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No fear no risk! Human risk behavior is affected by chemosensory anxiety signals

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ABSTRACT

An important aspect of cognitive functioning is decision-making, which depends on the correct interpretation of emotional processes. High trait anxiety has been associated with increased risk taking behavior in decision-making tasks. An interesting fact is that anxiety and anxiety-related chemosignals as well as decision-making share similar regions of neuronal activation. In order to ascertain if chemosensory anxiety signals have similar effects on risk taking behavior of healthy participants as high trait anxiety we used a novel computerized decision-making task, called Haegler's Risk Game (HRG). This task measures risk taking behavior based on contingencies and can be played repeatedly without a learning effect. To obtain chemosensory signals the sweat of 21 male donors was collected in a high rope course (anxiety condition). For the chemosensory control condition sweat was collected during an ergometer workout (exercise condition). In a double-blind study, 30 healthy recipients (16 females) had to play HRG while being exposed to sweat samples or empty control samples (control condition) in three sessions of randomized order. Comparison of the risk taking behavior of the three conditions showed significantly higher risk taking behavior in participants for the most risky choices during the anxiety condition compared to the control conditions. Additionally, recipients showed significantly higher latency before making their decision in the most risky choices during the anxiety condition. This experiment gives evidence that chemosensory anxiety signals are communicated between humans thereby increasing participants' risk taking behavior.

1. Introduction

Anxiety induces physiological responses, like an increase in sweating, heart rate, or muscular tension, as well as behavioral responses, which can either be a fight, flight, or freeze reaction (Ackerl, Atzmueller, & Grammer, 2002). Some animals and man react with an increase others with a decrease in caution, response time, adjustment to their environment, as well as with the ability to conceive relationships between properties of uncertain situations when receiving a threat through sensory channels (Koolhaas et al., 1999). Anxiety-related chemosignals released by an animal can trigger conspecifics to either escape or accumulate to attack a common enemy (Valenta & Rigby, 1968).

Until now anxiety-related chemosignals are well established in animals including mammals (Egan et al., 2009; Gerlai, 2010; Hauser et al., 2008; Kiyokawa, Kikusui, Takeuchi, & Mori, 2004; Kiyokawa, Shimozuru, Kikusui, Takeuchi, & Mori, 2006; Speedie & Gerlai, 2008), while research is still at the beginning of exploring anxiety chemosignals in humans (Ackerl et al., 2002; Chen & Haviland-Jones, 2000; Mujica-Parodi et al., 2009; Pause, Adolph, Prehn-Kristensen, & Ferstl, 2009; Pause, Ohrt, Prehn, & Ferstl, 2004; Prehn, Ohrt, Sojka, Ferstl, & Pause, 2006; Zhou & Chen, 2009). Previous findings demonstrate that women perform more accurately on a word-association task, and had a slower response time in word pairs containing ambiguous content when exposed to chemosensory anxiety signals (Chen, Katdare, & Lucas, 2006).

In the present study we explored if anxiety-related chemosignals derived from a visit in a high-rope course change the willingness to take a risk using a novel decision-making task, called Haegler's Risk Game (HRG). Decision-making, i.e. choosing one out of several alternatives with an uncertain outcome, consists of several cognitive processes. One important aspect of decision-making is risk taking which is defined as the tendency of preferring

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an action with a possible large profitable or harmful outcome, although unlikely, over an alternative action with a small profitable more likely outcome. In essence, risk taking can be subdivided into anticipation, award, and penalty-related processing (Paulus, Rogalsky, Simmons, Feinstein, & Stein, 2003).

Existing decision-making tasks like, e.g. Iowa Gambling Task (IGT), Risk Task, or Gamble Task (Bechara, Damasio, Damasio, & Anderson, 1994; Rogers, Everitt, et al., 1999; Rogers, Owen, et al., 1999) have been utilized in several functional magnetic resonance imaging (fMRI) studies. Neural substrates being involved in real-life decision-making, more precisely in high risk behavior, showed brain activation in amygdala, thalamus, cingulate cortex, dorsolateral prefrontal cortex, cerebellum, and anterior insula (Bush et al., 2002; Doya, 2008; Ernst et al., 2002; Paulus et al., 2003; Rogers et al., 2004; Thut et al., 1997). Some of these brain areas were also activated in patients with anxiety disorders, for example amygdala, cingulate cortex, and medial prefrontal cortex (Bishop, Duncan, Brett, & Lawrence, 2004; Etkin et al., 2004; Paulus, Feinstein, Simmons, & Stein, 2004; Simpson, Drevets, Snyder, Gusnard, & Raichle, 2001). Just recently, effects of anxiety-related chemosignals were analyzed using fMRI. Activation patterns were found in amygdala, cerebellum, precuneus, fusiform gyrus, insula, cingulate cortex, thalamus, dorsomedial prefrontal cortex, and vermis (Mujica-Parodi et al., 2009; Prehn-Kristensen et al., 2009) when healthy participants were exposed to chemosignals of anxiety. Therefore, it could be speculated that anxiety as well as the perception of chemosignals of anxiety affect decision-making at an emotional as well as at a cognitive level. Lately, two studies investigated the effects of high trait anxiety on decision-making (de Visser et al., 2010; Miu, Heilman, & Houser, 2008). Both studies reported that participants with high trait anxiety showed a higher risk taking behavior when playing IGT than normal participants, which emphasizes a possible relationship between anxiety and decision-making.

