

# Characteristic Odor Emanating From Skin During Emotional Tension

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## Research Article

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# Abstract

Humans frequently experience the transmission of the psychological state of people around them. Gas emanating from human skin is known to vary depending on body condition and/or food intake. This characteristic is gaining substantial scholarly attention because skin gas can be an effective non-invasive biomarker to know body condition. The study focuses on the relationship between psychological status and skin gas, which remains unclear to date. It demonstrates that an identifiable odor containing allyl mercaptan and dimethyl trisulfide is released from human skin during psychological stress and tension. An interview confirms a possible scenario where such a characteristic odor reproducibly appears. Undoubtedly, the scene is extreme. Furthermore, the study found that individuals who perceive this tension-stress model odor experience psychological tension, confusion, and fatigue (Profile of Mood States scale). The result indicates the possibility of human non-verbal communication through odor, which could enhance understanding of human interaction.

## Introduction

Human emotions appear in motions, voices, facial expressions, and other forms, and people perceive and understand such emotions. Frequently, a person's emotion can be perceived through non-verbal indicators. The study focuses on the effects of body odor as a form of non-verbal communication.

Scholars report two main routes for the generation of body odor. The first is degeneration by oxidation that occurs through the interaction between microorganisms and sebum/sweat on the surface of the skin [1, 2]. The second is odor generated through the skin from inside the body. This type of odor constitutes transcutaneous blood volatile organic compounds or skin gas [3–5]. For a long time, scholars recognize the fact that body odor changes with physical condition, such as during illnesses. Recent studies propose that skin gas generated by the body is an accurate method of determining the state of the body along with other biological indicators, such as saliva, urine, and blood [6]. Since then, research in this field has advanced significantly.

For example, in the medical field, acetone content found in the skin gas of diabetes patients was discovered to be higher than that of healthy individuals [7, 8]. In lieu of this finding, interventions for the management of various disease states are being examined. Similarly, many studies reported that dogs can detect the presence of early-stage cancer in their owners through odor. Consequently, dogs are being trained for cancer detection [9, 10]. In the same manner, the current researchers investigated the relationship between skin gas and the effects of diet, physical condition, and aging in healthy volunteers, instead of people suffering from illnesses or disorders. The results indicated that aged people emit 2-nonenal [11], which occurs by the oxidation of sebum in elderly individuals, and people with constipation emit high levels of p-cresol [12].

Based on the abovementioned findings, skin gas is deemed a useful means of investigating the condition of the body, including diseases and general physical condition. The study further hypothesized that

psychological changes may alter skin gas. Therefore, the study aimed to investigate changes in skin-gas components during stress-inducing sessions.

The results of the study indicate that humans reproducibly emit discernible odors that contain allyl mercaptan and dimethyl trisulfide through the skin during interviews that induce psychological tension. Further, it was found that when other people smell this odor, they undergo psychological tension, confusion, and tiredness. In particular, skin gas may contain ingredients that convey human psychological conditions.

## Results

### Physiological responses and skin-gas characteristics under emotional tension

To examine changes in skin-gas composition as a result of psychological changes, the study investigated physiological responses and changes in the components of skin gas gathered from the hands (Fig. 1) of subjects during interview sessions that were intended to induce stress (see the Methods section). For one physiological response, heart-rate “R wave” intervals were calculated using electrocardiogram data. The low frequency (LF)/high frequency (HF) during the interviews was significantly higher ( $p < 0.01$ ) and sympathetically dominant when compared before and after the interviews (Fig. 2). For another physiological response, salivary cortisol was quantified using ELISA. A significant increase ( $p < 0.01$ ) in salivary cortisol levels was observed after the interviews compared with baseline values recorded during home rest (Fig. 3).

The LF/HF during the interview was significantly higher than those of previous and subsequent measurements, which indicates that the sympathetic nervous system was dominant (\*\* $p < 0.01$  after Bonferroni correction).

