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Responses to Human Bioeffluents at Levels Recommended by Ventilation Standards

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Abstract

The purpose of this study was to examine whether exposure to human bioeffluents, at the levels recommended by the current ventilation standards, would cause any effects on humans. Ten subjects were exposed in a low-emission stainless-steel climate chamber for 4.25 hours. The outdoor air supply rate was set to 33 or 4 l/s per person, creating two levels of bioeffluents with carbon dioxide (CO_2) at 500 or 1600 ppm. Subjective ratings were collected, cognitive performance was examined and physiological responses were monitored. The results show that exposures to human bioeffluents at ventilation rate of 4 l/s per person caused sensory discomfort of visitors, reduced pNN50 (a domain of ECG measurement), but did not produce negative effects on cognitive performance or health symptoms.

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Keywords: Human bioeffluents; Perceived air quality; Acute health symptoms; Cognitive performance; Physiological reactions

1. Introduction

A variety of pollutants are produced during metabolic processes that take place within the human body. They include CO_2, ammonia, hydrocarbons, alcohols, ketones and aldehydes [1, 2]. Field studies show that human bioeffluents are an important component of the pollution ‘footprint’ indoors [3]. Sensory perception of the quality of air polluted by human bioeffluents is the basis of current ventilation standards [4, 5]. Most of the published work in

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which bioeffluents were mentioned and CO_2 was used as the marker of indoor air quality were field experiments where human bioeffluents are not the only or a dominant source of pollution but one of the many other potential sources of pollution that cause sensory discomfort [6].

There are only few experiments that examined the effects of bioeffluents on humans except the effects on sensory perception. Bakó-Biró [7] exposed 23 subjects to two different levels of human bioeffluents for 2.8 hours with a CO_2 concentration of 650 ppm and 1,100 ppm. They reported no significant changes in the acute health symptoms or the performance of simulated office work. Maddalena et al. [8] exposed 16 subjects for 4 hours to human bioeffluents at two levels, with CO_2 concentrations at 900 ppm and 1,800 ppm. They did not observe any effects on the acute health symptoms of exposure to increased level of bioeffluents either. However, the subjects performed marginally worse on a Strategic Management Simulation (SMS) test [9], which is designed to examine performance of complex decision-making. Zhang et al. [10, 11] exposed 25 subjects for 255 minutes in a climate chamber to three levels of human bioeffluents with CO_2 concentrations of 500, 1,000 and 3,000 ppm. They showed that bioeffluent levels with CO_2 of 3,000 ppm caused increased intensities of some symptoms and reduced performance of simulated office task and cue-utilization test. In parallel, physiological measurements showed that diastolic blood pressure, end-tidal CO_2 ($ETCO_2$) level and concentration of salivary a-amylase increased after exposure to higher level of bioeffluents.

The results from these few experiments suggest that human bioeffluents may cause unwanted effects on acute health symptoms and on the cognitive performance of building occupants but at pollutant levels higher than those that are currently recommended for achieving low percentages dissatisfied with air quality, i.e. higher than 1,000 ppm. To extend and supplement this evidence, laboratory experiment was performed to examine the effects of bioeffluents on humans at an intermediate level of bioeffluents in which the CO_2 concentration was 1,600 ppm.

2. Methods

The experiment was conducted in a 3.6 × 2.5 × 2.5 m (L×W×H) stainless climate chamber described in detailed by Zhang et al. [10]. The construction of the chamber ensures that the level of background pollution is very low. The chamber is equipped with an air-conditioning system. The outdoor air was firstly conditioned to the required temperature and humidity, and then was supplied to the chamber through a perforated floor from a sub-floor plenum. Six workstations were installed in the chamber, each workstation consisting of a table, a chair, a laptop PC and a desk lamp, to accommodate 5 subjects and an experimenter during the experiments.

Two levels of human bioeffluents were examined in the present experiment. At the reference condition, outdoor air supply rate was set to 720 m^3/h (33 l/s per person) to keep the human bioeffluents generated by subjects sufficiently low; the resulting CO_2 concentration was at 500 ppm (the reference level termed B500). At the higher exposure level, ventilation rate was restricted to 83 m^3/h (4 l/s per person) with CO_2 concentration at 1,600 ppm (the exposure level termed M1600). In both conditions, the temperature in the chamber was kept constant at 24°C and relative humidity (RH) at 35%.

Ten Danish students (2 males, 8 females), with an average age of 23±2 years old, participated in the experiment. They were randomly assigned to 2 groups of 5 subjects. Each group was exposed to each condition twice in a balanced design.

Fig. 1 shows the experimental procedure. Each exposure started at 13:00 and completed at 17:30. During each exposure, four types of measurements were conducted: physical measurements inside the climate chamber including air temperature, relative humidity and CO_2 concentration, subjective evaluations of perceived air quality, odour intensity, general comfort, acute health symptoms and work performance, objective measurements of cognitive performance using Baddeley test, neuro-behavioural tests, proof-reading, addition, text typing and Tsai-Partington test, and physiological measurements including blood pressure, $ETCO_2$, saturation of oxygen in blood (SPO_2), heart rate and electrocardiogram (ECG). They were similar to the measurements performed in the closely related experiments conducted by Zhang et al. [10, 11].