A crucial drawback of existing decision-making tasks is that they cannot be executed repeatedly without excluding a learning effect. Therefore, in the current study we introduced a novel computerized decision-making task in which participants have to make decisions between contingencies. Due to the lack of a winning strategy, a participant can play HRG repeatedly without a learning effect. In our study each participant played the game three times, i.e. once during each of the three different stimulation conditions (anxiety, exercise, control condition), while their risk taking behavior as well as the response time was monitored.

2. Material and methods

The local Medical Ethics Review Committee of our University approved the entire study, which was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained by all participants.

2.1. Participants

2.1.1. Sweat donors

A total of 21 healthy male nonsmokers (age: mean 28.3 years, SD 7.9 years) attended in both sweat donation sessions (exercise, anxiety). None of the participants took any medication or had any disease. They were exclusively heterosexual determined on a 7-point scale (mean 0.0, SD 0.0) (Kinsey, Pomeroy, Martin, & Gebhard, 1953). Donors were screened using the Spielberger's state-trait anxiety inventory (STAI X (Spielberger, Gorsuch, & Lushene, 1970), German version by Laux, Glanzmann, Schaffner, and Spielberger (1981)). This test consists of two subtests for obtaining how participants feel in general (trait anxiety, STAI X2) and how they feel at a specific moment (state anxiety, STAI X1), while each scale is composed of 20 items. Donors had a normal anxiety level with a mean trait anxiety score of 31.7 (SD 6.2). The donors answered the STAI X1 during both sweat assessments at several time points.

2.1.2. Pilot study

In a pilot study 50 healthy participants (25 females; age: mean 33.1 years, SD 11.5 years) were instructed to play Haegler's Risk Game in the absence of olfactory stimuli. No sex-differences in age were present (independent two-sample t-test: $t(48) = 0.53$, p = not significant [n.s.]) and none of the participants took part in the main experiment.

2.1.3. Sweat recipients

Thirty healthy participants (16 females; age: mean 31.7 years, SD 8.4 years) took part in the main experiment. All recipients were normosmic, their sense of smell was tested using the Sniffin' Sticks Battery (Hummel et al., 1996) (TDI: mean 35.6, SD 2.3). They were not taking any medication known to interfere with the olfactory system (Doty & Bromley, 2004; Schiffman, 1994), and none of them reported any olfactory disturbances. Recipients were instructed to fill in the STAI X2 questionnaire (Laux et al., 1981). All of them showed a normal anxiety level with a mean trait anxiety score of 38.0 (SD 8.4). Female participants reported neither to be pregnant nor to lactate. No sex-differences were found, neither for age, nor for STAI X2 or TDI score (all independent two-sample t-tests with $t(28) < 1.10$, p = n.s.).

2.2. Sweat sampling procedure

The sweat sampling procedure was part of a larger study on chemosensory anxiety signals. Two days before either sweat collection as well as on the day of both sweat donations, donors were instructed to follow a certain dietary and behavioral procedure. They were not allowed to use any odorous toiletry (deodorants/antiperspirants, perfumes, aftershaves, perfumed shower gels, or body lotions). Two days before the sweat donation they could shower as often as they wanted using an odorless shower gel (Balea, Ultra Sensitive, dm-dogerie markt, Karlsruhe, Germany) provided by the instructors. They were instructed not to attend a swimming pool due to the chlorine in the water, not drink alcohol or eat food containing garlic, onions, hot spices, or asparagus. The evening before the sweat sampling they should take a shower and wear only loose, odorless clothes until the sweat sampling. On either day of the sweat samplings donors were only allowed to wash their armpits with pure water.

During the exercise condition donors had to ride a bicycle ergometer twice for 30 min (run 1, run 2), respectively, with a power of 120 W and 90 revolutions per minute, having a 15 min break in between the two runs. The workout took place in the Department of Physiotherapy of our institution.

In the anxiety condition donors had to attend a high rope course (www.hochseilgartenundmehr.de). During this visit they had to overcome two different challenges lasting approximately 30 min each with a 15 min break in between. The first challenge was a parcour consisting of five demanding tasks at an altitude of nine meters. First they had to balance free-hand over a *beam*, followed by a walk over a *tremor bridge*, third they crossed a swinging *double beam* without holding on, forth they had to do the *flea jump*, and finally they were instructed to climb along a *cargo net*. In the second challenge, called the *pamper pole*, donors had to climb a pole, which was 7 m tall. Their task was to stand free-hand at the top of the pole for a short period of time.

Fresh cotton pads (16 cm × 5.5 cm) were attached to both armpits during each session (exercise run 1, exercise run 2, anxiety parcour, anxiety pole) covered by tight white cotton long-sleeve shirts. Additionally, participants wore raincoats to increase their perspiration. To prevent any bacterial degradation, pads were collected immediately after each of the four sessions and deposited in dry ice. All donor samples were subdivided into 1 cm × 1 cm large pieces, samples of both anxiety sessions and samples of both exercise sessions were pooled and stored at −40 °C in big odorless freezer bags. Follow-up experiments were completed within the following 4 months (Lenochova, Roberts, & Havlicek, 2009). As a reference control condition, clean empty cotton pads were cut and stored using the same procedure as for the sweat samples.

On either day of the sweat samplings donors had to fill in the STAI X1 form multiple times. They had to complete the form once before the anxiety/exercise condition (t_0), during each of the two sweat samplings (t_1), and after either sweat sampling (t_2). To obtain the values during the sweat sampling, donors were told to fill in the form focusing on how they had felt during each assignment, respectively. Scores were averaged for the exercise condition over run 1 and run 2 and for the anxiety condition over parcour and pole.