### Sensory assessment of skin gas

Collected skin gases were smelled by a panel of four experts on odor to compare the differences in odor during stress and at rest. A characteristic odor similar to sulfur-containing compounds was recognized in all gas samples collected during the interviews, whereas none existed in the samples taken at baseline. Additionally, the intensity of this characteristic odor was positively correlated with the rate of increase in sympathetic nerve activity during the interview (compared with values before the interview; Spearman's correlation coefficient,  $r = 0.66$ ;  $p < 0.01$ ; Fig. 4). Furthermore, in a test to confirm this phenomenon in non-Japanese women, this characteristic odor was detected in the gases collected during tension in all subjects (Japanese: 4 men; Chinese: 1 woman and 2 men; and French: 2 men). Conversely, no sulfur-like odor was observed in samples taken during elevated heart rates after exercising on a bicycle. (Fig. 5)

### Identifying characteristic odorants

To identify the main components of characteristic odors, the collected gases were analyzed using gas chromatography–olfactometry (GC-O) and gas chromatography–mass spectrometry (GC–MS) analyses.

Analysis i: One of the characteristic odorants similar to the typical stress odor was detected and identified as dimethyl trisulfide (DMTS) by GC/MS-O analysis (Fig. 6a).

Analysis ii: In addition to DMTS, a characteristic odorant was detected and estimated as propyl mercaptan (PM) or allyl mercaptan (AM) by GC-O analysis (retention time and odor).

Analysis iii: After comparing retention time and odor between the target odorant with PM and AM using GC-O analysis, the result indicates that retention time and odor of collected skin gas were in good agreement with those of the AM standard. Furthermore, AM was detected in the sample through GC–MS (SIM) analysis (Fig. 6b).

The results suggested that DMTS and AM were major contributors to the characteristic odor, which is similar to typical sulfur-containing compounds, in gas emanating from the skin during the stress-inducing interviews.

## Psychological effects of tension odor

The study found that sniffing the tension model odor significantly increased the psychological scores for “tension–anxiety” ( $p < 0.01$ ), “confusion–bewilderment” ( $p < 0.01$ ), and “fatigue–inertia” ( $p = 0.12$ ) among seven items that represent the psychological states of the subjects (Fig. 7).

## Discussion

Scholars recently noted that humans release a wide variety of gases from the skin, whose components may act as a barometer for indicating the state of the body.

For example, persons with diabetes characteristically release acetone, whereas those with liver diseases typically emit ammonia. Moreover, the study confirmed that the human skin releases specific components due to changes in the body unrelated to illnesses, such as aging and constipation.

Alternatively, studies reported body odor in samples collected mainly from the armpit, which is caused by various emotional states. Majority of the studies examined the reactions of dogs and humans who smell human odors of different states [13–15]. Reports of human odors estimated by statistical methods do not indicate how such odor affects humans [16]. Therefore, this study hypothesized that changes in psychological state chemically affect skin gas and its components affect human psychology. This study was conducted with the aim of identifying the main components of skin gas released during certain emotional states and examining their psychological effects. In the middle of various psychological changes, the study opted to induce mild tension in a manner that is easy to control and with reference to the Trier social stress test method [17, 18].

Collecting body odor from humans can be conducted using various methods, such as armpits using cotton balls [13–15], clothing [2, 19], and the back and neck [20]. However, such methods contain a mixture of bacterial metabolites of sebum and/or apocrine gland secretions in addition to the odor that comes directly from the body. Thus, the study examined the specific relationship between changes in skin-gas components and the body. For this reason, samples were collected from the hand because it contains less sebaceous glands and no apocrine glands [21].

