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Psychological and physiological responses to airflow stimuli: Differences in responses based on sex and targeted body site

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ABSTRACT

The purpose of this study was to clarify the effects of psychological and physiological measures of body sites and sex on the perception of different frequencies and speeds of airflow. In this study, we administered various airflow stimuli, which were produced by an airflow-generating device developed in a previous study, to 20 participants (10 men and 10 women) on the back of the hand, palm, cheek, and back of the neck in a room with the temperature set to 20 °C and humidity to 65%. We found the following: 1) Higher airflow speeds were associated with a greater decline in cutaneous temperature, higher coldness scores, and more negative preference scores. While a higher amplitude and frequency of sine wave signal (FSS) was associated with higher coldness scores, a higher level of temperature decline (delta-*T*) accompanying a higher FSS did not influence the preference score. 2) Women tended to give higher coldness scores and more positive preference scores, and men tended to give lower coldness scores and more negative preference scores. 3) Coldness scores were highest for the back of the hand, followed in order by the palm, cheek, and the back of the neck. Preference scores were most negative for the cheek, followed in order by the back of the neck, back of the hand, and palm (only among men). 4) Coldness scores were higher for body sites associated with a low two-point discrimination threshold, while preference scores were lower for body sites associated with larger pressure sensitivity thresholds.

Relevance to industry: The above outcomes (1–4) are relevant for industries involved in the development of comfortable life spaces, including the electronics industry, for developing air-conditioning systems; the entertainment industry, for using air as a new medium of entertainment; and the lifestyle industry, for providing new standards of life to humans.

1. Introduction

Airflow has physiological effects, such as decreasing skin temperature, and psychological effects, such as creating comfortable or uncomfortable sensations. Airflow acts as a physical stimulus in the form of low-frequency air vibrations (0.1–20 Hz; Adachi and Hujisiro, 1980) and infrasound (< 20 Hz; JIS C 1400-0, 2005). Humans detect this stimulus on their skin as a cutaneous sensation. The airflow stimuli that create the cutaneous sensation are classified as airborne contactless stimuli, and as such, they are distinguished from vibro-tactile and pressure-tactile stimuli. Accordingly, when studying the skin's sensory mechanism, it is important to take into consideration how these different types of stimuli are associated with one another. Regarding existing literature on sensitivity to vibro-tactile and pressure-tactile stimuli, Verrillo (1963) quantitatively demonstrated that sensitivity thresholds to vibro-tactile stimuli depend on the body site targeted and individual attributes, such as age and sex. Weinstein (1968) quantitatively demonstrated that sensitivity thresholds to pressure-tactile stimuli also vary depending on body site. As for the literature on sensitivity to airborne contactless stimuli, Leider (1976) presented several low frequency air vibration and infrasound-based stimuli and measured levels of participant discomfort produced by each stimulus. Additionally, Okai et al. (1979) described the physiological responses to airborne contactless stimuli, highlighting changes in heartrate, pulmonary circulation waves, and breathing rate. However, none of the existing studies on airflow sensitivity clarified how or to what extent psychological and physiological responses can vary by factors such as body site and sex. Moreover, when examining the skin's sensory mechanism, it is important to clarify correlations between psychological/physiological responses to tactile stimulation and such responses to

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contactless stimulation. Regarding psychological responses to airflow, Leider's study (1976) highlighted negative responses, such as harm to health, while other studies have emphasized positive responses, such as a relaxation effect (Chesky and Michel, 1991; Fukada et al., 1998; Skille, 1989). Because these studies used different types of airflow stimuli, their findings cannot be compared to one another. Thus, it is necessary to clarify the positive and negative psychological responses using standardized and quantitatively measurable airflow stimuli.

In a previous study (Hashimoto et al., 2014), we developed an airflow generating device (AFGD; described in Section 2.1) that generates airflow within a fixed range in response to input sinusoidal (i.e., sine wave) signals of variable amplitudes and frequencies. In another study (Takahashi et al., 2016), we used the AFGD to present a range of precisely configured airflow stimuli to different body sites. The results showed the effects of airflow speed on absolute sensitivity thresholds and sensation attributes. Absolute sensitivity threshold is the minimum amount of stimulus energy that generates sensation. However, none of our previous studies have clarified the physiological and psychological (negative/positive) responses to airflow stimuli according to body site and sex.

Thus, the aim of the present study was to clarify the psychological and physiological effects of airflow stimuli, and we measured their psychological responses (coldness score, pleasantness score) and physiological responses (decline in cutaneous temperature).

