl R, Pause BM. 2006. Chemosensory anxiety signals augment the startle reflex in humans. *Neurosci Lett*. 394:127–130.

Prehn-Kristensen A, Wiesner C, Bergmann TO, Wolff S, Jansen O, Mehdorn HM, Ferstl R, Pause BM. 2009. Induction of empathy by the smell of anxiety. *PLoS One*. 4:e5987.

Radulescu AR, Mujica-Parodi LR. 2013. Human gender differences in the perception of conspecific alarm chemosensory cues. *PLoS One*. 8:e68485.

Rubin D, Botanov Y, Hajcak G, Mujica-Parodi LR. 2012. Second-hand stress: inhalation of stress sweat enhances neural response to neutral faces. *Soc Cogn Affect Neurosci*. 7:208–212.

Sarrami N, Pemberton MN, Thornhill MH, Theaker ED. 2002. Adverse reactions associated with the use of eugenol in dentistry. *Br Dent J*. 193: 257–259.

Saxton TK, Lyndon A, Little AC, Roberts SC. 2008. Evidence that androstadienone, a putative human chemosignal, modulates women's attributions of men's attractiveness. *Horm Behav*. 54:597–601.

Semin GR, Groot JH. 2013. The chemical bases of human sociality. *Trends Cogn Sci*. 17:427–429.

Wide Boman U, Carlsson V, Westin M, Hakeberg M. 2013. Psychological treatment of dental anxiety among adults: a systematic review. *Eur J Oral Sci*. 121:225–234.

Wudarczyk OA, Kohn N, Bergs R, Goerlich KS, Gur RE, Turetsky B, Schneider F, Habel U. 2016. Chemosensory anxiety cues enhance the perception of fearful faces - an fMRI study. *Neuroimage*. 143:214–222.

Zernecke R, Haegler K, Kleemann AM, Albrecht J, Frank T, Linn J, Wiesmann M. 2011. Effects of male anxiety chemosignals on the evaluation of happy facial expressions. *J Psychophysiol*. 25:116–123.