During the interviews with instigated tension, physiological indicators before, during, and after the interview were measured to confirm the subject's condition. The results indicate that the LF/HF values during the interviews were significantly higher than those before and after the interviews, which indicate sympathetic dominance. Cortisol levels of saliva during the interviews were also significantly higher than those collected at baseline at the same time on another day. In particular, when the effects of the circadian rhythm [22] on cortisol was canceled and compared, the finding demonstrated that the stress level was high. The results suggested that the subjects were psychologically tense during the tension-inducing interviews. Additionally, sensory assessment was performed to confirm changes in odor components as a result of the altered psychological states. Consequently, a common characteristic odor that smells similar to sulfur-containing compounds was recognized in all samples of skin gas collected during the interviews despite their short duration (20 min). Notably, the intensity of this characteristic odor was positively correlated with the rate of increase in sympathetic activity during the interviews. Moreover, a positive correlation was found between heart-rate variability and odor intensity. On another test, this phenomenon was also observed in men or non-Japanese individuals while they were feeling tensed. These findings suggest that with greater emotional tension, characteristic odor is emitted more strongly from humans, and this phenomenon may be an instinctive physiological reaction among humans. Conversely, the characteristic odor was unrecognized in the results of the sensory evaluation of skin-gas samples collected during a bike exercise, which featured an elevated heart rate (> 140bpm for 20 min) (Fig. 5). This result suggests that a mere increase in heart rate and accompanying increase in thermal sweating was not the direct cause of the characteristic odor released by the skin.

The characteristic odor was clearly recognized through sensory evaluation. However, determining the target compounds was extremely difficult due to the very low concentrations. Thus, the study searched for effective sample preparation methods and analytical conditions and finally succeeded in identifying the target compounds as DMTS and AM. The successful identification of the two sulfur-like compounds rendered possible the artificial recreation of the model tension-stress odor. Moreover, the study examined the psychological effects of subjects directly inhaling and smelling the odor. The second edition of the short version of the Profile of Mood States (POMS 2) was used to evaluate psychological status. POMS 2 is a widely used self-report questionnaire for the rapid assessment of mood states, including transient, fluctuating feelings, and enduring affect states. The higher the *T* scores for anger–hostility (AH), confusion–bewilderment (CB), depression–dejection (DD), fatigue–inertia (FI), and tension–anxiety (TA), the more negative the mood. Conversely, positive mood states, such as vigor–activity (VA) and friendliness (F), indicate that the higher the *T* score, the better the mood [23]. POMS is also used in various research fields to measure mood disturbance and/or fatigue [24, 25]. The results showed that

sniffing the model's tension-stress odor increased negative emotions such as tension–anxiety (TA), fatigue–inertia (FI), and confusion–confusion (CB). This finding suggests that the odor emanating from emotionally stressed people may exert a psychological impact on people within their immediate vicinity. If odors released from people are a profound means of communication, then this finding may have a great impact on various fields. Thus, the elucidation of the mechanism and significance of this characteristic odor development is a subject for future research. Moreover, the current finding that emotional changes may influence body odor produced from areas apart from the apocrine glands, which is specific to axillary odor, may indicate new concepts and potential applications in the field of biogas research. Thus, the study aims to proceed with the development of a practical fragrance material as it endeavors to elucidate the odor generation mechanism. The study intends to eliminate the discomfort that may be caused by a tension-induced odor by formulating a scent that harmonizes with this odor and removes its negative psychological effects instead of covering it with a strong odor.

This research is not only an etiquette issue in interpersonal relationships but is also applicable to the personal management of mental health and smooth communication in social interaction in the case of a serious COVID-19 pandemic. Conversely, in the rescue of victims of natural and man-made disasters, consideration is given to the use of human body odor as a clue for those who are still alive [25–27]. The perspective of tension- and stress-induced human odor in the field of rescue can be extremely helpful in detecting humans in crisis. Such applications hold great potential. Therefore, further research is required.

