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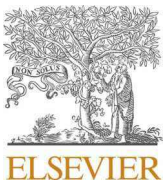

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It's trust or risk? Chemosensory anxiety signals affect bargaining in women

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ABSTRACT

It is well documented how chemosensory anxiety signals affect the perceiver's physiology, however, much less is known about effects on overt social behavior. The aim of the present study was to investigate the effects of chemosensory anxiety signals on trust and risk behavior in men and women. Axillary sweat samples were collected from 22 men during the experience of social anxiety, and during a sport control condition. In a series of five studies, the chemosensory stimuli were presented via an olfactometer to 214 participants acting as investors in a bargaining task either in interaction with a fictitious human co-player (trust condition) or with a computer program (risk condition). It could be shown that chemosensory anxiety signals reduce trust and risk behavior in women. In men, no effects were observed. Chemosensory anxiety is discussed to be transmitted contagiously, preferentially in women.

1. General introduction

Not surprisingly, humans, like all animals studied so far, chemosensorily convey information about their emotional status. Meanwhile numerous studies have been conducted, demonstrating effects of chemosensorily transmitted emotions on the perceiver's neural, motor- and sensory system (for reviews see Calvi et al., 2020; de Groot, Semin, & Smeets, 2017; Fialová & Havlíček, 2012; Lübke & Pause, 2015; Pause, 2012, 2017). The closely related emotions anxiety and fear have been investigated in detail. Chemosensory signals of anxiety and fear seem to act contagious, as they are processed in empathy-related brain regions (Prehn-Kristensen et al., 2009) and induce facial mimicry (de Groot, Smeets, Kaldewaij, Duijndam, & Semin, 2012). Furthermore, they prime the behavioral withdrawal system (Pause, Adolph, Prehn-Kristensen, & Ferstl, 2009) and sharpen the perceptual acuity for fearful facial expression (Kamiloğlu, Smeets, de Groot, & Semin, 2018) while dampening the perceptual acuity for happy facial expressions (Pause, Ohrt, Prehn, & Ferstl, 2004).

While the perceiver's physiological systems undoubtedly adjust to chemosignals of fear and anxiety, much less is known about possible effects on overt motor or social behavior. First studies reveal that chemosignals of stress and fear act on minute motor activity and further, on risk and trust behavior: Dentistry students' operation performance is reduced through exposure to body odors obtained from their stressed classmates (Singh et al., 2018). In addition, the administration of body odor collected from individuals during a high rope course boosts the magnitude of non-adaptive risk-behavior in the receivers (Haegler et al., 2010), mirroring the increased risk-taking behavior of stressed individuals (Algren et al., 2018). Both results are in line with the theory of chemosensory emotional contagion between sender and receiver.

Two studies investigated the impact of stress and fear odor on interpersonal trust, however, trust had to be expressed towards dolls or avatars instead of humans. In the first study, stress sweat was collected from male tandem skydivers and attached to a human-sized doll, proposing the solution of a chance-based pre-programmed two-alternative task (Endevelt-Shapira et al., 2018). Healthy male participants followed the suggestion of the doll more often when it emitted the smell of men walking (control) as when it emitted the smell of stressed men. In accordance with the authors, admitting that this study explains rather human-machine interaction instead of real life social interactions, it can be questioned whether trust towards humans and machines follows the same rules. Obviously, human actions are more difficult to anticipate, as only humans but not machines have the ability to intentionally cheat somebody during bargaining. Thus, instead of having affected the trust level, the stress sweat alternatively might have disrupted schema-based automatic stimulus processing (like being obedient to advices), and induced emotion-based controlled stimulus processing (Fiske & Neuberg, 1990), resulting in a lower amount of automatic following. In the second study, women were exposed to the sweat of males having been watching fear-inducing movies, and rated the trustworthiness of a non-speaking and non-moving avatar in a virtual environment (Quintana, Nolet, Baus, & Bouchard, 2019). While the exposure to fear sweat

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had no direct effect on the trustworthiness ratings, it increased the level of state anxiety in the receivers. Mediation analyses further showed that higher state anxiety scores were related to lower trustworthiness ratings, and accordingly, an indirect effect of fear odor on trustworthiness ratings was proposed. Again, it is to be questioned whether trust expressed towards a static, computer programmed avatar, resembles trust towards human individuals in any way. On the other hand, it is well known that state anxiety increases during the perception of anxiety-related body odors (Albrecht et al., 2011), which in turn might decrease general trustfulness.

In the following, a series of experiments will be presented, investigating the effects of anxiety chemosignals on trust behavior in pretended real life social encounters. Sweat was collected from healthy male participants experiencing anxiety during a social stress test (Trier Social Stress Test for Groups, TSST-G, von Dawans, Kirschbaum, & Heinrichs, 2011) and presented to female and male participants, acting as investors in the Trust Game (Berg, Dickhaut, & McCabe, 1995). It was hypothesized that social anxiety would be transmitted between the sender and the receiver and thereby reduce interpersonal trust in the receiver (Takahashi et al., 2005). However, as males are known to fail to respond to social chemosignals of anxiety or fear regarding several response systems (muscular: de Groot, Semin, & Smeets, 2014; neural: Pause, Lübke, Laudien, & Ferstl, 2010), male and female participants were investigated separately. In accordance with Kosfeld, Heinrichs, Zak, Fischbacher, and Fehr (2005), trust and risk behavior were disentangled by setting up a control experiment on risk behavior, implementing a computer instead of an individual as the interaction partner. According to Endevelt-Shapira et al. (2018); Haegler et al. (2010), and Quintana et al. (2019), trust and risk studies might reveal different outcomes and are also investigated separately. The conductance of different experiments avoids redundant group comparisons and thereby increases the statistical power of the single experiments. However, the comparison of study results should rather be based on the interpretation of confidence intervals than of significance tests (Nieuwenhuis, Forstmann, & Wagenmakers, 2011).

2. Study 1: females trust

2.1. Introduction

The first study was intended to examine whether chemosensory anxiety signals reduce women's trust in realistic dyadic human interactions. Females' trust behavior was assessed by implementing the Trust Game (Berg et al., 1995), and indicated by the amount of money transferred from an investor (participant) to a trustee (fictional co-player). Anxiety had been provoked in male sweat donors during a social stress task (TSST-G, von Dawans et al., 2011). However, the stress task had been adjusted to maximize feelings of anxiety and to minimize feelings of anger.

2.2. Methods

2.2.1. Participants

A total of 60 non-smoking females aged between 18 and 43 (M = 23.1, SD = 5.4) participated in study 1. Participants were recruited via flyers at the Heinrich-Heine-University Düsseldorf. All participants reported being healthy, and not being pregnant, having a regular menstrual cycle, and not taking any medication other than oral contraceptives (N = 41). In order to assess for general hyposmia, all participants had to identify a bottle containing phenyl-ethyl alcohol (rose-like odor; 1:100 diluted in 1,2-propanediol) from a series of three bottles in a forced choice test. The remaining two bottles contained the non-odorous solvent only. The test was repeated three times, and participants who failed once were excluded from the study. As socially anxious individuals show a deviant processing of anxiety related chemosignals (Pause et al., 2010), in the present study only non-anxious individuals were included. Accordingly, participants scored within the normal range on trait anxiety (M = 34.25, SD = 5.43; according to the German adaptation of the Spielberger State-Trait Anxiety Inventory, STAI, Laux, Glanzmann, Schaffner, & Spielberger, 1981) and also within the normal range on social anxiety (M = 22.25, SD = 12.36; according to the German adaption of the Social Interaction Anxiety Scale, SIAS, Stangier, Heidenreich, Berardi, Golbs, & Hoyer, 1999). To assess for social desirability, the German version of the Social Desirability Scale (Stöber, 1999, 2001) was conducted prior to all experiments and participants with scores of 13 or more were excluded. All participants gave written informed consent and were paid for participation. All studies reported here were carried out in accordance with the Declaration of Helsinki and approved by the ethics committee of the Science Faculty of the Heinrich-Heine-University Duesseldorf.

2.2.2. Task and material

2.2.2.1. Chemosensory stimuli. Axillary sweat was collected from 22 men, recruited at the Heinrich-Heine-University Düsseldorf via flyers. Sweat was sampled from males only for three reasons: First, in order to ensure comparability with so far published studies on the effects of stress, -anxiety-, and fear sweat on trust and risk behavior (Endevelt--Shapira et al., 2018; Haegler et al., 2010; Quintana et al., 2019), as in all of these only male sweat was applied. Second, in order to ensure comparability with most of the studies published so far on the effects of anxiety and fear sweat in general, as according to a meta-analysis, most studies published effects of male sweat only (de Groot & Smeets, 2017; de Groot et al., 2017). Third, the findings presented here are most probably to be generalized to female sweat, as the few studies which directly compared the effects of male and female anxiety- and fear sweat did not reveal biological or statistical significant differences (regarding the startle reflex: (Pause et al., 2009); regarding the voltage distribution across the scalp: (Pause et al., 2010); regarding facial muscle activity: (de Groot et al., 2014).