2.3. Haegler's Risk Game

For repeated measures of participants' risk taking behavior under different conditions without a learning effect we invented a new computerized card game. Participants were told that they would see an unknown amount of play card pairs with values from 1 to 10, 1 being the smallest and 10 being the highest possible card. After seeing the first card (Fig. 1a), participants had to decide whether the second card (Fig. 1b), would be either higher or lower than the first card. If their choice was correct, participants gained reward points. If their choice was wrong, participants lost points.

Starting with 0 points, reward points were accumulated over the rounds, while it was also possible to accumulate a negative amount of points. Participants were instructed that reward points were valuable, and it was the goal of the game to accumulate as many points as possible. They were paid a fixed amount of money, which they were aware of before the study started, but there was no mapping between points and dollars. Nevertheless, participants were instructed to play HRG with the objective of winning as many points as they could. In total, 100 card pairs were pre-

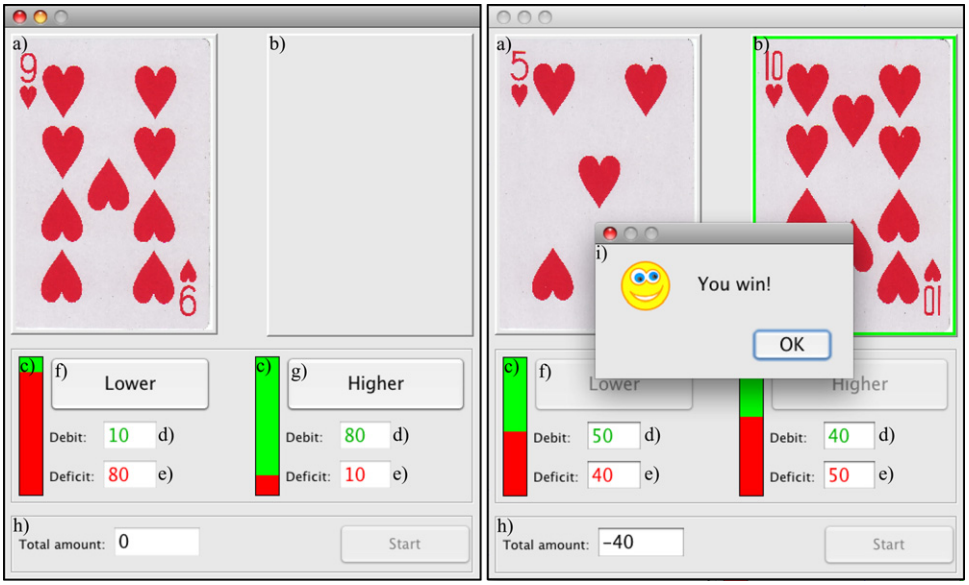

Fig. 1. Typical displays of Haegler's Risk Game before (left) and after (right) the participant had made a choice. Shown are the decks of the first (a) and second (b) card, the green–red bars (c) indicating the ratio of points that could be won or lost, the amount of points that could be won (d) or lost (e), the *lower* (f) and *higher* (g) button, the total amount of points (h), and a "You win!" dialog window (i) coinciding with the green frame of the right choice. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

sented per game cycle, taking approximately 5 min for completion. The first card was pseudo-randomized and ranged from 2 to 9. The second card was selected by chance ranging from 1 to 10 but always occupying a different value than the first card.

When the first card was presented to the participants, additional information was displayed on the computer screen. The amount of points to be won if the participants' choice was correct was shown in green ink (Fig. 1d). The amount of points that could be lost was shown in red ink (Fig. 1e). Additionally, a green–red bar (Fig. 1c) indicated the ratio between the possible number of points to be won or lost. Participants indicated their choice by either pressing the *lower* (Fig. 1f) or the *higher* (Fig. 1g) button in the response panel. After making their choice the points were either added or subtracted from the total amount of points (Fig. 1h) depending on the accuracy of the response. Additionally, the second card appeared highlighted by a green or red box in combination with a dialog window saying either "You win!" or "You loose!" (Fig. 1i) depending on the accuracy.

Since the second card was drawn completely random, the statistical probability for the second card to be lower varied according to the value of the first card. As an example, if the first card carried the value 2, the probability for the second card to be lower was 1/9. If the first card carried the value 9, the probability for the second card to be lower was 8/9. The amount of points to be won or lost for a correct or incorrect choice varied and was directly correlated to the statistical likelihood of the event to occur. The probability of the second card to be higher if the first card carried a value $x \in \{2, \ldots, 9\}$ was $p_{\text{higher}} = (10 - x)/9$, therefore, the points that could be lost were $(10 - x) \times 10$ and the points that could be gained were $90 - ((10 - x) \times 10)$. For the second card to be lower, the probability was $p_{\text{lower}} = 1 - p_{\text{higher}}$, resulting in either a deficit of $90 - ((10 - x) \times 10)$ points or a debit of $(10 - x) \times 10$ points.

Due to the fact that the points to be won or lost were opposed to the probabilities, the chances of winning or loosing were random, resulting on average in a total amount of 0 points at the end of the game cycle. Hence, no strategy could be learned which would help the participants to win the game. Thus, in contrast to other gambling games like, e.g. the IGT (Bechara et al., 1994) participants can play HRG multiple times without a learning effect.