## **Materials And Methods**

### **1. Effects of tension on skin gases**

#### **Subject**

The subjects of the main study consisted of 40 healthy, non-smoking Japanese women aged 35–44 years. In the confirmation test of skin gas odor, four Japanese men, three Chinese men and women, and two French men in the 20–30 years age group who were healthy and non-smoking participated in this study. Prior to the study, the subjects were informed of the purpose, methods, anticipated clinical benefits, and disadvantages of the study. All participants provided written informed consent. The study was conducted in compliance with ethical principles based on the Declaration of Helsinki. Furthermore, the study was conducted with the approval of the Shiseido Ethics Committee (Approval Number: C01402, C01555, C01577, C01824).

Restrictions for participation in the study were as follows: (a) the subjects did not consume odorous food 1 day prior to the study and (b) the subjects did not make contact with odor-intense objects. Lastly, (c) they were instructed not to wear any fragrance.

#### **Test methods and skin-gas collection methods**

Samples of skin gas were collected in an air-controlled room. Samples were extracted from each subject's non-dominant hand in two situations: at rest (sitting on a chair and relaxing while reading a magazine) and under stress (answering questions for 20 min from an interviewer they did not know). The subject's hand was washed with unscented soap prior to testing. The washed hand was covered with a sampling bag made of polyvinyl fluoride polymer resin film (Tedlar®) with a single-ended mini valve. Nitrogen gas (500 mL) was added after degassing the air in the bag, which was closed and left for 20 min (Fig. 1). Afterward, gas obtained from the sampling bags was recovered, placed in a storage bag (ANALYTIC-BARRIER™, GL Science Co., Ltd.) using connected silicone tubes. The gas was used as a sample.

## Physiological index measurement

### Autonomic status

Four electrodes were placed under the left and right subclavian bones and the left and right tenth ribs, whereas electrocardiographic activity was continuously measured by an electrocardiogram monitor (Ledarcirc, Sumitomo Dainippon Pharmaceutical).

Based on the electrocardiogram data, a power spectrum analysis of the heartbeat "R wave" intervals was performed using an autonomic nervous system activity analysis software (Sumitomo Dainippon Pharmaceutical, FLUCLET®). The intensities of the HF (ranging from 0.2 to 2 Hz) and LF (ranging from 0.04 to 0.15 Hz) components were determined. Additionally, the LF/HF component was used as an activity index of the sympathetic nervous system.

### Salivary cortisol measurements

Saliva samples were collected twice. The first measurement denotes samples collected immediately after the interview, whereas the second measurement refers to samples collected at baseline during home rest at the same time frame as the interview but on a different day. This process was observed to avoid cortisol changes resulting from the circadian rhythm. Salivary cortisol was quantified using ELISA (Cortisol Salivary Immunoassay Kit Salimetrics LLC).

## Odor assessment

The skin-gas samples collected at the relaxed and tense states were subjected to sensory evaluations by four experts to identify differences in odor. The experts noted a characteristic smell in the tension samples, which they could not detect in the relaxed sample. A five-point Likert-type scale was used to evaluate the intensity of the characteristic smell. The gases containing this smell in the tension samples, which were not identified in the control samples, were subjected to the following analysis for component identification.

## 2. Identifying the components of the characteristic odor

To identify the main components of the characteristic odor, collected gas samples were analyzed in the following order:

## Analysis i

Each 1 L of skin gas (at rest/during interviews) was collected in a canister and analyzed using particle tracking velocimetry coupled with GC/MS-O (PTV-GC/MS-O). Oven Prog.; 40°C (5 min) to 200°C (5°C/min). Column; DB-wax (60 × 0.25 mm, 0.25 µm, Agilent J & W).

**Analysis ii:** Volatile components of the skin-gas samples collected during interviews (3 L) was trapped by an adsorbent (Tenax GR) and subjected to GC-O analysis using a thermal desorption device. Oven Prog.; 50°C (1 min) to 230°C (4°C/min). Column: Rxi-5 ms (30 × 0.25 mm, 0.25 µm, Restek).