All donors were of European descent, their age ranged between 20 and 31 (M = 23.6, SD = 3.0) and their body mass index (BMI) between 19.5 and 27.1 kg/m^2 (M = 23.3, SD = 2.1). They reported being non-smokers, healthy, and not taking any medication. All of them donated sweat during an anxiety and a sport control condition from both axillae (duration: 90 min) using cotton pads. Donors were asked to refrain from eating garlic, onions, asparagus or spicy food, using deodorant and partaking in any sports activity the day before and the day of the donation. Donors were also asked to wash their armpits exclusively with an unscented medical soap (Eubos®, Dr. Hobein GmbH, Germany) the day prior to the donations, and to refrain from washing their armpits at the day of the donation. Beginning one hour before the donations, donors were not allowed to eat anything and instructed to drink water only. All donors gave written informed consent, and were paid for their donation. The donation procedure was approved by the ethics committee of the Science Faculty of the Heinrich-Heine-University of Duesseldorf. None of the sweat donors acted as a participant in any of the here described studies.

In order to provoke anxiety in the donors, a modified version of the Trier Social Stress Test for Groups (TSST-G, von Dawans et al., 2011), including a mock job interview and an arithmetic task in front of an evaluative committee, was established. In the present version, the anger provoking arithmetic task was dropped and replaced by two anxiety provoking tasks: A group discussion and a general knowledge examination (see below). Both types of tasks reliably induce social stress and feelings of social threat and anxiety (Dickerson & Kemeny, 2004). Within the TSST-G, four sweat donors participate simultaneously; the sport control condition was carried out with just one person at a time.

In detail, at the beginning of the anxiety sweat donation (anxiety condition), the donors had 10 min to prepare for a three minutes lasting public speech in front of an evaluative committee (mock job interview).

The committee consisted of one man and one woman pretending to be experts in the evaluation of non-verbal behavior. Thereafter, the donors engaged in two group discussions, both in front of the evaluative committee. Here, two donors were instructed to argue in favor of a politically significant statement (e.g. "Death penalty has to be reinstated in Germany"), and two had to argue against it. Each donor had to present their statement and rationale for two minutes. The second group discussion was conducted immediately afterwards, focusing a different but equally politically significant topic. Finally, a general knowledge task was conducted. One donor was given a difficult task (e.g. "name all German chancellors" or "name seven winners of the Nobel Peace Prize") and one minute to answer it correctly. After one minute, the next donor was given a new question, and so on. In total, each donor had to answer three of these difficult questions. Following this task, the donors were allowed to dispatch the cotton pads. The sport control session (sport condition) was carried out between 4 and 11 days (M = 7.5, SD = 1.9) after the anxiety condition and conducted for each participant separately. In the sport condition, the tasks of the modified TSST-G were replaced with three units of mild ergometric training (see Fig. 1). Ensuring an equal physiological arousal of the donors in both conditions, for each donor the exercise load was adjusted to result in the mean heart rate of the TSST-G session.

The STAI was used to assess feelings of anxiety (state version, score range: 20–80), and the German adaption of the State-Trait Anger Expression Inventory (STAXI state version, score range 10–40; Schwenkmezger, Hodapp, & Spielberger, 1992) was implemented to assess feelings of anger. The donors answered each questionnaire at the beginning and at the end of both sessions (at t1 and t4, see Fig. 1).

To assess free saliva cortisol, saliva samples (Salicaps, IBL, Hamburg, Germany) were obtained four times per condition (see Fig. 1). Saliva samples were frozen at −20 °C until assayed using a commercial enzyme immunoassay kit, cortisol saliva ELISA, IBL, Hamburg, Germany (as the amount of saliva donated by two men was too small for the analyses, cortisol data are related to 20 participants only).

The sweat donors reported medium anxiety scores in the anxiety condition (t1: M = 41.62, SD = 10.97; t4: M = 41.55, SD = 9.75), as compared to low scores in the sport condition (t1: M = 33.93, SD = 5.80; t4: M = 31.17, SD = 5.06; main effect Session: F(1, 21) = 47.82, p < 0.001, $\eta_p^2 = 0.695$). In addition, they reported a near to bottom anger level in the anxiety condition (t1: M = 11.86, SD = 3.24; t4: M = 11.77, SD = 2.09), which was even lower in the sport condition (t1: M = 10.18, SD = 0.40; t4: M = 10.14, SD = 0.35; main effect Session: F(1, 21) = 14.42, p = 0.001, $\eta_p^2 = 0.407$). Accordingly, the donors did not experience any psychologically significant anger during either session.

In the anxiety condition, the donors had a higher level of cortisol as compared to the sport condition (main effect Session: F(1, 19) = 21.66, p < 0.001, $\eta_p^2 = 0.533$). The cortisol level changed significantly during the anxiety condition (increase from t1 to t2 and t1 to t3, followed by a decrease from t2 to t4 and t3 to t4, all ps < 0.05), but not in the sport condition (interaction Condition x Time: F(3, 57) = 5.28, p = 0.003, $\eta_p^2 = 0.217$, see Fig. 2).

Following the completion of sweat sampling, the cotton pads were chopped and homogenized with respect to the sampling condition. The same amount of pure, unused cotton pads, to be introduced as an additional control condition, underwent the same treatment, resulting in three pooled and homogenized super-samples (anxiety, sport, cotton). These three samples were stored at −20 °C and used for all five experiments. For presentation, small portions of 0.3 g of each sample pool were placed in separate opaque glass chambers of a 3 channel pulse olfactometer, and presented to the participants within a permanent air stream of 46 ml/ s. Chemosensory stimuli were delivered through teflon tubes, which ended in an odorless standard hospital oxygen mask which participants were wearing during the Trust Game. Channel activation was computer controlled through magnetic valves. Check valves prevented contamination of the mask with inactivated airstreams. The chemosensory stimuli were presented to participants at a constant room temperature of 21 °C. Portioned samples were reused for a maximum of five consecutive sessions with in between session cooling at 3 °C.

2.2.2.2. The trust game. The Trust Game (Kosfeld et al., 2005), a version of the Investment Game (Berg et al., 1995), was implemented to measure trust behavior. In the Trust Game the participants (investors) were led to believe that they would play a game with three different male co-players

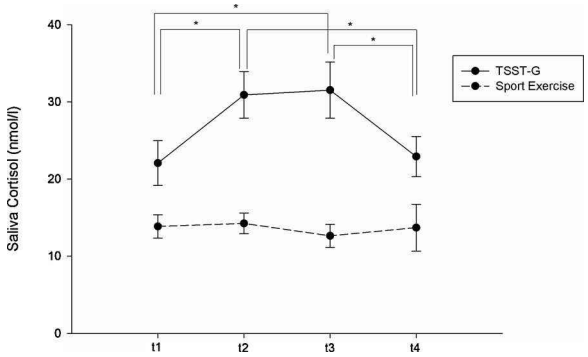

Fig. 2. Cortisol response of the male sweat donors during the modified TSST-G and the sport control condition (means and standard errors).

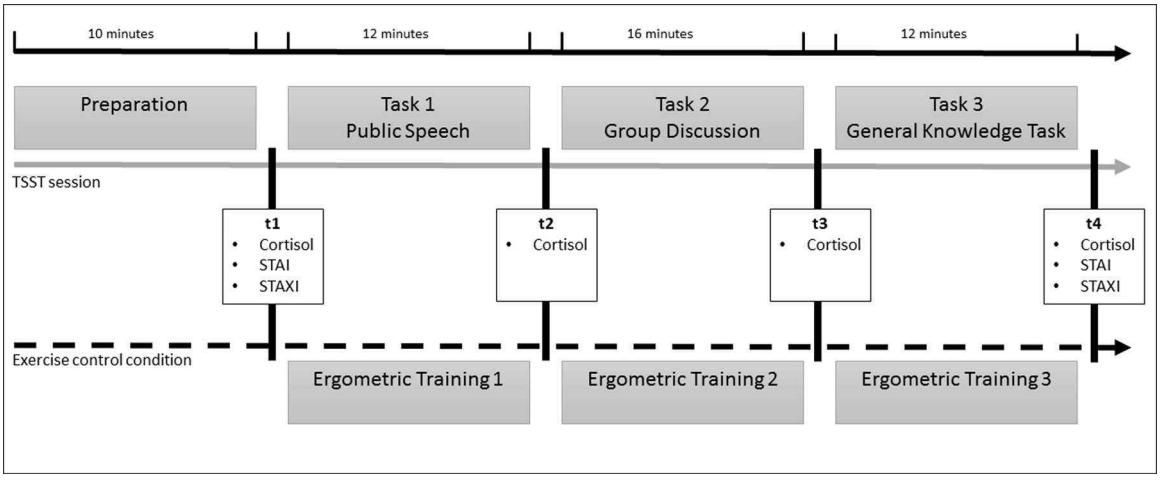

Fig. 1. Procedure of the modified TSST-G and the sport control condition for the collection of the sweat samples. Note: TSST-G = Trier Social Stress Test for Groups; STAI = Spielberger State-Trait Anxiety Inventory; STAXI = State-Trait Anger Expression Inventory.

(trustees). With each of them, they would play 3 consecutive rounds of the game (9 rounds in total). At the beginning of each round, both the participant and the co-player would be equipped with 3 Euros. The participants could choose to invest 0, 1, 2 or all 3 Euros; the amount would then be tripled and transferred to their co-player. Then, the co-player would decide on how much of his total amount he would retransfer to the participant. The participants were told that they would not be informed about how much money they would receive from the trustees in each round, but asked to indicate how much they expected it to be. Moreover, they were informed that no money would be transferred from one round to the next, neither on their account, nor on that of the co-player. They were further told, that their final profit would be selected from one of the three rounds by chance. In fact, all participants received the same amount of profit.

The chemosensory stimuli were introduced as being body odor samples obtained from the respective co-player, and presented just before the participants had to decide how much money to invest (see below). After 3 rounds, the participants were informed via an onscreen notification that they would now play with a new co-player. In fact, they were then exposed to another chemosensory condition (anxiety, sport, cotton).