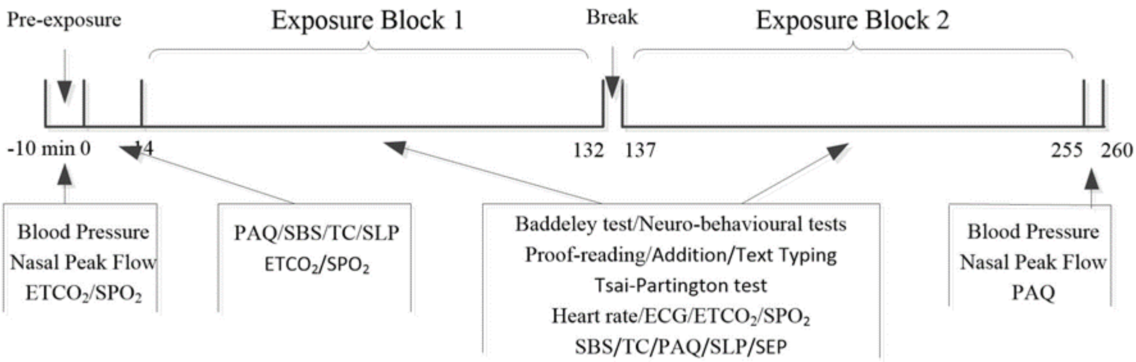

Fig. 1. Experimental procedure, where PAQ/TC/SBS/SLP/SEP stands for subjective assessments of perceived air quality, thermal condition, acute health symptoms, sleepiness and self-estimated performance.

All outcomes were analyzed using a general linear analysis of variance model with repeated measures. Exposure conditions (c) and the time at which different assessments were made or measurements were performed during the day (t) were included as within-subject factors; the condition×time interaction (ct) was automatically included in the model as a within-subject factor. Post-hoc analyses were performed using a paired-t test to compare differences between different exposure conditions at the same point in time during each exposure; the 2-Tail significance level was set to 0.05. The analysis was made with the SPSS 19.0 program.

3. Results

Fig.2 shows the outcomes for which the effect of condition was statistically significant. The acceptability of air quality judged by the subjects upon entering the chamber before the exposure and upon re-entering the chamber after the exposure was systematically lower when the outdoor air supply rate to the chamber was reduced to 4 l/s per person in condition M1600. The subjective ratings of acceptability of air quality increased significantly during the course of the exposure to bioeffluents due to adaptation (sensory fatigue), so there was no difference between the air quality perceptions of adapted subjects. The ratings of odour intensity and air freshness exhibited similar trends and provided further evidence that the air quality worsened when the concentration of bioeffluents was higher.

ECG measurement was conducted twice and each recording lasted for 5 minutes overlapping proof-reading task. ECG was then used to analyze heart rate variability (HRV) by calculating time-domain and frequency-domain indexes. The results show that only pNN50, a time-domain index of HRV reflecting the activation of parasympathetic nervous system, was systematically lower at M1600 than at B500, but the difference reached statistical significance only at the first measurement occasion during the period of 32^{nd}-67^{th} min of exposure. The change of pNN50 may suggest that the stress level increased when subjects were exposed to higher level of bioeffluents.

There were no any other significant differences between the two conditions in the self-reported acute health symptoms, in the performance of cognitive tests and tasks simulating office work, or other physiological reactions.