**Analysis iii:** Volatile components were collected using solid-phase microextraction (SPME) sampling of skin-gas samples and analyzed by GC-O and GC/MS (SIM: m/z 74). Oven Prog.; 35°C (3 min) to 250°C (10°C/min). Column: DB-Sulfur SCD (60 × 0.32 mm, 4.2 µm, Agilent J & W). SPME conditions: 85 µm Carboxen/SPME fiber assembly polydimethylsiloxane (SUPELCO), room temp., 30 min.

## 3. Psychological effect

The study developed a model odor using the components identified in the previous section and examined their psychological impact on other people.

### Subjects and restrictions

The subjects consisted of 33 Japanese women aged 35–44 years. Prior to the study, the subjects were informed of the purpose, methods, anticipated clinical benefits, and disadvantages of the study. Written informed consent was obtained from all participants. The study was conducted in compliance with ethical principles based on the Declaration of Helsinki. Furthermore, the study was conducted with the approval of the Shiseido Ethics Committee. Restrictions for participation in the study were as follows. (a) The subjects did not consume odorous food 1 day before the study. (b) The subjects did not make contact with odor-intense objects. They were instructed not to wear any fragrances.

### Assessing the psychological state

The model tension-stress odor, whose concentration was adjusted according to the odor threshold, was used as test samples. The study first confirmed the threshold per subject prior to assessing their psychological states.

The model tension-stress odor was presented to the subjects, who continuously sniffed it for 2 min. The participants then completed the validated questionnaires:

The psychological state of the subjects before and after sniffing was measured using POMS 2, which contains 35 questions that assess the following moods: AH, CB, DD, FI, TA, VA, and F.

## 4. Statistical analysis

The results of the test samples and each experiment are presented as mean ± SD. Paired Student's *t*-test was used to verify of the significance of the results of salivary cortisol levels. Bonferroni's method was

used for the significance tests of the activity of the sympathetic nervous system. The relationship between odor intensity and autonomic nervous activity was assessed using pairwise non-parametric correlations (Spearman's). Lastly, Wilcoxon's signed-rank test was used to determine significant differences in the results of the psychological index. A p value < 0.05 on both sides was considered statistically significant.

## Declarations

### ACKNOWLEDGMENTS

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### AUTHOR CONTRIBUTIONS

M.K. designed the study and the human tests and interpreted the data; T.N., M.N., K.K., M.O., and N.K. prepared and performed the human tests; T.N. performed the Elisa experiment; A.K. and Y.K. performed gas analysis; and M.K. and A.K. wrote the manuscript.

### COMPETING INTERESTS

The authors declare no competing interests

### FUNDING

This research did not receive any funding.

### DATA AVAILABILITY

The datasets generated during and/or analyzed during this study are available from the corresponding author on request.

### CODE AVAILALBILITY

Not applicable

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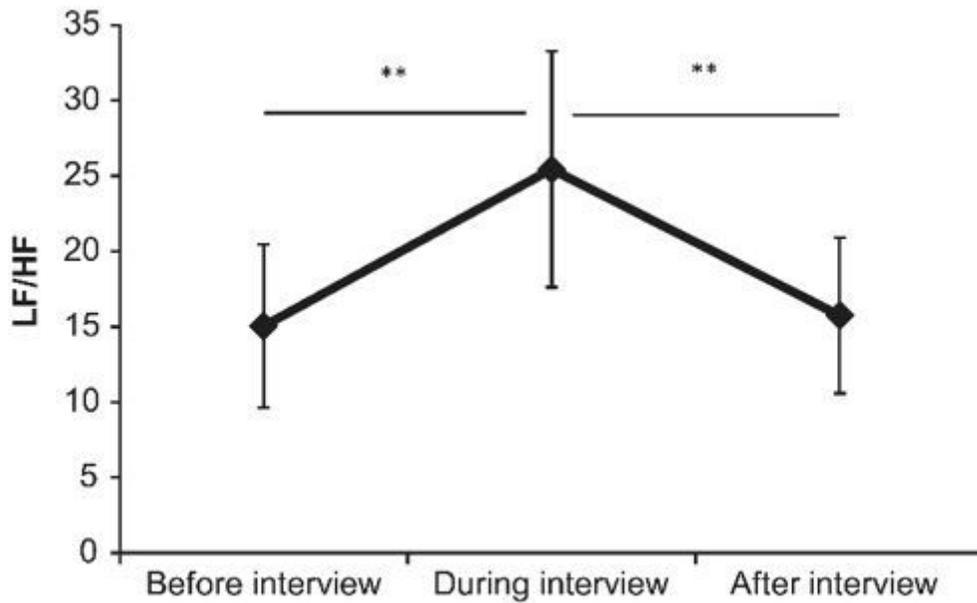
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## Figures