Chemosensory stimuli were presented in each of the 9 trials, for a duration of 4 s. The participants were instructed to exhale for 3 s, 2 s prior to the activation of the odor channel and 1 s after its activation (preparation phase = 3 s), and then to inhale for another 3 s, 1 s after the activation of the odor channel until the end of the odor presentation (inhalation phase = 3 s). Thereby, it was ensured that the air stream in the mask was fully odorous when participants started to inhale. Right after the end of the odor presentation the participants had to decide how much money to transfer. Each odor type was presented in three consecutive trials, with the order of stimulus presentations being balanced across the participants.

The Trust Game and the odor presentation were programmed using Presentation 16 (Neurobehavioral Systems Inc., CA).

2.2.2.3. Odor detection and ratings. To assess whether the participants were able to detect the body odors, a detection test was carried out prior to the Trust Game. The participants were presented with a three-alternative forced choice test including two stimuli of pure, unused cotton, and one stimulus of one of the two body odors. Three trials were carried out for each of the body odors (anxiety, sport). A participant was defined as a detector if she could successfully detect the body odors in all three trials. The odors were administered via the olfactometer and presented for 3 s each.

Participants were also asked to evaluate the odors' intensity (1 = lowest degree to 9 = highest degree). To assess participants' emotional response towards the stimuli, they were asked to rate their own feelings while smelling the odors using the Self-Assessment Manikin (SAM; Bradley & Lang, 1994) with the scales valence (-4 to +4) and arousal (1–9). The ratings were recorded while the chemosensory stimuli were administered for a duration of 3 s via the 3 channel olfactometer.

2.2.3. Statistical analyses

To evaluate the effects of the odors on trust behavior, a repeated measures one-way ANOVA with the within-subjects factor Odor (anxiety, sport, cotton) was computed. Trust behavior was indexed by the sum of all three monetary transfers per condition (0–9 Euros). Post hoc t-tests for comparisons between the conditions were computed. A similar ANOVA was conducted for the expected retransfer, again using the sum of all three expected monetary retransfers per condition. Further ANOVAs were conducted for the stimulus intensity ratings and emotional responses to the stimuli (valence, arousal). All statistical analyses were conducted using SPSS 24 (IBM Corp., NY) with an alpha level of $p < 0.05$. Huynh–Feldt corrected degrees of freedom were calculated and corrected p-values are reported. Partial eta square (η_p^2) was reported as a measure of effect size. Furthermore, the analyses of the behavioral data include power values (1-beta error probability) according to (Cohen, 1988) and 95 % confidence intervals (CI) of means.

2.3. Results

2.3.1. Odor detection

More participants than expected by chance were able to detect the anxiety odor (48 out of 60 participants, binomial test, $p < 0.001$). However, not more participants than expected by chance correctly detected sport sweat (35 out of 60 participants, binomial test, $p = 0.245$). Anxiety was significantly detected more often than sport odor (McNemar, $p = 0.001$).

2.3.2. Ratings

Participants rated the anxiety odor as the most intense compared to pure cotton ($t(59) = 11.43$, $p < 0.001$) and sport odor ($t(59) = 9.03$, $p < 0.001$). They also rated the sport odor as more intense than pure cotton ($t(59) = 3.97$, $p < 0.001$; main effect Odor: $F(2, 118) = 82.90$, $p < 0.001$, $\eta p2 = 0.584$).

Participants felt unhappier and more aroused after smelling anxiety odor as compared to pure cotton (valence: $t(59) = -6.37$, $p < 0.001$; arousal: $t(59) = 4.06$; $p < 0.001$), and as compared to sport odor (valence: $t(59) = -3.92$, $p < 0.001$; arousal: $t(59) = 4.09$; $p < 0.001$). After smelling cotton, participants felt happier as compared to sport odor ($t(59) = -4.67$, $p < 0.001$; main effect Odor: $F(2, 118) = 28.84$, $p < 0.001$, $\eta p2 = 0.328$), but the level of arousal was similar while smelling sport odor and cotton ($p > 0.05$; main effect Odor: $F(2, 118) = 12.30$, $p < 0.001$, $\eta p2 = 0.173$). All ratings are presented in Table 1.

2.3.3. Trust behavior

Women transferred less money to their fictional co-players, when chemosensory anxiety signals were presented as the presumably body odors of their fictional co-players (M = 3.68 Euros, SD = 2.16, 95 % CI [3.13, 4.24]) as compared to pure cotton (M = 6.35 Euros, SD = 1.99, 95 % CI [5.84, 6.86]; $t(59) = -7.435$, $p < 0.001$), or sport odor (M = 5.05 Euros, SD = 1.78, 95 % CI [4.56, 5.48]; $t(59) = -4.926$, $p < 0.001$). Women also transferred less money to co-players when believing they smelled like sport odor compared to the odor of pure cotton ($t(59) = -4.511$; $p < 0.001$; main effect Odor: $F(2, 118) = 36.88$, $p < 0.001$, $\eta_p^2 = 0.385$, power = 0.99, see Fig. 3). 95 % CIs of the three odor conditions do

Table 1
Odor intensity and self-ratings of valence and arousal.

Study	Condition	Intensity		Valence		Arousal	
		M	SD	M	SD	M	SD
Study 1	Anxiety	6.37	2.16	−1.03	1.54	5.27	1.55
	Sport	3.67	1.94	−0.20	1.16	4.48	1.41
	Cotton	2.57	1.73	+ 0.70	1.45	4.12	1.71
Study 2	Anxiety	6.63	1.74	−1.32	1.52	5.68	1.36
	Sport	3.47	1.59	+0.03	1.19	4.60	1.21
	Cotton	2.55	1.52	+0.43	1.00	4.08	1.51
Study 3	Anxiety	6.23	2.08	−1.23	1.57	5.53	1.76
	Sport	3.93	2.10	+0.10	1.37	5.07	1.38
	Cotton	2.53	1.41	+1.07	1.39	4.53	1.36
Study 4	Anxiety	5.25	2.76	−1.08	1.63	5.36	1.71
	Sport	3.48	2.06	+0.20	1.47	4.52	1.90
	Cotton	2.36	1.25	+0.32	0.85	4.20	1.76
Study 5	Anxiety	5.13	2.27	−1.03	1.48	4.97	1.58
	Sport	4.13	2.03	−0.21	1.77	4.59	1.63
	Cotton	2.74	1.74	+0.92	1.44	3.92	1.44

Note: M = Mean, SD = Standard deviation. Range (Intensity, Arousal): 1 = lowest degree to 9 = highest degree. Range (Valence): -4 (unhappy) to +4 (happy).

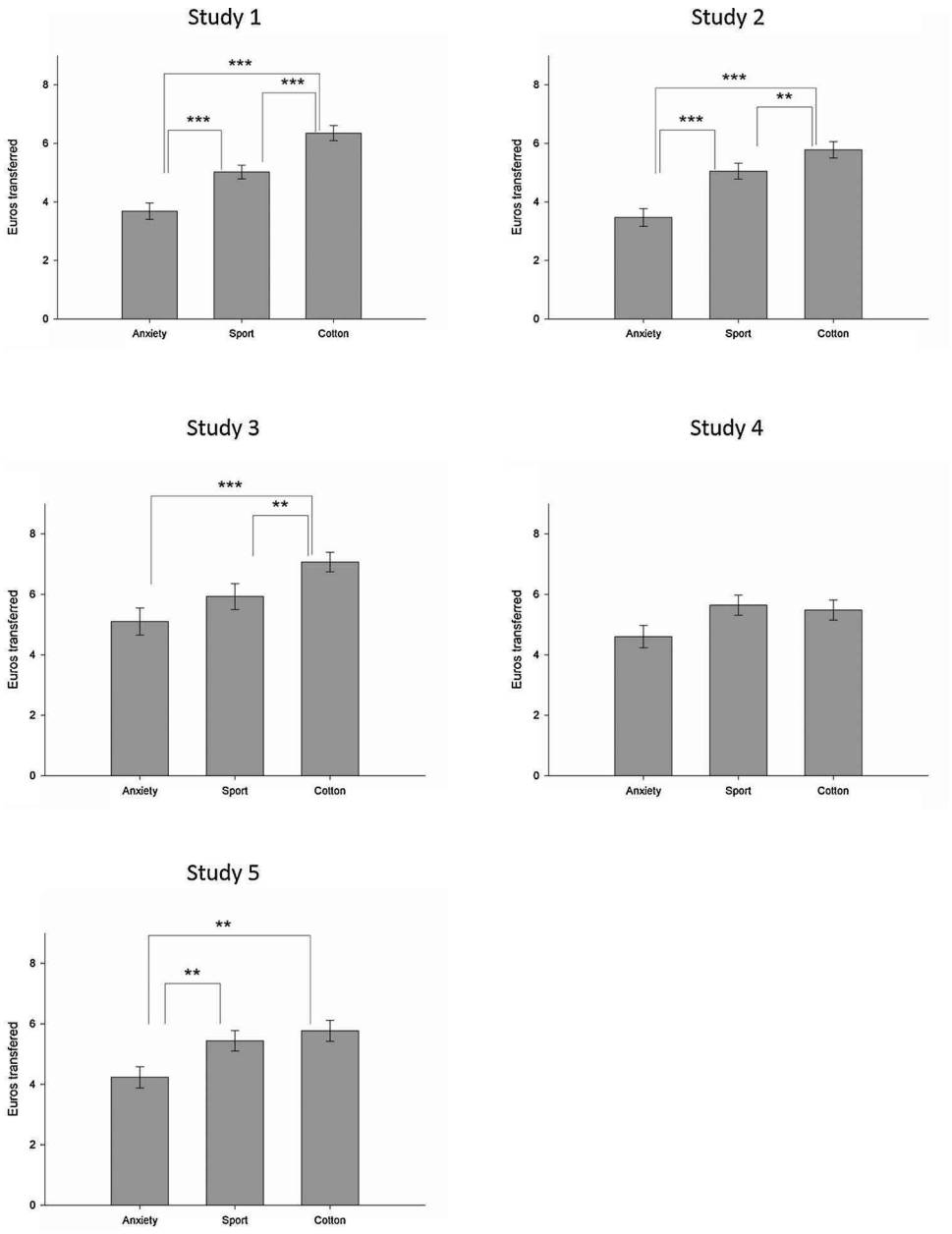

Fig. 3. Results of the money transferred to the fictional co-players (studies 1, 3, 5) or to the computer (studies 2, 4): Means and standard errors. ** $p < 0.01$, *** $p < 0.001$.