2. Method

2.1. AFGD and the stimuli presentations

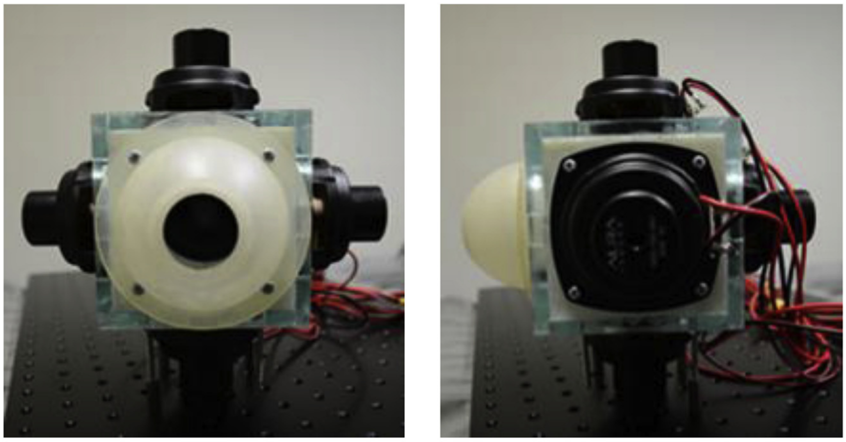
Fig. 1 shows the front side and a lateral side of the AFGD. The AFGD consists of a 6-sided casing with an opening on each side (113 × 113 × 113 mm, thickness of casing: 8 mm, cubic volume: 1.16 L) to which are attached 5 speaker units (AURASOUND NS3-193-8A) and 1 nozzle. Air inside the casing is pushed out in response to the speakers synchronized with the input signal, creating an external airflow. The nozzle is dome-shaped with an opening 30 mm in diameter. Our preliminary tests indicated that this was the optimal nozzle design for enabling efficient airflow emission. The nozzle emits airflows of varying speeds and transition frequencies. A function generator (FG-350) controls the frequency of sine wave signal (FSS). We set 3 FSS conditions: 40 Hz, 60 Hz, and 80 Hz. We decided on these settings because Ohyama et al. (1994) reported that vibro-stimuli around 40 Hz influence the sensitivity threshold. Karkkainen and Mitsui (2006) reported that human muscle tissue resonates with sonic stimuli at 0–100 Hz and that the skin starts to sense sonic stimuli at levels below 80 Hz. We also set 3 airflow speed conditions for each FFS condition: 2 m/s, 5 m/s, and 8 m/s. We decided to use airflow speed settings above the stimulus threshold because the airflow stimulus threshold has been demonstrated to be roughly 2 m/s when a stimulus is presented 300 mm from the target (Takahashi et al., 2016).

2.2. Participants

Twenty participants (10 women and 10 men) were employed in this study, with ages ranging from 18 to 22 years. They were undergraduate students from the Faculty of Engineering at Utsunomiya University. Their physical conditions were normal, without illnesses or health problems such as a fever or cold. The study was approved by the institutional review board of the Independent Ethics Committees of Utsunomiya University, and informed consent was obtained from all participants.

2.3. Experiment environment

We conducted the experiment in a 2 × 5 m room (ceiling height = 2.4 m) in which we could maintain constant temperature and humidity levels. The temperature was 20 ± 1 °C (Japanese Industrial Standards Committee, 2014) and the humidity level was approximately 65%. For all the body sites (i.e., the palm, back of hand, cheek, back of neck), we set the AFGD-generated stimulus 300 mm away from the target. To mask the vibration noise of the AFGD during the experiment, we asked the participants to wear a pair of headphones that emitted white noise (66 dB). The 66-dB white noise was set as the lowest level that masks the vibration noise of the AFGD, based on the results of the preliminary study. Fig. 2 illustrates the experiment procedure. The participants spent 20 min adjusting to the environment of the room and then 3 min adjusting to the white noise from the headphones. The participants rested for 45 s before each stimulus presentation in order to erase the psychological and physiological effects created by the stimulus presented immediately before. The participants undertook a series of iterations consisting of a 45-s pre-stimulus rest (Rest 1), a 15-s stimulus presentation, and a 45-s post-stimulus rest (Rest 2), each iteration lasting for a total of 1 min and 45 s. Over the course of each iteration, we measured the participants' physiological responses. At the end of each iteration, the participants evaluated the relevant stimulus. Each participant underwent a total of 36 iterations (3 FSS × 3 amplitudes × 4 body sites). To control for ordinal effects, we randomized the order of body site and stimulus strength. The 45-s periods of Rest 1 and Rest 2 were confirmed to be the necessary and sufficient time periods required for skin temperature to recover from the residual effects of the



(a) AFGD (front side)

(b) AFGD (lateral side)

Fig. 1. Air flow generating device (AFGD).