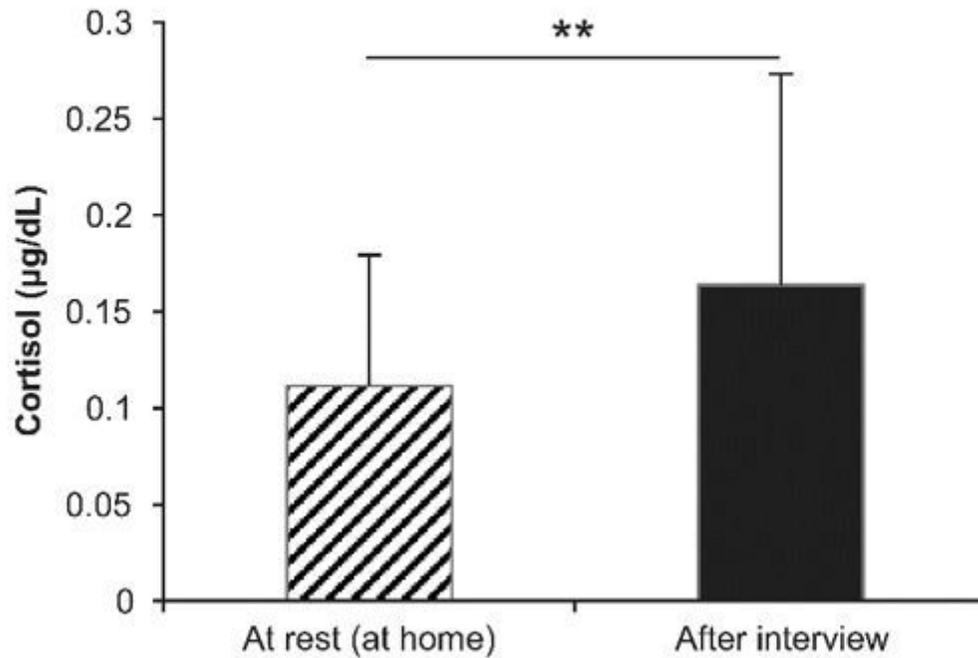
**Figure 1**

Collection bag for skin gas emanating from subjects' hand. Hands washed with unscented soap were covered with sampling bags made from a fluorinated ethylene–propylene copolymer material. The air inside was replaced with nitrogen and recovered after a certain period of time.