not overlap. Consistently, participants expected less money back from co-players being associated with anxiety odor (M = 6.07 Euros, SD = 3.77), as compared to co-players being associated with pure cotton (M = 10.40 Euros, SD = 5.64; t(57) = -5.63; $p < 0.001$) or sport odor (M = 8.48 Euros, SD = 4.75; t(59) = -4.94; $p < 0.001$). They also expected less money back after interacting with co-players smelling like sport odor as compared to co-players smelling like pure cotton (t(57) = −2.62; p = 0.011; main effect Odor: F(2, 114) = 20.36, $p < 0.001$, $\eta_p^2 = 0.263$).

To investigate whether the differences in trust behavior between the anxiety and sport condition are due to the significant differences in perceived odor intensity, difference values were computed between intensity ratings of anxiety and sport sweat and between trust behavior in the context of anxiety odor and sport odor for each participant. No significant correlation between the difference values of intensity ratings and of trust behavior could be observed (Pearson r = −0.014, p = 0.916).

2.4. Discussion

It could be shown that women trust less in fictitious co-players emitting chemosignals of anxiety than in fictitious co-players associated with neutral sweat. More women than expected by chance could olfactorily detect the body odor of the anxious odor donors (but not the sport-control odor), and rated it to be more intense than sport-control sweat. Accordingly, women rated themselves as less happy and more aroused smelling anxiety related body odor as compared to sport related body odor.

This study is the first to show that the level of trust towards humans, supposedly smelling like anxiety, is reduced. The results are in line with the hypothesis of chemical emotional contagion (Prehn-Kristensen et al., 2009), as the experience of social stress (TSST) is associated with reduced general trust scores (Takahashi et al., 2005), and in socially anxious participants the extent of giving in a prisoner's dilemma task is reduced (Rodebaugh et al., 2013). In the present study, the

chemosensory anxiety effects on reduced trust are accompanied by the expectation of a reduced pro-sociality (back-transfer) of the fictitious co-player. Even though the anxiety related body odor was rated as more intense than the sport odor and cotton pad control, the change in trust behavior cannot be attributed to the odor characteristics of the sweat samples, as they are not statistically correlated.

In line with Quintana et al. (2019), participants' well-being (valence) decreased while exposed to the anxiety odor. However, in contrast to the study of Quintana et al. (2019), the anxiety related chemosignals used in the present study directly affected trust behavior. A reason for the stronger and unambiguous effects in the present study might be found regarding the differences in the emotion induction procedures used for the sweat donors. Quintana et al. (2019) presented fear-inducing film clips lasting 20 min to their odor donors. In the current study, the odor donors felt anxiety directly relevant to their self-concept. Emotion induction methods like the TSST evoke emotional states resembling real-life experiences, more specifically, the anxiety to receive negative evaluations on social skills, relevant to parts of self-concept and self-esteem. Real-life emotion induction methods are accompanied by intensive physiological adaptions (e.g. Campbell & Ehlert, 2012; Stemmler, Heldmann, Pauls, & Scherer, 2001), which in turn are the necessary conditions for affecting the axillary sweat composition (Lübke & Pause, 2015).

Apart from inducing intense emotional experiences, it was intended to adapt the TSST-G protocol in order to evoke a specific emotion instead of a general stress response. As anger and anxiety are the most prominent feelings evoked by the TSST (Moons, Eisenberger, & Taylor, 2010), the anger provoking arithmetic task was dropped and replaced by two anxiety provoking tasks (Dickerson & Kemeny, 2004). In the stress condition, sweat donors showed increased cortisol values, and experienced relatively strong feelings of anxiety but reported a near to bottom anger level. Therefore, it is concluded that the TSST-G adaption was successful. This result justifies the conclusion that anxiety related and not stress related sweat was investigated. Investigating specific emotions, instead of a generalized stress response, has the advantage of being able to investigate whether different chemosensorily transmitted emotional states have differential effects on the receiver. This could be an important prerequisite for future research on chemosensory communication of emotions in humans.

3. Study 2: females risk

3.1. Introduction

The first study revealed that anxiety related chemosignals reduce trust behavior in women in pretended real-life interactions. However, the reduced amount of money transferred to the trustee could either be due to a reduced level of trust, corresponding to the prediction of the trustworthiness of the co-player, or just to a reduced level of risk behavior, resembling the general tendency to invest less money in risky situations (see Kosfeld et al., 2005). As it has been proposed that the perception of sweat samples from individuals performing a high-rope course affect risk behavior in humans (Haegler et al., 2010), the present experiment was carried out in order to disentangle effects of chemosensory anxiety signals on trust and risk behavior. The experimental protocol was identical to that of study 1, with the exception that participants were told to act as investor in interaction with a computer, programmed for back-transferring money on the basis of a random mechanism.

3.2. Methods

3.2.1. Participants

60 non-smoking females aged between 18 and 44 (M = 22.8, SD = 4.0) participated in study 2. They fulfilled the same criteria as the participants of study 1, with 42 of them reporting to take oral contraceptives. The participants of study 2 scored in the normal range for trait anxiety (STAI: M = 35.62, SD = 7.52) and social anxiety (SIAS: M = 21.38, SD = 10.01).

3.2.2. Task and material

3.2.2.1. Chemosensory stimuli. In study 2, the same materials as in study 1 were used. The presentation of the stimuli during the Risk Game was equivalent to the Trust Game: Three trials were carried out for each condition (anxiety, sport, sweat), with the odors being presented for four seconds right before each money transfer.

3.2.2.2. The risk game. The Risk Game (Kosfeld et al., 2005) was conducted in the same way as the Trust Game (see study 1), with the only exception that participants were asked to play with a computer, thereby erasing any social context from the pretended interaction. The amount of money retransferred after the initial investment was said to be based on a predetermined but random mechanism. In fact, the rate of back-transfer was exactly the same as in the Trust Game. The body odors were introduced as body odors of three different individuals (one per condition). Participants were told that the study purpose was to assess the effect of different body odors on decision making.

3.2.2.3. Odor detection and ratings. The measurements for odor detection and stimulus ratings were the same as in study 1.

3.2.3. Statistical analyses

To evaluate the effects of the odors on risk behavior, a repeated measures one-way ANOVA with the within subject condition Odor (anxiety, sport, cotton) was computed. Risk behavior was indexed by the sum of all three money transfers per condition. Post hoc t-tests for comparisons between the conditions were computed. A similar ANOVA was conducted for the expected retransfer, again using the sum of all three expected money retransfers per condition. Further ANOVAs were conducted for the stimulus intensity ratings and emotional reactions to the stimuli (valence, arousal). All statistical analyses were conducted using SPSS 24 (IBM Corp., NY) with an alpha level of $p < 0.05$. Huynh–Feldt corrected degrees of freedom were calculated and corrected p-values are reported. Partial eta square (ηp2) was reported as a measure of effect size. Furthermore, the analyses of the behavioral data include power values (1-beta error probability) according to (Cohen, 1988) and 95 % confidence intervals (CI) of means.

3.3. Results

3.3.1. Odor detection

More participants than expected by chance were able to detect the anxiety odor (52 out of 60 participants, binomial test, $p < 0.001$). However, not more participants than expected by chance level correctly detected sport sweat (33 out of 60 participants, binomial test, $p = 0.519$). Accordingly, anxiety was detected significantly more often than sport odor (McNemar, $p < 0.001$).

3.3.2. Ratings

Participants rated the anxiety odor as more intense as compared to pure cotton ($t(59) = 12.62$, $p < 0.001$) and sport odor ($t(59) = 11.68$, $p < 0.001$). Sport odor was also rated as more intense than pure cotton ($t(59) = 3.33$, $p = 0.001$; main effect Odor: $F(2, 118) = 108.39$, $p < 0.001$, $\eta_p^2 = 0.648$).

Participants felt unhappier and more aroused after smelling anxiety odor as compared to pure cotton (valence: $t(59) = -7.30$, $p < 0.001$; arousal: $t(59) = 5.47$; $p < 0.001$), and as compared to sport odor (valence: $t(59) = -7.05$, $p < 0.001$; arousal: $t(59) = 4.40$; $p < 0.001$). After smelling cotton, participants felt happier ($t(59) = -2.13$, $p = 0.037$; main effect Odor: $F(2, 118) = 39.05$, $p < 0.001$, $\eta_p^2 = 0.398$), and

less aroused (t(59) = 2.87, p = 0.006; main effect Odor: F(2, 118) = 22.41, p < 0.001, η_p^2 = 0.275) as compared to smelling sport odor. All rating results are presented in Table 1.