Recipients were considered as playing more risky if they chose *higher* while the first card was 6, 7, 8, or 9 or if they chose *lower* while the first card was 2, 3, 4, or 5 more often. The key dependent variable was, therefore, the summed number of risky selections of each participant. Accordingly, the pairs *2-lower and 9-higher*, *3-lower and 8-higher*, *4-lower and 7-higher*, as well as *5-lower and 6-higher* were combined by summing up the number of single selections, due to equal probabilities. This resulted in a total of 4 risk values per participant. Drawing a connection to the IGT where decks A and B contain high gains but also very high losses leading to an overall loss, while decks C and D contain lower gains but also lower losses leading to an overall gain. If deck A would contain even higher gains and higher losses than deck B and vice versa for decks C and D one could compare the overall number of selections of deck A with our *2-lower and 9-higher* parameter, the overall number of selections of deck B with our *3-lower and 8-higher* parameter, the overall number of selections of deck C with our *4-lower and 7-higher* parameter, and the overall number of selections of deck D with our *5-lower and 6-higher* parameter.

On average each card value of the first card appeared 12.5 times during a game cycle, hence, the average number of presentations of one card pair was 25 per game cycle. During each game cycle the response time, meaning the time from the display of the first card until participants pressed either the *higher* or the *lower* button, as well as each choice made by the participants were monitored.

2.4. Pilot study

For evaluation of HRG a pilot study was conducted. Participants had to play the game without any olfactory stimulus, followed by a questionnaire. On a 100 mm visual analog scale (VAS) (Aitken, 1969; Folstein & Luria, 1973) participants had to assess how difficult the procedure of playing the game was (very easy (0) – very difficult (100)) and how experienced they were in playing card games (very inexperienced (0) – very experienced (100)). Furthermore, they had to rate their fatigue (not tired (0) – very tired (100)), valence (negative (0) – positive (100)), arousal (calm (0) – aroused (100)), as well as their alertness (not alert (0) – very alert (100)) while playing the game.

2.5. Main experiment

The experiment was conducted in a randomized double-blind study design, i.e. the recipients were not aware of the nature of the assessed samples, and the experimenters were not aware which of the three olfactory stimuli was presented. Each recipient attended three game cycles in total, once for each condition (anxiety, control, exercise condition). To prevent adaptation and possible interferences of the different chemosensory stimuli, only one condition per day was performed. Furthermore, an interval of at least three days between the sessions was assured, not exceeding a total of three weeks in which all experiments of one recipient had to be finished.

At the beginning of each session recipients had to perform a d2 Test of Attention to determine their degree of attention for each condition (Brickenkamp & Zillmer, 1998). The recipients were required to scan the lines and cross out all occurrences of the letter "d" with two dashes while ignoring all other characters. Measures of attention included the total number of items processed (TN), the total number of errors (E), the percentage of errors ($E\%$), the total number of items minus errors (TN – E), and the concentration performance (CP) derived from the number of correctly crossed out items minus errors of commission. To diminish ceiling effects due to repeated testing the time for crossing out the target letter in one line was reduced from 20 to 15 s, according to instructions of the test manual. For determining standard values (SV) of the concentration performance, which should be located between 94 and 106 for a normal level of attention, the norm sample table of Brickenkamp and Zillmer (1998) was used.

Afterwards the participants were exposed to 0.5 g of the respective sample (anxiety, control, exercise condition). These samples were wrapped in an odorless tea bag and fixed under the recipients' nose by an elastic band, resulting in birhinal stimulation.

Table 1
Mean values and standard deviations of the state anxiety (STAI X1) of the donors ($n = 21$) before (t_0), during (t_1), and after (t_2) the anxiety and the exercise condition.

	Anxiety condition	Exercise condition
STAI X1		
t_0	39.3 ± 11.7	32.6 ± 7.3
t_1	50.2 ± 8.5	36.1 ± 9.3
t_2	37.1 ± 11.3	31.0 ± 6.7

Shortly after sample exposure, recipients were asked to fill in a questionnaire consisting of eight questions. On a visual analogue scale participants had to rate different features of the samples, like the pleasantness (unpleasant (0) – pleasant (100)), the intensity (very weak (0) – very intensive (100)), the familiarity (not familiar (0) – very familiar (100)), the masculinity/femininity (very feminine (0) – very masculine (100)), and the sexual attractiveness (not appealing (0) – very appealing (100)). To measure their emotional state participants were instructed to rate their valence (negative (0) – positive (100)), arousal (calm (0) – aroused (100)), and dominance (submissive (0) – dominant (100)).

Approximately 15 min after sample exposure recipients were instructed to play HRG. All code was implemented in Java and executed on a Windows XP Intel Pentium computer.

Directly after finishing HRG participants were instructed to fill in a second questionnaire in which they had to rate their fatigue, their emotional conditions (valence; arousal), and their alertness while playing the game, as well as their experience in playing card games using a VAS as described for the pilot study.

2.6. Data analyses

SPSS 18.0 for Macintosh (SPSS Inc., Chicago, IL, USA) was used for statistical analyses of the data. Normality of the data was tested using the Kolmogorov–Smirnov test. Data of the STAI X1 questionnaire of the sweat donors (normally distributed) were submitted to two-tailed Student's paired *t*-tests to explore inter-condition differences.

Results of recipients' d2 Test of Attention, and the questionnaires (normally distributed) were submitted to repeated measures analyses of variance (ANOVA). Not normally distributed variables (response time, game parameters) were tested using Friedman tests in combination with post hoc non-parametric Wilcoxon signed-rank test. Sex-differences as well as differences between the pilot study and the main experiment with equal variances were tested using Mann–Whitney-*U* tests (not normally distributed data) or independent two-sample *t*-tests (normally distributed data). In case of unequal variances normally distributed data was submitted to independent two-sample *t*-tests for unequal variances; not normally distributed data with unequal variances was ranked before being submitted to the independent two-sample *t*-test for unequal variances as described by Ruxton (2006). Results of the questionnaire were corrected for multiple testing using the Bonferroni method. *p*-Values < 0.05 were considered significant.