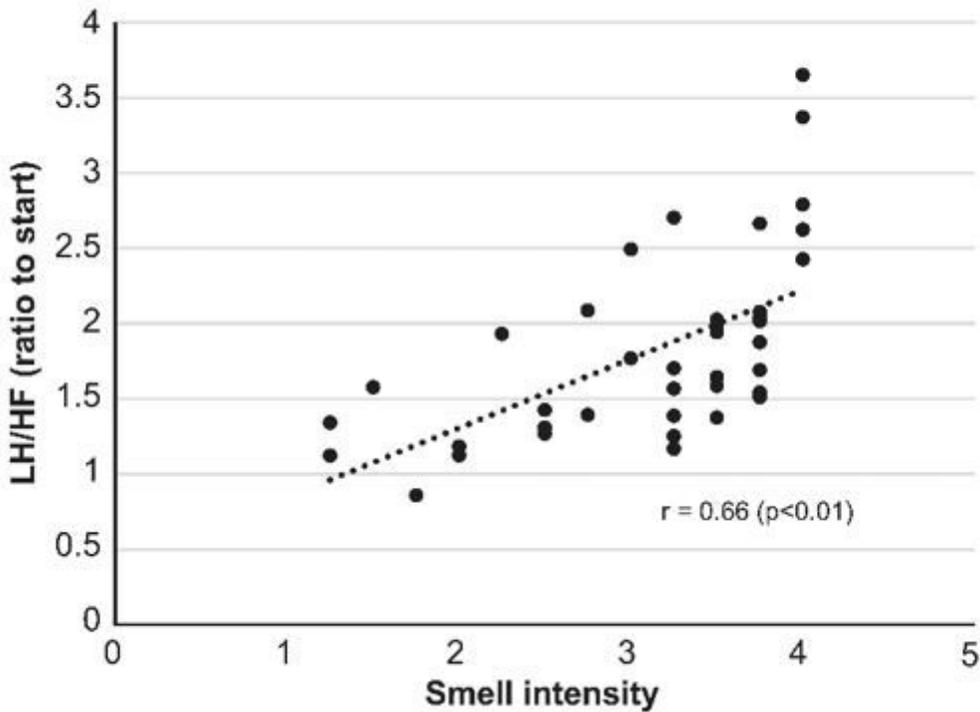
**Figure 2**

Autonomic nervous system activity during a stress-inducing interview. The heart-rate “R wave” intervals were calculated using electrocardiogram data. The intensity levels of high-frequency (HF, 0.2 to 2 Hz range) and low-frequency (LF, 0.04 to 0.15 Hz range) components were identified. The LF/HF components were calculated using the activity index of the sympathetic nervous system.



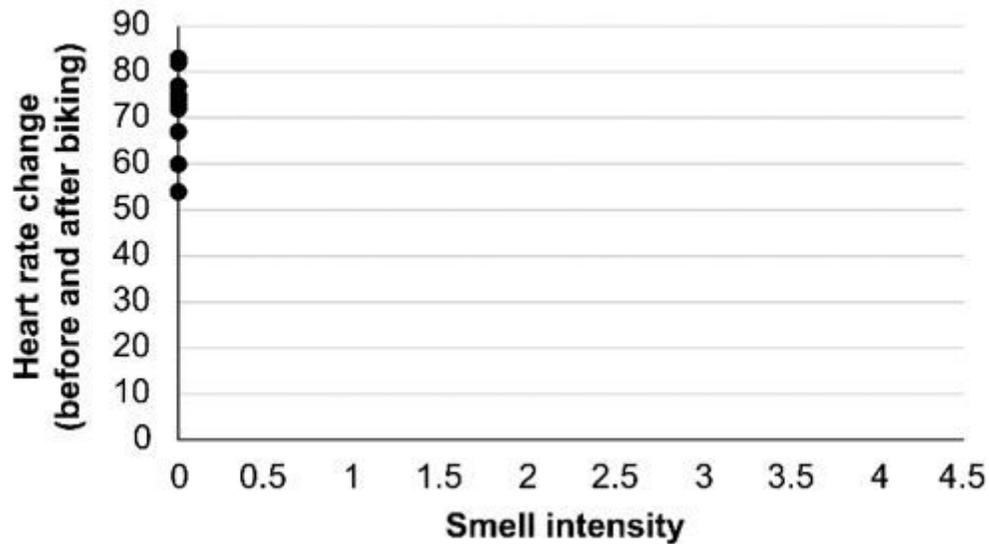
**Figure 3**

Salivary cortisol measurements. Saliva was collected twice. One sample was collected immediately after the interview, whereas the other was collected at baseline during home rest within the same time frame as the interview but on a different day. Then, salivary cortisol levels were quantified using ELISA. Salivary cortisol levels after the interviews were significantly higher than those at baseline (\*\* $p < 0.01$ , paired t-test).