3.3.3. Risk behavior

Women risked less money when smelling anxiety related odor (M = 3.47 Euros, SD = 2.30, 95 % CI [2.87, 4.06]), as compared to pure cotton (M = 5.78 Euros, SD = 2.16, 95 % CI [5.22, 6.34]; t(59) = −6.718, p < 0.001) or sport odor (M = 5.05 Euros, SD = 2.07, 95 % CI [4.52, 5.58]; t(59) = −4.755, p < 0.001). CIs between the anxiety and cotton condition and between the anxiety and sport condition do not overlap. Women also risked less money when smelling sport odor as compared to pure cotton (t(59) = −2.59; p = 0.012; main effect odor: F(2,118) = 27.14, p < 0.001, η_p^2 = 0.315, power = 0.99, see Fig. 3). However, CIs of means of the sport and cotton condition are not completely separated. Regarding the expected return, participants expected less money back in trials with the anxiety odor (M = 6.33 Euros, SD = 3.80), as compared to trials with pure cotton (M = 8.77 Euros, SD = 3.47; t(55) = −4.56; p < 0.001) and sport odor (M = 7.69 Euros, SD = 3.23; t(52) = −2.70; p = 0.009). However, there was no difference in the expected retransfer when being exposed to sport odor as compared to pure cotton (p > 0.05; main effect Odor: F(2, 102) = 11.67, p < 0.001, η_p^2 = 0.186).

To investigate whether the differences in risk behavior between the anxiety and sport condition are due to the significant differences in perceived odor intensity, difference values were conducted between intensity ratings of anxiety and sport sweat and between risk behavior in the context of anxiety odor and sport odor for each participant. No significant correlation between the difference values of intensity ratings and of risk behavior could be observed (Pearson r = -0.013, p = 0.921).

3.4. Discussion

Chemosensory anxiety signals decrease the number of risky choices in a non-social transaction in a similar way as they decrease trust in social transactions (study 1). Women acting as investors in a computer game risked less money and expected less money back while being exposed to anxiety-related chemosignals as compared to sport-related chemical transmissions. Even though the sweat samples from anxious donors were smelling stronger than those from donors riding a bike (sport control), no correlation between risk behavior and odor intensity could be observed. While smelling anxiety related body odors, participants felt less happy and more aroused than in both control conditions. It is here proposed that the effects of chemosensory anxiety signals on social trust (study 1) might be accompanied by a general tendency to make cautious and non-risky decisions (study 2).

The here presented results support the view of differential effects of stress and anxiety on risk-behavior. It has been shown before that participants exposed to sweat from individuals performing a high-rope course show more risky decisions than control participants (Haegler et al., 2010). The walk on a high-rope course is a form of extreme sportive activities, like bungee jumping, sky-diving or jumping from fixed objects. The voluntary nature of these activities indicates that they seem to be associated to emotional states related to processes of fulfilling one's potentials, experiencing meaning in life and enhancing self-esteem. Accordingly, while doing extreme sports, individuals experience very heterogeneous and high intensity emotions (Hetland & Vittersø, 2012). These emotions vary from very positive (like pleasure, satisfaction and happiness) to very negative emotions (like anger or fear). Furthermore, while right before the sport performance the amount of positive and negative experienced emotions closely resemble each other, right after the sport performance the experience of positive emotions usually outreaches the experience of negative emotions, even in individuals doing extreme sports for the first time (Meyer et al., 2015). In sum, the experience of various but extreme emotions equals the disruption of physiological homeostasis and forms the basis of the allostatic stress response (McEwen, 1998).

As feelings of stress might be transmitted chemosensorily from the signal sender to the receiver, it is to be expected that risky choices in individuals exposed to stress sweat are similar to risky choices of stressed individuals. Apart from the well-known increase in health-related risk behavior in stressed individuals (Algren et al., 2018), acute laboratory stress also leads to an increase in risky choices in non-social gambling tasks (Bendahan et al., 2017). Anxiety, on the contrary, seems to act in the opposite way on risk behavior. State as well as trait anxiety are considered to be associated with pessimistic risk appraisals, e.g., a heightened perception of the likelihood and severity of negative outcomes. Accordingly, anxious individuals avoid risky decision making (Maner & Schmidt, 2006).

In sum, chemosensory anxiety signals reduce the tendency for risky decisions in social (study 1) and non-social (study 2) interactions. It is concluded that anxiety is chemosensorily contagious, and that women perceiving the anxiety related chemosignals behave similar to anxious women.

4. Study 3: males trust

4.1. Introduction

Study 1 and 2 revealed marked effects of chemosensory anxiety signals on trust and risk behavior in women. Here, studies in women and men were conducted separately, as the research on chemosensory communication of emotions in humans sometimes reveals profound gender differences. Regarding the chemosensory communication of anxiety and fear, two studies even reported strong effects in women but zero effects in men. In detail, only women but not men respond with distinct event-related brain potentials to anxiety chemosignals (Pause et al., 2010). The brain potentials in men in response to chemosensory anxiety signals are not only weak but almost absent. Similarly, only women but not men respond to chemosensory fear signals with facial mimicry (de Groot et al., 2014). Again, the strong effects in women were not even rudimentarily seen in men. However, gender differences in chemosensory emotional communication seem to vary with the emotion in question. For example, in contrast to chemosensory anxiety signals, chemosensory aggression signals do evoke distinct brain potentials in men and women, which, however, refer to gender-specific activation of differing brain areas during stimulus processing (Pause, Storch, & Lübke, 2020).

Study 3 was conducted in order to investigate whether male participants respond to chemosensory anxiety signals with a change in trust behavior. Methods and design of study 3 were identical to study 1.

4.2. Methods

4.2.1. Participants

30 non-smoking males aged between 18 and 45 (M = 22.9, SD = 5.0) participated in study 3. They reported being healthy, and not taking any medication. Further, participants were included based on the same restrictions as in studies 1 and 2. All participants scored in the normal range for trait anxiety (M = 38.83, SD = 9.97) and social anxiety (M = 21.33, SD = 10.18).

4.2.2. Task and material

In study 3, the Trust Game was carried out, and the same tasks, materials and statistics were used as in study 1.

4.3. Results

4.3.1. Odor detection

More participants than expected by chance were able to detect the anxiety odor (21 out of 30 participants, binomial test, p = 0.045). In contrast, not more participants than expected by chance correctly detected sport sweat (17 out of 30 participants, binomial test, p =

0.584). However, detection rates for anxiety and sport odor were not significantly different (McNemar, $p = 0.344$).

4.3.2. Ratings

Participants rated the anxiety odor as more intense as compared to pure cotton ($t(29) = 8.41$, $p < 0.001$) and sport odor ($t(29) = 5.08$, $p < 0.001$). They also rated the sport odor as more intense than pure cotton ($t(29) = 2.79$, $p = 0.001$; main effect Odor: $F(2, 58) = 32.20$, $p < 0.001$, $\eta_p^2 = 0.526$).

After smelling anxiety odor, participants felt unhappier and more aroused as compared to pure cotton (valence: $t(29) = -4.79$, $p < 0.001$; arousal: $t(29) = 2.32$; $p = 0.028$), and unhappier ($t(29) = -3.44$, $p = 0.002$) but equally aroused when compared to sport odor ($p > 0.05$). After smelling cotton, participants felt happier as compared to sport odor ($t(29) = -3.02$, $p = 0.005$; main effect Odor: $F(2, 58) = 16.58$, $p < 0.001$, $\eta_p^2 = 0.364$), but the level of arousal was similar while smelling sport odor and cotton ($p > 0.05$; main effect Odor: $F(2, 58) = 3.45$, $p = 0.038$, $\eta_p^2 = 0.106$). All ratings are presented in Table 1.

4.3.3. Trust behavior

Men transferred less money when they interacted with fictitious co-players who emitted chemosensory anxiety signals (M = 5.10 Euros, SD = 2.44, 95 % CI [4.19, 6.01]) as compared to the odor of pure cotton (M = 7.07 Euros, SD = 1.74, 95 % CI [6.42, 7.72]; $t(29) = -4.39$, $p < 0.001$). This result is supported by non-overlapping CIs. Similarly, when believing their co-players smelled like sport odor (M = 5.93 Euros, SD = 2.36 95 % CI [5.05, 6.82]) compared to the odor of pure cotton, men transferred less money ($t(29) = -3.26$; $p = 0.003$). However, overlapping CIs do not confirm a valid mean difference. According to the CIs and t-tests, there was no difference between the money transferred to co-players smelling like anxiety related odor and sport related odor ($t(29) = -1.92$, $p > 0.05$); main effect Odor: $F(2, 58) = 11.44$, $p < 0.001$, $\eta_p^2 = 0.283$, power = 0.86, see Fig. 3).

Consistently, participants also expected less money back from the fictitious co-players being associated with the anxiety odor (M = 8.67 Euros, SD = 4.63) as compared to co-players being associated with pure cotton (M = 11.63 Euros, SD = 4.53; $t(27) = -3.95$; $p = 0.001$), but not in comparison to fictitious co-players being associated with sport odor (M = 9.70 Euros, SD = 4.52; $t(29) = -1.21$ $p > 0.20$). They also expected less money back after interacting with fictitious co-players smelling like sport odor as compared to co-players represented by pure cotton ($t(28) = -3.19$; $p = 0.003$; main effect Odor: $F(2, 52) = 7.43$, $p = 0.001$, $\eta_p^2 = 0.222$).