3. Results

3.1. STAI X1 of sweat donors

State anxiety values were significantly higher in the anxiety condition than in the exercise condition at all time points (Student's paired *t*-test; t_0: $t(20) = 2.31$, $p = 0.032$, t_1: $t(20) = 5.88$, $p < 0.001$, t_2: $t(20) = 2.57$, $p = 0.018$). Descriptive statistics are shown in Table 1. Starting from the beginning of the conditions (t_0), STAI X1 values increased during the sessions (t_1) and decreased towards the end (t_2), in the anxiety as well as in the exercise condition. The highest state anxiety value was observed during the high rope course at time point t_1 (mean 50.2, SD 8.5). This indicates that donors were significantly more anxious during the high rope course than during the bicycle workout.

3.2. HRG pilot study

Results of HRG data and questionnaires of the pilot study are shown in Table 2. The game parameters, i.e. the number of risky card selections were monotonically decreasing from the least risky (*5-lower and 6-higher*) to the most risky (*2-lower and 9-higher)* parameters. The highest number of selections was present for the least risky parameters and the lowest number of selections was present for the most risky parameters. In total participants needed approximately 5 min to finish the game.

Table 2
Results of the pilot study ($n = 50$). Shown are means and standard deviations of the number of card selections of the game parameters, the total time needed to finish HRG, as well as the results of the questionnaire ranging from 0 to 100 on a VAS.

Pilot study data	
No. of risky card selections	
2-lower and 9-higher	0.5 ± 1.0
3-lower and 8-higher	2.0 ± 3.0
4-lower and 7-higher	4.4 ± 4.1
5-lower and 6-higher	10.0 ± 4.7
Total time [s]	289.9 ± 100.6
Difficulty playing game	8.4 ± 12.7
Fatigue	14.7 ± 24.6
Valence	58.3 ± 30.1
Arousal	56.1 ± 31.1
Alertness	54.7 ± 24.1
Card game experience	29.2 ± 28.4

Participants stated that HRG was easy to play and that they were rather inexperienced in playing card games. They were not tired, felt neither positive nor negative, were slightly aroused, and alert during the game. No sex-differences could be observed (all Mann–Whitney-*U* tests with p = n.s.).

3.3. Sweat recipients

3.3.1. D2 Test of Attention

There were neither any significant sex-differences regarding all parameters of the d2 Test of Attention (all independent two-sample *t*-tests with p = n.s.) nor any significant differences between the conditions (all ANOVAs with $F(2,58) < 2.60$; p = n.s.). Hence, the state of attention was similar between men and women and in all conditions, excluding condition specific effects due to attention differences. SV values of the concentration performance of all conditions were in the normal range between 94 and 106 (cf. Table 3).

3.3.2. Questionnaires

Table 4 contains mean values and standard deviations of recipients' ratings of both questionnaires. In the first questionnaire, filled in shortly after sample application, there were neither significant sex-differences nor differences between the three conditions in participants' ratings of the familiarity, masculinity/femininity, sexual attractiveness, arousal, and dominance (all ANOVAs with $F(2,58) < 4.00$; p = n.s.). Recipients rated all odorants as neither masculine nor feminine and as rather sexually unattractive. Furthermore, they stated to be predominantly calm and neither submissive nor dominant. Significant differences could be observed regarding the parameters pleasantness (ANOVA, $F(2,58) = 11.97$; $p < 0.001$), intensity (ANOVA, $F(2,58) = 13.67$; $p < 0.001$), and valence (ANOVA, $F(2,58) = 9.13$; $p < 0.001$). The anxiety and the exercise

Table 3
Recipients' ($n = 30$) means and standard deviations of the attentional parameters (d2 Test of Attention) during the anxiety, control, and exercise condition. Measures of attention included the total number of items processed (TN), the total number of errors (*E*), the percentage of errors (*E%*), the total number of items minus errors (TN – *E*), the concentration performance (CP), and the standard values (SV).

	Anxiety condition	Control condition	Exercise condition
TN	425.3 ± 79.0	435.6 ± 79.0	427.8 ± 84.5
E	20.4 ± 24.6	18.5 ± 15.2	17.3 ± 24.9
E%	0.05 ± 0.05	0.04 ± 0.04	0.04 ± 0.05
TN – *E*	398.2 ± 79.9	410.5 ± 94.7	410.6 ± 82.9
CP	167.4 ± 38.7	175.5 ± 38.7	175.0 ± 39.3
SV	95.8 ± 9.7	97.8 ± 10.1	97.6 ± 10.2

Table 4
Recipients' ($n = 30$) ratings of the questionnaires about sample perception shortly after sample exposure and of their emotional conditions during HRG execution, ranging from 0 to 100 on a VAS. Shown are means and standard deviations.