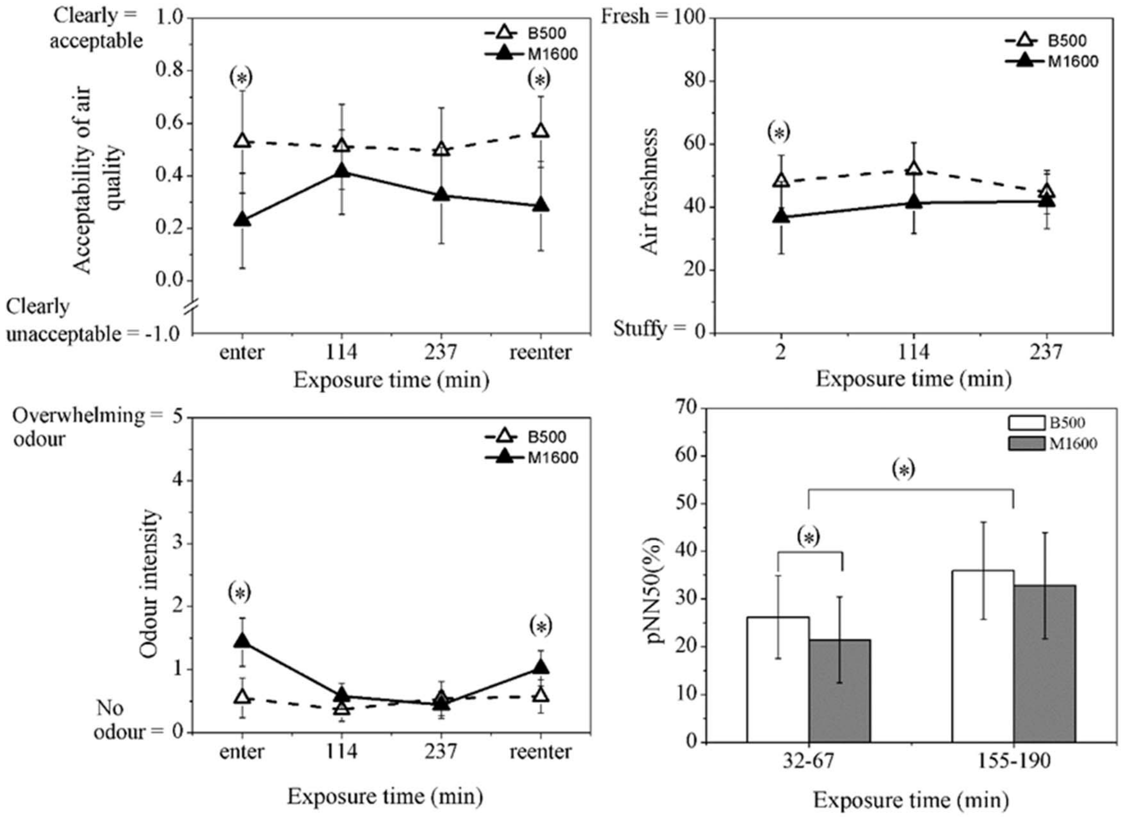

Fig. 2. Outcomes for which the effect of condition was statistically significant; the scales were coded as follows: for the assessment of acceptability, -1=clearly unacceptable, +1=clearly acceptable; for the assessment of air freshness, 0=stuffy, 100=fresh; for the as-sessment of odour intensity, 0=no odour, 1=slight odour, 2=moderate odour, 3=strong odour, 4=very strong odour, 5=overwhelming odour

4. Discussion

The results of the sensory measurements of air quality are in agreement with the findings of previous research [12, 13]. They show that when the concentration of human bioeffluents increases, the air quality assessed upon immediate exposure to bioeffluents is reduced and the odour intensity increases, while during longer exposures there were no significant differences in perception of air quality. These variations in sensory responses indicate a strong adaptation to body odours [14]. The requirements on air quality in volumes polluted by human bioeffluents should therefore depend on whether they address the occupants' or the visitors' requirements. This is reflected in ASHRAE 62 ventilation standard [4], which specifies separately the outdoor air supply rate needed to achieve acceptable indoor air quality for adapted and unadapted persons.

The present results show that no changes in acute health symptoms are to be expected below a level of 1,600 ppm. It agrees well with the previous study by Bakó-Biró [7], whose experiment with 23 subjects did not observe changes of symptoms at a CO_2 concentration of 1,100 ppm, and to some extent with the study by Maddalena et al. [8], who conducted an experiment with 16 subjects in which no changes in symptoms were observed when bioeffluent level increased to the level with a CO_2 concentration of 1,800 ppm. Yet present result does not rule out the likelihood of a dose-response relationship above the CO_2 level of 1,600 ppm, as suggested by Zhang et al. [10] who examined the effects of exposure to bioeffluents with CO_2 concentration at a range of 500 to 3,000 ppm.

Cognitive performance was not affected by conditions in the present experiment. Present result is in accordance with the previous findings [7, 10, 11, 15]. In the experiments of Maddalena et al. [8], subject taking the Strategic

Management Simulation (SMS) battery for examining the impact of stressors on decision-making performance performed less well when exposed to bioeffluents with a CO_2 concentration of 1,800 ppm, compared with 900 ppm. This was at a bioeffluent level higher than in the present experiment.

The present experiment did not observe significant changes in physiological reactions except for a decrease of pNN50 at the level of bioeffluents with a CO_2 concentration below 1,600 ppm. In the previous experiment, Zhang et al. [11] showed that $ETCO_2$ and heart rate both increased systematically when human bioeffluent levels increased so that the CO_2 concentration increased from 500 ppm to 1,000 ppm and to 3,000 ppm; at 3,000 ppm changes in diastolic pressure and nasal peak flow were also observed. The reasons for these differences are unknown and no other experiments have been published that would allow these results to be verified against other independent findings during exposures to human bioeffluents with CO_2 below 2,000 ppm.

Since some inconsistencies were observed between the results obtained in different experiments, especially as regards physiological responses and cognitive performance, it would be useful to focus in future studies on exposure to moderate-to-low levels of human bioeffluents (<1,600 ppm) in order to determine whether they have any impact on physiological reactions that lead to the development of acute health symptoms and reduced cognitive performance. This is particularly important because previous work, e.g. as summarized by Seppänen et al. [6], Seppänen et al. [16] and Fisk et al. [17], indicates that there are effects on these outcomes at levels of CO_2 below 1,600 ppm and often as low as 1,000 ppm.

5. Conclusions

Exposure to human bioeffluents with CO_2 at a concentration of 1,600 ppm (ventilation rate of about 4 l/s per person) caused sensory discomfort upon immediate exposure, but did not affect physiological responses except for reduced pNN50. It did not cause any acute health symptoms or measurable effects on cognitive performance.

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