As no behavioral differences between trust behavior in the anxiety and sport condition were observed, the investigation of a possible correlation between behavior and intensity ratings was not of interest.

4.4. Discussion

In contrast to the study in women (study 1), study 3 reveals that men's trust behavior is not affected by chemosensory anxiety signals. In detail, trust behavior in men was reduced to a similar amount in both body odor conditions (anxiety, sport) as compared to the pure cotton pad control condition. However, similar to the results observed in women (study 1), men rated the anxiety related body odor as more intense than the sport odor and felt less happy while being exposed to the anxiety related odor than during exposure to the sport control odor. Men's arousal was not differentially affected through anxiety and sport odor.

The results are in line with studies showing responsiveness to chemosensory anxiety and fear signals in female participants only (de Groot et al., 2014; Pause et al., 2010). However, trust behavior (or automatic obedience, see general introduction) towards a robot doll is reduced in male participants being exposed to sweat obtained from first time sky divers (Endevelt-Shapira et al., 2018). As it has been pointed out in the discussion of study 2, sky-diving evokes a variety of intensive feelings, best compared to an intensive stress response and far from being related to a distinct emotion (Meyer et al., 2015). Sweat of sky-divers has also been presented to male and female participants while functional brain imaging was obtained (Mujica-Parodi et al., 2009). In this study, statistical analyses revealed no gender differences. It is concluded that chemosensorily transmitted signals of fear and anxiety might predominantly be processed in women, whereas chemosensory stress signals might affect men and women in a comparable fashion. Accordingly, it is proposed that the social function of fear or anxiety signals is often related to promote social support and helping behavior, while mixed emotional signals deriving from stress are rather related to inform others about danger (Fischer & Manstead, 2008). It is here proposed that both sexes need to escape from a potential danger, signaled by surrounding others' chemosensory stress derivates. However, women seem to respond to individual social signals of fear and anxiety with a stronger tendency for affiliative behavior than men (Eagly, 2009; Taylor et al., 2000).

5. Study 4: males risk

5.1. Introduction

Similar to study 2, in study 4 it was intended to investigate males' willingness to invest money with uncertain amounts of retransfer. The participants were told to interact with a computer-program, which returned money on an unpredictable basis. Otherwise, the experimental conditions were the same as in study 3.

5.2. Methods

5.2.1. Participants

25 non-smoking males aged between 19 and 41 (M = 23.2, SD = 5.5) participated in study 4. They fulfilled the same criteria as the participants of study 3, and scored in the normal range for trait anxiety (M = 37.28, SD = 4.80) and social anxiety (M = 19.20, SD = 8.18).

5.2.2. Task and material

The Risk Game conducted in this study was the same as in study 2. Further, the same materials, tasks and statistics were used as in study 2.

5.3. Results

5.3.1. Odor detection

More participants than expected by chance were able to detect the anxiety odor (18 out of 25 participants, binomial test, $p = 0.043$). However, no more participants than expected by chance correctly detected sport odor (13 out of 25 participants, binomial test, $p = 1.000$). Detection rates for anxiety and sport odor were not significantly different (McNemar, $p = 0.063$).

5.3.2. Ratings

Participants rated the anxiety odor as the most intense compared to pure cotton ($t(24) = 5.09$, $p < 0.001$) and sport odor ($t(24) = 2.82$, $p = 0.009$). Sport odor was also rated as more intense than pure cotton ($t(24) = 2.30$, $p = 0.031$; main effect Odor: $F(2, 48) = 13.37$, $p < 0.001$, $\eta_p^2 = 0.358$).

Participants felt unhappier and more aroused after smelling anxiety odor as compared to pure cotton (valence: $t(24) = -3.70$, $p = 0.001$; arousal: $t(24) = 2.94$; $p = 0.007$) and as compared to sport odor (valence: $t(24) = -3.72$, $p = 0.001$; arousal: $t(24) = 2.15$; $p = 0.042$). Sport and cotton odor did not significantly differ regarding the reported happiness ($p > 0.05$; main effect Odor: $F(2, 48) = 9.04$, $p < 0.001$, $\eta_p^2 = 0.274$) or arousal ($p > 0.05$; main effect Odor: $F(2, 48) = 4.36$, $p = 0.018$, $\eta_p^2 = 0.154$). All ratings are presented in Table 1.

5.3.3. Risk behavior

There were no significant differences between odor conditions in the amount of money men transferred during the Risk Game (anxiety: M = 4.60 Euros, SD = 1.85, 95 % CI [3.84, 5.36]; sport: M = 5.64 Euros, SD = 1.66, 95 % CI [4.96, 6.32]; cotton: M = 5.48 Euros, SD = 1.64, 95 % CI [4.80, 6.16]; $F(2, 48) = 2.72$, $p = 0.076$, $\eta_p^2 = 0.102$, power = 0.29, see Fig. 3), with the CIs of all group means strongly overlapping. Accordingly, there were no significant differences between the odor conditions in the money expected back according to the computer algorithm (anxiety: M = 7.23 Euros, SD = 4.39; sport: M = 8.77 Euros, SD = 3.10; cotton: M = 9.59 Euros, SD = 3.33; $F(2, 42) = 3.55$, $p = 0.055$, $\eta_p^2 = 0.145$).

As no behavioral differences between risk behavior in the anxiety and sport condition were observed, the investigation of a possible correlation between behavior and intensity ratings was not of interest.

5.4. Discussion

Chemosensory anxiety signals do neither affect men's risk (study 4) nor men's trust behavior (study 3). In a similar vein, chemosensory anxiety signals do not affect men's expectation regarding the amount of money to be retransferred, independent of the social or non-social context of the investment game.

Due to the more difficult recruitment of male in comparison to female participants in psychological studies, only 25 males took part in study 4, increasing the probability of low statistical power. However, the achieved power (0.29) is considered to rather reflect the small effect of chemosensory anxiety signals on men's risk behavior than the low sample size: In study 3 (trust), 30 male participants underwent the same procedure as 60 female participants in study 1 (trust). Even though the number of participants was reduced by half in comparison to study 1, the experimental power was still satisfying (power = 0.86). Thus, it is to be assumed that in the two trust experiments the relation between effect and sample size is comparable between studies with men and women. Assuming a comparability of the effect size of the two risk studies in female (study 2) and male (study 4) participants respectively, a total of 23 male participants in study 4 would have sufficed in achieving significant results (based on a partial eta square of 0.315 as in study 2, an alpha error probability of 0.05, and a power of 0.80; according to G*Power 3.1.9.4, (Faul, Erdfelder, Lang, & Buchner, 2007). However, based on a sample of even 25 participants in study 4, a partial eta square of only 0.102 was observed. It is thus concluded that risk behavior in men is indeed not affected by chemosensory anxiety signals (as mirrored in the relatively small effect size), and that this result is not driven by low statistical power.

6. Study 5: females trust intensity control

6.1. Introduction

Studies 1 and 2 revealed that chemosensory anxiety signals reduce trust and risk behavior in women, whereas studies 3 and 4 could not observe similar effects in men. However, even though the level of physiological arousal of the sweat donors was held constant between the anxiety and the sport condition (according to comparable heart rates in both conditions), the anxiety sweat was obviously more odorous than the sport sweat in all four studies. Even though control correlations between odor intensity and trust and risk behavior did not reveal a direct association between perceived odor intensity and behavior, a control study was conducted minimizing the intensity differences between anxiety and sport odor.

The aim of study 5 was to investigate whether study 1 could be replicated with the quantity of sweat being strongly reduced. Therefore, in comparison to studies 1–4, only one sixth of the sweat material was put into the odor bottles of the olfactometer. By reducing the total amount of both sweat samples, it was intended to reduce the odor intensity differences between the samples.

6.2. Methods

6.2.1. Participants

39 non-smoking females aged between 18 and 34 (M = 22.6, SD = 4.3) participated in study 5. They fulfilled the same criteria as the participants of studies 1 and 2, with 26 of them reported to take oral contraceptives. The participants scored in the normal range for trait anxiety (M = 35.18, SD = 5.18) and social anxiety (M = 19.28, SD = 9.06).

6.2.2. Task and material

The Trust Game in study 5 was the same as in studies 1 and 3. The stimuli and their presentation were almost identical to study 1–4. However, in this study, smaller portions of sweat samples were put into the glass chambers of the olfactometer. In study 5, only 0.05 g of each chemosensory stimulus was used for the individual experiments (in contrast to the 0.3 g in studies 1–4). In study 5, all further tasks and statistics were identical to studies 1 and 3.

6.3. Results

6.3.1. Odor detection

No more participants than expected by chance were able to detect the anxiety odor (24 out of 39 participants, binomial test, $p = 0.200$) or the sport odor (21 out of 39 participants, binomial test, $p = 0.749$). Accordingly, detection rates for anxiety and sport odor were not significantly different (McNemar, $p = 0.549$).

6.3.2. Ratings

Participants rated the anxiety odor as more intense as compared to pure cotton ($t(29) = 5.57$, $p < 0.001$) and also sport odor as more intense than pure cotton ($t(29) = 3.60$, $p = 0.001$). However, the intensity of anxiety odor and sport odor was not significantly different ($p > 0.05$; main effect Odor: $F(2, 76) = 14.29$, $p < 0.001$, $\eta_p^2 = 0.273$).