	Anxiety condition	Control condition	Exercise condition
Shortly after sample exposure			
Pleasantness	34.3 ± 22.4	60.0 ± 19.7	37.4 ± 25.6
Intensity	42.0 ± 31.0	8.0 ± 14.5	36.8 ± 37.5
Familiarity	46.4 ± 25.5	44.5 ± 30.4	31.0 ± 29.1
Masculinity/femininity	54.7 ± 20.7	42.9 ± 20.4	50.9 ± 22.6
Sexual attractiveness	21.3 ± 21.8	35.2 ± 20.0	27.5 ± 24.0
Valence	42.9 ± 31.1	68.3 ± 25.8	48.3 ± 31.3
Arousal	28.2 ± 22.8	19.0 ± 23.4	32.6 ± 29.2
Dominant	50.0 ± 11.3	48.2 ± 12.8	50.1 ± 11.0
During HRG of the main experiment			
Fatigue	30.0 ± 23.0	33.1 ± 29.4	29.3 ± 30.9
Valence	37.0 ± 26.7	36.6 ± 25.3	31.2 ± 28.6
Arousal	54.9 ± 26.2	54.5 ± 31.1	55.6 ± 32.6
Alertness	58.6 ± 22.6	53.8 ± 25.6	60.5 ± 23.8
Card game experience	22.9 ± 21.3	22.8 ± 21.7	20.3 ± 23.5

sweat samples were rated as rather unpleasant and intense. The control sample was valued significantly more pleasant and less intense than the anxiety (post-hoc test, pleasantness: $p < 0.001$, intensity: $p < 0.001$) and the exercise (post-hoc test, pleasantness: $p = 0.004$, intensity: $p = 0.003$) sample. Men rated the control sample as more pleasant than women (independent two-sample t-test for unequal variances, $t(28) = 2.11$, $p = 0.039$; men: mean 52.2, SD 12.9; women: mean 66.6, SD 22.4). Recipients' valence was slightly positive during control condition, and revealed significant differences to the slightly negative evaluation during the anxiety (post-hoc test, $p < 0.001$) and the exercise (post-hoc test, $p = 0.003$) condition. Women felt significantly more negative than men during anxiety condition (independent two-sample t-test, $t(28) = 2.18$, $p = 0.038$; men: mean 55.4, SD 34.0; women: mean 32.0, SD 24.4).

Parameters of the second questionnaire, filled in shortly after playing HRG, revealed no significant differences in fatigue, valence, arousal, and alertness while playing the game, as well as in their experience in playing card games (all ANOVAs with $F(2,58) < 1.09$; p = n.s.). Recipients felt slightly tired, slightly negative, slightly aroused, and alert during the game and rated themselves to be inexperienced in playing card games. During the game men were significantly less tired than women (independent two-sample t-test, $t(28) = 3.09$, $p = 0.004$; men: mean 17.8, SD 18.9; women: mean 40.7, SD 21.3).

3.3.3. HRG game parameters

Fig. 2 illustrates the mean number of risky selections made during HRG. The lower the probability of a profitable choice was the smaller was the number of risky selections. *5-lower and 6-higher*, which were the least risky choices, showed the highest number of risky selections, and *2-lower and 9-higher*, which were the most risky choices, showed the lowest number of risky selections. Hence, the number of risky selections decreased monotonically from *5-lower and 6-higher* to *2-lower and 9-higher*. In the *5-lower and 6-higher* choices recipients picked in approximately one-third of the 25 possible choices the more risky button, but without showing significant effects between the conditions (Friedman test, p = n.s.). The *4-lower and 7-higher* and the *3-lower and 8-higher* (both Friedman tests with p = n.s.) choices showed also no significant differences in the number of selections regarding the three different conditions. Whereas, the parameter indicating most risky behavior (*2-lower and 9-higher*) was significantly higher in the anxiety compared to the control (Friedman test, $p = 0.020$; Wilcoxon signed rank test, $p = 0.039$) as well as the exercise (Wilcoxon signed rank test, $p = 0.005$) condition.

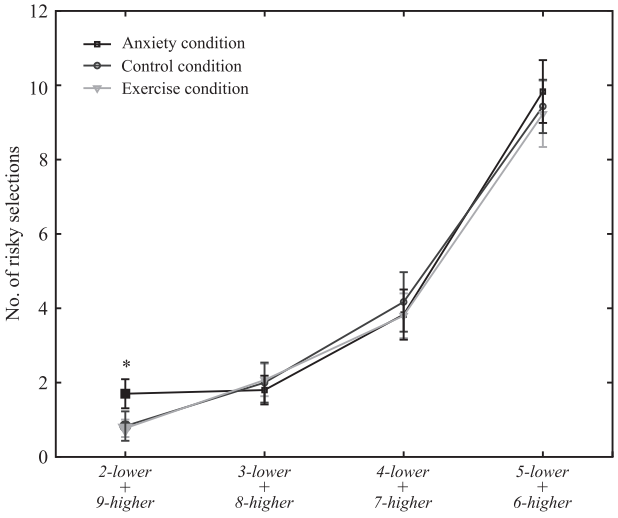

Fig. 2. Results of the HRG data obtained during the main experiment. Illustrated are means and standard errors of the mean of the number of risky selections ($n = 30$) during the different conditions (anxiety, control, exercise). Significant differences ($p < 0.05$) are labeled by an asterisk and enlarged symbols.

3.3.4. HRG response time

The response time monitored during HRG showed significant differences between the conditions for the most risky parameter *2-lower and 9-higher* (Friedman test, $p = 0.046$). Table 5 shows mean values and standard deviations of all response times obtained during the game as well as the total time needed to complete HRG. Recipients needed significantly longer for responding to the most risky choices during the anxiety condition compared to the control (Wilcoxon signed rank test, $p = 0.019$) and the exercise condition (Wilcoxon signed rank test, $p = 0.001$). The total time needed for playing HRG was longer during the anxiety compared to the other

Table 5
Recipients' ($n = 30$) HRG response time and total time of the main experiment in seconds. Shown are means and standard deviations of all three conditions.