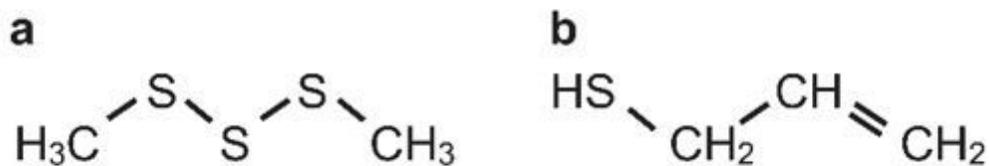
**Figure 4**

Relationship between intensity of tension-stress odor and autonomic nervous activity during the interview. A panel of four experts on odor evaluated the collected skin-gas samples to compare differences between odors emanated during stress and at baseline. Based on all interview samples, the characteristic sulfur-smelling compound odor was discovered. Further, the intensity of this characteristic odor was positively correlated with the rate of increase in sympathetic nerve activity during the interview compared with before the interview (Spearman's correlation coefficient:  $r = 0.66$  ( $p < 0.01$ )).



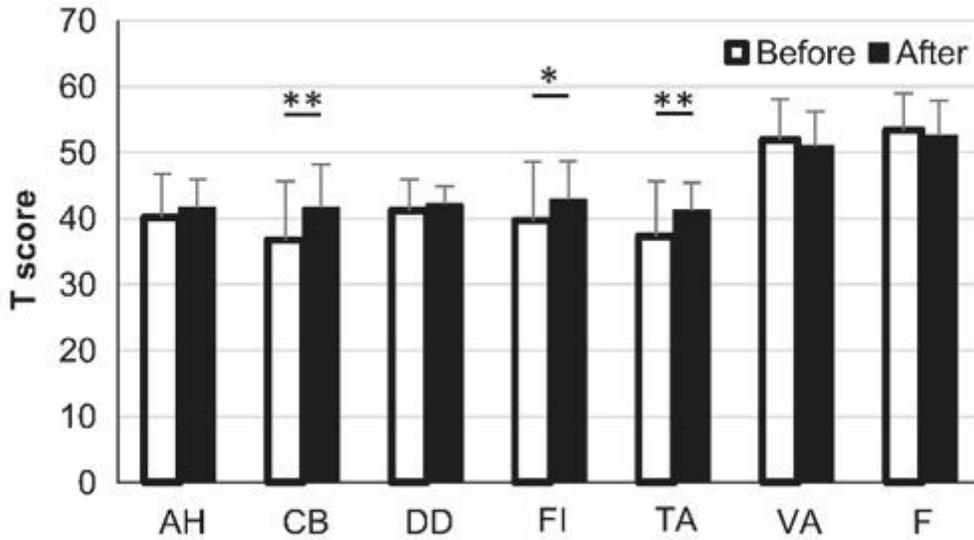
**Figure 5**

Relationship between the intensity of tension-stress odor during exercise and changes in heart rate. A panel of four experts on scent evaluated the collected skin-gas samples to compare the difference in odor between exercise and rest. No characteristic sulfur compound odor was observed in any of the samples when heart rate increased because of exercise.



**Figure 6**

a Dimethyl trisulfide, b Allyl mercaptan



**Figure 7**

Psychological results. The model tension odor, which was formulated according to the threshold, was continuously sniffed for 2 min. POMS 2 was used to measure the subjects' psychological status at baseline and immediately after sniffing the sample. The study observed significant increases in "tension-anxiety" ( $p < 0.01$ ), "confusion-bewilderment" ( $p < 0.01$ ), and "fatigue-inertia" ( $p = 0.012$ ). Note: AH: anger-hostility, CB: confusion-bewilderment, DD: depression-dejection, FI: fatigue-inertia, TA: tension-anxiety, VA: vigor-activity, and F: friendliness.