Participants felt unhappier and more aroused after smelling anxiety odor as compared to pure cotton (valence: $t(29) = -6.780$ $p < 0.001$; arousal: $t(29) = 3.02$; $p = 0.005$), and more negative ($t(29) = -2.13$, $p = 0.040$) but equally aroused ($p > 0.05$) as compared to sport odor. After smelling cotton, participants felt happier as compared to sport odor ($t(29) = -3.10$, $p = 0.004$; main effect Odor: $F(2, 76) = 15.82$, $p < 0.001$, $\eta_p^2 = 0.294$), but the level of arousal was similar while smelling sport odor and cotton ($t(29) = 2.00$, $p = 0.053$; main effect Odor: $F(2, 76) = 4.95$, $p = 0.009$, $\eta_p^2 = 0.115$). All ratings are presented in Table 1.

6.3.3. Trust behavior

Women transferred less money when they interacted with fictitious co-players who "emitted" chemosensory anxiety signals (M = 4.23 Euros, SD = 2.18, 95 % CI [3.52, 4.94]) as compared to the odor of pure cotton (M = 5.77 Euros, SD = 2.17, 95 % CI [5.07, 6.47]; $t(29) = -3.68$, $p = 0.001$) or sport odor (M = 5.44 Euros, SD = 2.15, 95 % CI [4.74, 6.13]; $t(29) = -3.71$, $p = 0.001$). However, the CI of the reduced mean transfer in the anxiety condition did not overlap with the CI of the mean transfer in the cotton condition only. No difference was found between the sport and cotton condition ($p > 0.05$; main effect Odor: $F(2, 76) = 9.73$, $p < 0.001$, $\eta_p^2 = 0.204$, power = 0.80, see Fig. 3). Consequently, the participants expected less money back from co-players smelling like anxiety odor (M = 6.95 Euros, SD = 4.40) compared to pure cotton (M = 9.85 Euros, SD = 6.84; $t(29) = -2.63$, $p = 0.012$), and sport odor (M = 9.59 Euros, SD = 5.90; $t(29) = -3.61$, $p = 0.001$). Again, no difference in the amount of expected return was found when comparing sport odor and cotton ($p > 0.05$; main effect Odor: $F(2, 76) = 6.09$, $p = 0.006$, $\eta_p^2 = 0.138$).

Across participants, neither the anxiety odor nor the sport odor could be detected above chance level, and both odors were perceived to be similar in intensity. However, in order to investigate even subtle effects

of odor intensity on behavior, a correlational analysis based on difference values was conducted between intensity ratings of anxiety and sport sweat and between trust behavior in the context of anxiety odor and sport odor for each participant. A zero correlation between the difference values of intensity ratings and of trust behavior was observed (Pearson $r = 0.000$, $p = 1.000$).

6.4. Discussion

Even though only half of the participants could detect an odor from the anxiety and sport sweat samples, and even though both samples were perceived to have a similar intensity, the results of study 1 could be replicated: Women's trust behavior is reduced in the context of chemosensory anxiety signals as compared to the control cotton pad condition. It is concluded that the effects of chemosensory anxiety signals are not related to perceptual odor characteristics, like odor intensity. Similarly, a number of studies have reported on effects of chemosensory anxiety or fear signals even though participants could not detect an odor from the samples (e.g. de Groot et al., 2014; Hoenen, Lübke, & Pause, 2018; Pause et al., 2009). In line with these studies it is assumed that the effects of chemosensory anxiety signals are not cognitively mediated.

Similar to the comparable intensity ratings of the anxiety and sport sweat samples, emotional self-ratings revealed that participants experienced a comparable level of arousal while smelling the two sweat samples. However, they described themselves as less happy while smelling anxiety related sweat as compared to sport related sweat. This effect is in accordance with the theory of chemical contagion of anxiety (Prehn-Kristensen et al., 2009), and might mirror the increased anxiety ratings of participants being exposed to fear odor (Quintana et al., 2019).

7. General discussion

In a series of five studies it could be shown that chemosensory anxiety signals reduce trust and risk behavior in women, however, in men no such effects were observed. Therefore, this study adds important knowledge on the behavioral relevance of chemosensory anxiety signals.

By means of these studies, several ambiguous results present in the literature can be re-explained on the basis of the here implemented methodological uniqueness. On the side of the signal sender it is here proposed that the emotion induction procedure needs to induce a well-defined emotional state. It is assumed that emotion induction methods like asking participants to walk on a high rope course or to parachute (Endevelt-Shapira et al., 2018; Haegler et al., 2010) evoke several high intensity emotions at once, resembling an undefined stress state (Hetland & Vittersø, 2012; Meyer et al., 2015). The effects of chemical stress signals are supposed to be different from the effects of chemosensory anxiety signals obtained from sweat donors experiencing anxiety as the most prominent emotion (e.g. Prehn-Kristensen et al., 2009). One important difference between chemosensory stress and anxiety signals seems to be their gender specificity: While chemosensory stress signals seem to affect both genders in a similar manner (Endevelt-Shapira et al., 2018; Mujica-Parodi et al., 2009), chemosensory anxiety or fear signals might exert their effects predominantly in women (present study; de Groot et al., 2014; Pause et al., 2010). The reason is supposed to be related to a different functional significance of stress and anxiety signals. Because stress signals inform others about a non-specific physiological dysbalance, it is important for either gender to avoid potentially underlying dangerous circumstances. Anxiety or fear signals on the other hand are often directly related to prompting social support. As females are considered to rather select tending and befriending behavior in potentially dangerous situations (Taylor et al., 2000), they might be more sensitive to subtle signals of individual anxiety expressions than males (Eagly, 2009).

The second difference between anxiety and stress signals is related to the response profile of the receiver. While chemosensory stress signals (deriving from individuals on a high rope course) increase the amount of risk behavior (Haegler et al., 2010), chemosensory anxiety signals decrease the amount of risk behavior (present study). It is here proposed that high intensity stress disrupts cognitive processes, necessary for careful decisions in situations with unambiguous outcomes (Bendahan et al., 2017). Anxious states, on the other hand might rather be associated with negative outcome expectations, favoring less risky decisions (Maner & Schmidt, 2006).

By separating trust behavior in human interactions from risk behavior in non-social conditions, the present study could further explain and add to the results on trust effects of chemosensory fear signals (Quintana et al., 2019). Here, it could be shown that chemosensory anxiety signals reduce trust behavior in a similar way as risk behavior. Therefore, the proposed reduction in interpersonal trust seems to be due to a reduction in risk behavior in general, a characteristic phenomenon in anxious individuals.

Finally, the here presented studies took special care to control for confounding effects of odor intensity on trust and risk behavior. It was, however, abstained from adding another experiment with artificial odors resembling the intensity of the anxiety odor in order to exclude the possibility that behavioral effects are affected by perceived odor intensity in general. As the perceptual thresholds to odors are extremely variable between individuals (Stevens, Cain, & Burke, 1988), at least partly caused by the individual configuration of olfactory receptor alleles (Mainland et al., 2014), odor intensity matches on a sample basis (i.e. mean intensity) cannot predict odor intensity matches on an individual basis. We therefore avoided the very time-consuming task of finding odor intensity matches on an individual basis, bearing the additional disadvantage that intensity adjustments are not accompanied by adjustments in odor pleasantness (Trimmer et al., 2019). Instead, in studies 1 and 2 correlational analyses were performed between odor related intensity differences and odor related behavioral differences, which, however, did not reveal a significant relationship between the perceived odor intensity and social behavior. Furthermore, in study 5, odor intensity differences were equalized by strongly reducing the total sweat quantity, resulting in odor detection rates below the chance level. As the behavioral effects of chemosensory anxiety signals were still reliable, it is concluded that the chemosensory effects are not or only scarcely mediated cognitively.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Albrecht, J., Demmel, M., Schopf, V., Kleemann, A. M., Kopietz, R., May, J., et al. (2011). Smelling chemosensory signals of males in anxious versus nonanxious condition increases state anxiety of female subjects. *Chemical Senses, 36*, 19–27.

Algren, M. H., Ekholm, O., Nielsen, L., Kjær Ersbøll, A., Kronborg Bak, C., & Tanggaard Andersen, P. (2018). Associations between perceived stress, socioeconomic status, and health-risk behaviour in deprived neighbourhoods in Denmark: A cross-sectional study. *BMC Public Health, 18*, 250.

Bendahan, S., Goette, L., Thoresen, J., Loued-Khenissi, L., Hollis, F., & Sandi, C. (2017). Acute stress alters individual risk taking in a time-dependent manner and leads to anti-social risk. *European Journal of Neuroscience, 45*, 877–885.

Berg, J., Dickhaut, J., & McCabe, K. (1995). Trust, reciprocity, and social history. *Games and Economic Behavior, 10*, 122–142.