	Anxiety condition	Control condition	Exercise condition
time [s]			
2-lower and 9-higher	2.1 ± 3.7	1.7 ± 1.0	1.9 ± 4.5
3-lower and 8-higher	2.0 ± 2.6	1.8 ± 2.2	2.1 ± 6.0
4-lower and 7-higher	2.1 ± 3.3	2.0 ± 3.3	1.9 ± 2.1
5-lower and 6-higher	2.2 ± 3.4	2.2 ± 4.0	2.0 ± 3.3
Total time [s]	208.4 ± 93.6	192.5 ± 71.4	198.6 ± 63.2

two conditions, but without showing a significant effect (Friedman test, p = n.s.). Sex-differences were found regarding the response time of the parameters *5-lower and 6-higher* of the anxiety (independent two-sample t-test for unequal variances of ranked data, $p = 0.015$; men: mean 2.3, SD 2.0; women: mean 2.1, SD 4.3) and the control (independent two-sample t-test for unequal variances of ranked data, $p = 0.014$; men: mean 2.5, SD 5.5; women: mean 2.0, SD 2.1) condition. Additional sex-differences for the response time were found in the anxiety condition for the parameter *3-lower and 8-higher* (independent two-sample t-test for unequal variances of ranked data, $p = 0.029$; men: mean 2.3, SD 3.7; women: mean 1.7, SD 1.0).

3.4. Comparison of pilot study and main experiment

Comparing HRG data from the pilot study, which can be considered as yet another control condition, with the HRG data collected during the main experiment with three different conditions, significant differences were observed between the anxiety condition and the pilot study regarding the parameter *2-lower and 9-higher* (Mann–Whitney-U test, $p = 0.008$). Participants showed significantly higher risk taking behavior during the anxiety condition of the main experiment compared to participants of the pilot study regarding the parameter *2-lower and 9-higher* (Mann–Whitney-U test, $p = 0.008$). All other parameters and conditions showed no significant differences (all Mann–Whitney-U tests with p = n.s.).

4. Discussion

This study provides two major findings: firstly we detected that anxiety-related chemosignals are associated with higher risk taking behavior in the most risky choices using a new computerized decision-making task, called Haegler's Risk Game. Secondly we found that anxiety chemosignals are associated with higher response time latency in HRG being confronted with the most risky choices.

Miu et al. (2008) and de Visser et al. (2010) suggested that high trait anxiety has an effect on decision-making. Both studies revealed increased risk taking behavior in high trait anxiety participants. In our experiment anxiety-related chemosignals showed a similar effect. Participants demonstrated increased risk taking behavior under the exposure of anxiety in contrast to exercise and control samples. Since anxiety and the consideration of less task-relevant cues, i.e. an affected discrimination between relevant and irrelevant cues in a reasoning task, are closely related, chemosignals of anxiety might be associated with a higher level of insecurity as reflected by increased response latency and a more pronounced risk taking behavior (Easterbrook, 1959; Leon & Revelle, 1985). This can be seen in the current study where participants being under the influence of chemosignals of anxiety hesitated longer before choosing the risky decks *2-lower and 9-higher* more frequently.

Furthermore, trait anxiety as well as anxiety-related chemosignals have been associated with enhanced neural activity in brain regions including amygdala, cingulate cortex, and medial prefrontal cortex (Bishop et al., 2004; Etkin et al., 2004; Mujica-Parodi et al., 2009; Paulus et al., 2004; Prehn-Kristensen et al., 2009; Simpson et al., 2001), areas which are also essential in decision-making (Bechara, Damasio, Damasio, & Lee, 1999; Bush et al., 2002; Doya, 2008; Ernst et al., 2002; Paulus et al., 2004; Paulus et al., 2003; Rogers et al., 2004; Thut et al., 1997). The anterior cingulate cortex and the lateral prefrontal cortex engage in cognitive control by supervising negative events (Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004). Simultaneously, connectivity between the anterior cingulate cortex and the amygdala may involve inhibitory feedback to reduce affective cortical processing for achieving cognitive control of the justified decision (Pezawas et al., 2005). This fact could be important in decision-making concerning HRG, since no profitable strategy is present all choices in HRG could have a negative result with a certain probability. The neural correlates of HRG should be investigated in future studies.

Many studies have shown that with increasing trait and state anxiety the performance on reasoning tasks decreases, affecting not only performance accuracy but also leading to a prolonged latency (Cain, Gent, Goodspeed, & Leonard, 1988; Cowen, 1952; Leon & Revelle, 1985). Furthermore, using sweat samples from donors watching terrifying movies, Chen et al. (2006) ascertained slower response time in word pairs containing ambiguous content in a word-association task. In our game the probability of winning and loosing was equally high due to the fact that the deficit and the debit were controversial to the probabilities. Therefore, the latency in response time during exposure of anxiety chemosignals could be explained by the ambiguity of the choices in combination with the induced state anxiety.

Results of the pilot study show that HRG was easy to play without requiring experienced card gamblers, ruling out performance differences due to differences in gambling experience or intellect. Furthermore, no differences between the control conditions of the main experiment and the pilot study were present, although independent participant groups were used. Since the pilot study can be considered as yet another control condition, lower risk taking behavior in the pilot study compared to the condition during anxiety exposure underlines our major finding that anxiety-related chemosignals augment risk taking behavior in participants.

