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Influence of indoor and outdoor temperatures on the fingertip blood flow rate

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ABSTRACT

A total of 58 healthy subjects participated to elucidate the influence of indoor and outdoor temperatures on blood flow. After walking outdoors for 20 min, the blood flow rate of a subject was measured. The subject then entered a classroom and studied for 120 min, and afterwards, the blood flow rate was measured again. The subjects were exposed to outdoor temperature ranging from −2.5 to 33.7 °C. During the summer, the average blood flow rate after walking outdoors was 45.95 ± 25.790 TPU (tissue perfusion units); after the class, this decreased to 36.14 ± 21.837 TPU ($p < 0.05$). During the autumn, the blood flow rate decreased from 27.69 ± 12.334 TPU to 12.47 ± 12.255 TPU ($p < 0.001$). When the outside air temperature was below 3 °C, the blood flow rate indoors increased significantly from 6.74 ± 3.540 TPU to 13.95 ± 11.522 TPU ($p < 0.05$). In a comfortable and healthy environment, the blood flow rate was not constant but fluctuated between 15 TPU and 40 TPU.

1. Introduction

The human body is exposed to indoor and outdoor environments during daily life. A comfortable outdoor climate leads to a comfortable indoor environment (Ahmed, 2003). Song et al. (2012) found that a person who comes indoors from a hot outdoor environment sets the air conditioner to a low temperature because the heated human body should be cooled to a comfortable temperature range. Thermal sensation and thermal physiology are affected by the state of the outdoor environment and the time spent outdoors, and the outdoor climate affects clothing style and the clothing insulation value (Nikolopoulou et al., 2001). Thermal comfort theory has been developed based on psychological responses; the acceptable temperature range is calculated using the subjective thermal sensation vote (TSV) (Fanger, 1970; ISO 7730, 1994; ASHRAE Standard 55, 2004). Psychological responses are used to evaluate productivity indoors (Parsons, 2003). However, many people enjoy hot saunas, and some people like swimming during the cold winter season. These preferences cannot be explained by the traditional thermal comfort theory. Physiological responses are used to evaluate the health of humans exposed to different thermal environments. The skin temperature and blood flow rate can be used to assess the quality of a healthy space.

The environment is sometimes extreme in a transitional space or outdoors. During the summer, the outdoor temperature is extremely high, and during the winter, this temperature is extremely low. The human body should maintain homeostasis; therefore, human thermal behaviours have been developed to allow people to adapt to extreme environments. The level of clothing insulation varies, with light clothes worn during the summer and heavy clothes worn during the winter. A person's metabolism can be changed by low-speed or brisk walking. When a person is exposed to an extreme environment, the person feels uncomfortable, and blood flow is controlled by vasomotor functions. If the body is exposed to an extremely cold environment, blood flow is minimised to maintain homeostasis. In contrast, if the body is exposed to an extremely hot environment, blood flow is maximised along with sweating to dissipate heat from the body's core (Schimidt and Thews, 1989). A high blood flow rate indicates that high levels of oxygen are transported to cells. This high-oxygen environment induces oxidative stress and the dysfunction of hormones, and the DNA can be damaged (Marczynska et al., 1980; Ivell, 2007; Song, 2010).

Exposure to low temperatures induces pain (Yarnitsky and Ochoa, 1991), cold drafts (Griefahn et al., 2001) and the loss of manual dexterity (Heus et al., 1995). Tissue ischemia leads to limited angiogenesis and associated disorders, such as Raynaud's phenomena, pain, numbness, paleness, cyanosis swelling, or tingling. Furthermore, exposure to extremely cold environments can result in tissue necrosis (Yu et al., 2006). Indoor environments

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should mitigate these extreme outdoor environments and serve as a comfortable shelter for occupants.

Several researchers have investigated changes in the blood flow rate depending on the indoor environment. Song (2008) measured the blood flow in the toe contacting a floor's surface and reported that the blood flow rate increased proportionally with the skin temperature of the foot. Song argued that the surface temperature of the floor should be maintained in the range of 23–33 °C. Tanaka et al. (2003) investigated peripheral blood flow in the hands and feet. They concluded that an ambient temperature of 17 °C may be too low for comfort due to decreased blood flow. These studies were performed in an artificial climate chamber, and the duration of the experiment was short (approximately three months). Human responses in climate chambers are different from responses in the field, and the human body changes seasonally. Studies on blood flow performed in the field and covering all seasons are limited. The aim of the current study was to investigate the seasonal changes in blood flow in the field. The fingertip blood flow was measured during (1) the summer, which is hot and humid; (2) the autumn, which is mild and comfortable; and (3) the winter, which is cold and dry. The purpose of this work was to elucidate the influence of indoor and outdoor environments on blood flow.