Bradley, M. M., & Lang, P. J. (1994). Measuring emotion - the self-assessment manikin and the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry, 25*, 49–59.
Calvi, E., Quassolo, U., Massaia, M., Scandurra, A., D'Aniello, B., & D'Amelio, P. (2020). The scent of emotions: A systematic review of human intra-and interspecific chemical communication of emotions. *Brain and Behavior, 10*, Article e01585.
Campbell, J., & Ehlert, U. (2012). Acute psychosocial stress: Does the emotional stress response correspond with physiological responses? *Psychoneuroendocrinology, 37*, 1111–1134.
Cohen, J. (1988). *Statistical power analysis for the behavioural sciences* (2nd edn). Hillsdale, NJ: L. Erlbaum Associates.
de Groot, J. H., & Smeets, M. A. (2017). Human fear chemosignaling: Evidence from a meta-analysis. *Chemical Senses, 42*, 663–673.
de Groot, J. H. B., Semin, G. R., & Smeets, M. A. M. (2014). Chemical communication of fear: A case of male–Female asymmetry. *Journal of Experimental Psychology: General, 143*, 1515–1525.
de Groot, J. H. B., Semin, G. R., & Smeets, M. A. M. (2017). On the communicative function of body odors: A theoretical integration and review. *Perspectives on Psychological Science, 12*, 306–324.
de Groot, J. H. B., Smeets, M. A. M., Kaldewaij, A., Duijndam, M. J. A., & Semin, G. R. (2012). Chemosignals communicate human emotions. *Psychological Science, 23*, 1417–1424.
Dickerson, S. S., & Kemeny, M. E. (2004). Acute stressors and cortisol responses: A theoretical integration and synthesis of laboratory research. *Psychological Bulletin, 130*, 355–391.
Eagly, A. H. (2009). The his and hers of prosocial behavior: An examination of the social psychology of gender. *American Psychologist, 64*, 644–658.
Endevelt-Shapira, Y., Perl, O., Ravia, A., Amir, D., Eisen, A., Bezalel, V., et al. (2018). Altered responses to social chemosignals in autism spectrum disorder. *Nature Neuroscience, 21*, 111–119.
Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*, 175–191.
Fialová, J., & Havlíček, J. (2012). Perception of emotion-related body odours in humans. *Anthropologie, 50*, 95–110.
Fischer, A. H., & Manstead, A. S. R. (2008). Social functions of emotion. In M. Lewis, J. M. Haviland-Jones, & L. F. Barrett (Eds.), *Handbook of emotions* (pp. 456–468). New York: The Guilford Press.
Fiske, S. T., & Neuberg, S. L. (1990). A continuum of impression formation, from category-based to individuating processes: Influences of information and motivation on attention and interpretation. In *Advances in experimental social psychology* (vol. 23, pp. 1–74). New York: Academic Press.
Haegler, K., Zernecke, R., Kleemann, A. M., Albrecht, J., Pollatos, O., Brückmann, H., et al. (2010). No fear no risk! Human risk behavior is affected by chemosensory anxiety signals. *Neuropsychologia, 48*, 3901–3908.
Hetland, A., & Vittersø, J. (2012). The feelings of extreme risk: Exploring emotional quality and variability in skydiving and base jumping. *Journal of Sport Behavior, 35*, 154–180.
Hoenen, M., Lübke, K. T., & Pause, B. M. (2018). Empathic cognitions affected by undetectable social chemosignals: An EEG study on visually evoked empathy for pain in an auditory and chemosensory context. *Frontiers in Behavioral Neuroscience, 12*, 243.
Kamiloğlu, R. G., Smeets, M. A. M., de Groot, J. H. B., & Semin, G. R. (2018). Fear odor facilitates the detection of fear expressions over other negative expressions. *Chemical Senses, 43*, 419–426.
Kosfeld, M., Heinrichs, M., Zak, P. J., Fischbacher, U., & Fehr, E. (2005). Oxytocin increases trust in humans. *Nature, 435*, 673–676.
Laux, L., Glanzmann, P., Schaffner, P., & Spielberger, C. D. (1981). *Das State-Trait-Angstinventar (STAI)*. Göttingen: Beltz Test GmbH.
Lübke, K. T., & Pause, B. M. (2015). Always follow your nose: The functional significance of social chemosignals in human reproduction and survival. *Hormones and Behavior, 68*, 134–144.
Mainland, J. D., Keller, A., Li, Y. R., Zhou, T., Trimmer, C., Snyder, L. L., et al. (2014). The missense of smell: Functional variability in the human odorant receptor repertoire. *Nature Neuroscience, 17*, 114.
Maner, J. K., & Schmidt, N. B. (2006). The role of risk avoidance in anxiety. *Behavior Therapy, 37*, 181–189.
McEwen, B. S. (1998). Stress, adaptation, and disease: Allostasis and allostatic load. *Annals of the New York Academy of Sciences, 840*, 33–44.
Meyer, V. J., Lee, Y., Böttger, C., Leonbacher, U., Allison, A. L., & Shirtcliff, E. A. (2015). Experience, cortisol reactivity, and the coordination of emotional responses to skydiving. *Frontiers in Human Neuroscience, 9*, 138.
Moons, W. G., Eisenberger, N. I., & Taylor, S. E. (2010). Anger and fear responses to stress have different biological profiles. *Brain, Behavior, and Immunity, 24*, 215–219.
Mujica-Parodi, L. R., Strey, H. H., Frederick, B., Savoy, R., Cox, D., Botanov, Y., et al. (2009). Chemosensory cues to conspecific emotional stress activate amygdala in humans. *PloS One, 4*, e6415.
Nieuwenhuis, S., Forstmann, B. U., & Wagenmakers, E.-J. (2011). Erroneous analyses of interactions in neuroscience: A problem of significance. *Nature Neuroscience, 14*, 1105.
Pause, B. M. (2012). Processing of body odor signals by the human brain. *Chemosensory Perception, 5*, 55–63.
Pause, B. M. (2017). Human chemosensory communication. In A. Buettner (Ed.), *Springer handbook of odor* (pp. 987–1002). Dordrecht: Springer International Publishing.
Pause, B. M., Adolph, D., Prehn-Kristensen, A., & Ferstl, R. (2009). Startle response potentiation to chemosensory anxiety signals in socially anxious individuals. *International Journal of Psychophysiology, 74*, 88–92.
Pause, B. M., Lübke, K. T., Laudien, J. H., & Ferstl, R. (2010). Intensified neuronal investment in the processing of chemosensory anxiety signals in non-socially anxious and socially anxious individuals. *PloS One, 5*, Article e10342.
Pause, B. M., Ohrt, A., Prehn, A., & Ferstl, R. (2004). Positive emotional priming of facial affect perception in females is diminished by chemosensory anxiety signals. *Chemical Senses, 29*, 797–805.
Pause, B. M., Storch, D., & Lübke, K. T. (2020). Chemosensory communication of aggression: Women's fine-tuned neural processing of male aggression signals. *Philosophical Transactions of the Royal Society B, 375*.
Prehn-Kristensen, A., Wiesner, C., Bergmann, T. O., Wolff, S., Jansen, O., Mehdorn, H. M., et al. (2009). Induction of empathy by the smell of anxiety. *PLoS One, 4*, e5987.
Quintana, P., Nolet, K., Baus, O., & Bouchard, S. (2019). The effect of exposure to fear-related body odorants on anxiety and interpersonal trust toward a virtual character. *Chemical Senses, 44*, 683–692.
Rodebaugh, T. L., Shumaker, E. A., Levinson, C. A., Fernandez, K. C., Langer, J. K., Lim, M. H., et al. (2013). Interpersonal constraint conferred by generalized social anxiety disorder is evident on a behavioral economics task. *Journal of Abnormal Psychology, 122*, 39–44.
Schwenkmezger, P., Hodapp, V., & Spielberger, C. D. (1992). *Das State-Trait-Ärgerausdrucks-Inventar (STAXI)*. Huber, Bern.
Singh, P. B., Young, A., Lind, S., Leegaard, M. C., Capuozzo, A., & Parma, V. (2018). Smelling anxiety chemosignals impairs clinical performance of dental students. *Chemical Senses, 43*, 411–417.
Stangier, U., Heidenreich, T., Berardi, A., Golbs, U., & Hoyer, J. (1999). Die Erfassung sozialer Phobie durch Social Interaction Anxiety Scale (SIAS) und die Social Phobia Scale (SPS). *Zeitschrift für Klinische Psychologie, 28*, 28–36.
Stemmler, G., Heldmann, M., Pauls, C. A., & Scherer, T. (2001). Constraints for emotion specificity in fear and anger: The context counts. *Psychophysiology, 38*, 275–291.
Stevens, J. C., Cain, W. S., & Burke, R. J. (1988). Variability of olfactory thresholds. *Chemical Senses, 13*, 643–653.
Stöber, J. (1999). Die Soziale-Erwünschtheits-Skala-17 (SES-17): Entwicklung und erste Befunde zu Reliabilität und Validität [The social desirability scale-17 (SDS-17): development and first findings on reliability and validity]. *Diagnostica, 45*, 173–177.
Stöber, J. (2001). The Social Desirability Scale-17 (SDS-17): Convergent validity, discriminant validity, and relationship with age. *European Journal of Psychological Assessment, 17*, 222–232.
Takahashi, T., Ikeda, K., Ishikawa, M., Kitamura, N., Tsukasaki, T., Nakama, D., et al. (2005). Interpersonal trust and social stress-induced cortisol elevation. *Neuroreport, 16*, 197–199.
Taylor, S. E., Klein, L. C., Lewis, B. P., Gruenewald, T. L., Gurung, R. A. R., & Updegraff, J. A. (2000). Biobehavioral responses to stress in females: Tend-and-befriend, not fight-or-flight. *Psychological Review, 107*, 411–429.
Trimmer, C., Keller, A., Murphy, N. R., Snyder, L. L., Willer, J. R., Nagai, M., et al. (2019). Genetic variation across the human olfactory receptor repertoire alters odor perception. *Proceedings of the National Academy of Sciences, 116*, 9475–9480.
von Dawans, B., Kirschbaum, C., & Heinrichs, M. (2011). The Trier Social Stress Test for Groups (TSST-G): A new research tool for controlled simultaneous social stress exposure in a group format. *Psychoneuroendocrinology, 36*, 514–522.