HRG was developed to make sure that no learning effects would disturb the rather weak effects of chemosensory anxiety signals on the results of the game. The absence of learning effects can be explained statistically. Since the probability of winning or loosing was opposed to the points to be won or lost, the chance of winning or loosing was random. Hence, no strategy could be learned which would help the participant to win the game. The fact that our game is not hampered by learning effects is also illustrated by our results: each participant had to play the game three times in total being exposed to different samples in a randomized order; if learning effects were present, the weak effects of the chemosensory anxiety signal that have also been shown by other investigators (Chen & Haviland-Jones, 2000; Mujica-Parodi et al., 2009; Pause et al., 2009; Zhou & Chen, 2009) would not have been significant in this study. But as shown by our results chemosensory anxiety signals had a significant effect on risk taking behavior, which were in line with previous studies (de Visser et al., 2010; Miu et al., 2008).

In our study we did not obtain any performance differences between men and women, neither during the anxiety condition nor during the exercise or the control condition. Literature concerning sex-differences has been controversial in terms of performance differences and in terms of the influence of anxiety chemosensory signals. While some studies observed sex-differences in gambling performance (Bolla, Eldreth, Matochik, & Cadet, 2004; de Visser et al., 2010; Reavis & Overman, 2001), others did not observe any differences (Bechara et al., 1994; Lejuez, Aklin, Zvolensky, & Pedulla, 2003; Miu et al., 2008; Rogers et al., 2004) or did not even test for sex-differences at all (Bush et al., 2002; Manes et al., 2002). One reason for us not finding any sex-differences could be our rather small sample size. Our sample size was $n = 50$ for the pilot study and $n = 30$ for the main study, whereas, e.g. de Visser et al. (2010) included a total of 108 participants in their study and Reavis and Overman (2001) included even a total of 161 participants. Studies using stress odors showed similar controversial results, some studies had only female receivers or did not test for sex-differences at all (Ackerl et al., 2002; Chen et al., 2006; Prehn et al., 2006; Prehn-Kristensen et al., 2009; Zhou & Chen, 2009). There are only three studies which analyzed influences of chemosensory anxiety

signals; while Pause et al. (2009, 2004) found different effects of stress signals on men and women, Mujica-Parodi et al. (2009) did not find any different effects of stress signals on men and women. As previous findings are controversial regarding sex-differences our findings of no sex-differences regarding gambling performance during all three conditions are not surprising and do not contradict to existing studies.

Chen and Haviland-Jones (2000) reported that participants rated sweat samples as intense and as rather unpleasant being in line with our results. In some studies dealing with the effects of chemosensory alarm signals no significant differences between the presented neutral and sweat samples were found (Mujica-Parodi et al., 2009; Pause et al., 2009; Prehn et al., 2006; Prehn-Kristensen et al., 2009; Zhou & Chen, 2009) while participants rated sweat as well as neutral samples as low in intensity and as weakly pleasant. One reason why we found differences between control and sweat samples, while others did not, could be the higher intensity ratings and consequently the lower pleasantness ratings of the exercise and the anxiety sweat samples. But all in all no differences in questionnaires between the two sweat samples could be obtained which is in line with previous studies. The fact that no differences in pleasantness and intensity between the anxiety and the exercise condition were observed leads to the conclusion that the findings of Haegler's Risk Game were not due to odor differences but can be rather ascribed to the unconsciously perceived chemosensory signals of anxiety. Additionally, similar attentional performance levels of the recipients rule out that shown effects could have evolved from attention differences.

In previous studies stress sweat has been collected in many different ways, using movies inducing different emotions, pre-examinational stress, or first-time skydiving (Ackerl et al., 2002; Chen et al., 2006; Mujica-Parodi et al., 2009; Pause et al., 2009; Pause et al., 2004; Prehn et al., 2006; Prehn-Kristensen et al., 2009; Zhou & Chen, 2009). Except for the last sweat sampling procedure stressors cannot be related to real physical danger. Furthermore, Mujica-Parodi et al. (2009) reported that it cannot be excluded that some of their findings could be due to feelings of relief and/or thrill during the freefall. Therefore, their observed effects could be not exclusively anxiety-related. In our study we used a high rope course as stressor while monitoring self-reported anxiety measurements, confirming that our anxiety induction produced extensive emotional stress in sweat donors. State anxiety increased during the anxiety condition, but kept constant in the exercise condition. This demonstrates that participants were more anxious during the high rope course than during the ergometer training. Just like Mujica-Parodi et al. (2009) we can also not exclude that the sweat samples comprised possible chemosensory signals of relief and/or thrill as participants gained more confidence during the high rope course that they have not fallen or made mistakes but we suspect that the possibly felt relief/thrill was much lower than during the freefall. Additionally, although there has been considerable evidence of the presence of alarm chemosignals, to our knowledge there has not been evidence of the presence of a "thrill" chemosignal, which could intervene with chemosignals of anxiety. Thus, we assume that sweat donors probably excreted primarily anxiety substances during the high rope course.

Although it is not fully understood if perception of emotional chemical signals in humans may have the ability to alert conspecifics about possible danger, our findings suggest that anxiety in humans can be communicated through chemical senses. The present study confirms previous findings, which showed that chemosensory anxiety signals have effects on cognitive performance, physiological response, and emotion perception (Chen et al., 2006; Pause et al., 2009; Pause et al., 2004; Prehn et al., 2006; Zhou & Chen, 2009). By inventing a new decision-making game, which can be played repeatedly without a learning effect, we were able to show that anxiety-related chemosignals can be associated with both higher risk taking behavior and an increase in latency of response time in the most risky choices.

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