2. Subjects and methods

2.1. Subjects

Many students know that physiological experiments using human subjects are performed continuously in the author's laboratory. Three research staff supported this study, and their friends and classmates were recruited as subjects. After preparing the experimental protocol, a research staff member posted a recruitment announcement on the bulletin board at Bucheon University and used a smart phone message system. The notice explained that students with severe cardiovascular, pulmonary, renal or other diseases were not eligible to participate in the experiment (Frank et al., 1999). Because obesity can influence thermal sensations (Magnusdottir et al., 2005; Cho et al., 2013; Tanaka et al., 2003), only subjects with a BMI (body mass index) below 25 were eligible. The length of time since consuming a meal also affects blood flow (Munkelwitz and Gilbert, 1998; Song et al., 2012), and subjects were not allowed to eat for 1 h prior to the experiment.

The research staff informed the applicants that the blood flow measurements would be taken by attaching a probe to the fingertip. The Laser Doppler Meter is a non-invasive tool that is used to measure blood flow. Applicants who agreed to the terms of the investigation provided written consent. A total of 58 healthy students (33 males and 25 females) were recruited. The mean age, height, weight, and body mass index (BMI) were22.7 $\pm$ 2.94 years, 169.4 $\pm$ 8.9 cm, 62.1 $\pm$ 12.3 kg and 21.52 $\pm$ 2.91, respectively. The subjects that participated in the investigation were paid 20,000 Korean Won (approximately18 US dollars) for participating.

The clothing insulation value (Clo) of the subjects was not controlled. All subjects wore their clothes as normal according to their personal habits or the weather conditions. When a subject arrived at the laboratory, he or she was asked to check his or her clothes, and a research staff member calculated the clothing insulation value according to the recommendation of ASHRAE Standard 55 (2004).

2.2. Experimental procedure

The blood flow rate was measured in the middle left fingertip using a Laser Doppler Meter (Model: BLF21, Transonic Systems Inc., New York, USA). Because the blood flow rate constantly fluctuates (Song, 2008), it should be measured dozens of times per second. The DI-158U Data Logger (DATAQ Instrument Inc., Ohio, USA) is designed to appropriately measure the fluctuating blood flow rate. The blood flow rate was measured 50 times per second using the aforementioned tools.

The first measurement of the blood flow rate was performed for duration of 10 min after the subjects arrived at the laboratory. The second measurement was performed over 10 min after the subjects had left the laboratory and walked outdoors from the school to the subway station (20 min). During the walk, the climate conditions were measured using a portable temperature and humidity recorder (Model: TR-72S, T and D Corporation, Japan), each subject put the portable recorder into a small bag, and the sensor that measured temperature and humidity was located outside of the bag. The subjects were asked that the sensor should not come into contact with the subject's body. Data on the insolation and wind speed were obtained from the Bucheon weather station.

After the second blood flow measurement, the subjects entered a classroom and studied for 120 min. The third blood flow rate measurement was taken over 10 min after the subjects had studied for 2 h.

The number of measurements was 105 during the summer, when air conditioning was used; 63 during the autumn, when no air conditioning was used; and 96 during the winter, when heating was used. A total of 264 measurements were taken. Fig. 1 shows how the blood flow measurements were taken during the summer, and Fig. 2 shows the composition of the measuring instruments. Fig. 3 shows a subject and the data logging system in the winter after the subject had arrived at the classroom after walking for 20 min in the cold outdoor conditions of the winter season.

2.3. Outdoor thermal conditions

Korea has four seasons, and during the winter, a heating system should be used because the climate is very cold. During the summer, a cooling system is often used due to the hot weather conditions, and during the spring and autumn, air conditioning systems are not operated because the climate is mild.

Measurements were taken between July 20, 2010 and January 06, 2011 to estimate the blood flow rate during multiple seasons. During the summer, from July 20, 2010 to September 17, 2010, a cooling system was operated, and during the autumn, from September 30, 2010 to November 13, 2010, an air conditioning

Fig. 1. Subject and blood flow rate measurement device in the summer.