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Effect of outdoor thermal environment on pedestrians' behavior selecting a shaded area in a humid subtropical region

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ABSTRACT

This study analyzes the effect of microclimatic conditions on pedestrians' behavior in selecting shaded places when standing at the traffic signals in a subtropical region of Nagoya, Japan. On-site microclimatic measurements and unobtrusive observations were performed 18 times in two periods, July to October, 2012, and May to August, 2013, in order to obtain physical data and the number of pedestrians in sunlit and shaded areas. The universal thermal climate index (UTCI) model was adopted for assessing the outdoor thermal environment in the sunlit and shaded places in this study. The average UTCI values in the sunlit and shade areas over the measured periods were 38.0 °C and 29.3 °C, respectively, and the difference was 8.7 °C. The number of pedestrians was hardly influenced by heat environment since the observations were conducted on weekdays, thus, almost all had to go out for their routine tasks or work regardless of the conditions. Male and female pedestrians tended to wear hats and parasols, respectively, in order to avoid excessive heat during the hot season. The analytical results indicate that half of the pedestrians select shaded areas when stopping at the traffic signals in a hot environment over 40 °C in UTCI. Female pedestrians are more careful to protect themselves from solar radiation including ultraviolet rays than males. "Shade Design in the City" will be a critical strategy to improve the safety, comfort, and attraction of cities in a hot environment.

1. Introduction

Interest in outdoor thermal comfort and the corresponding subjective and behavioral reactions has been growing in recent years [1]. Many researchers have conducted studies in parks, plazas, squares, and streets in different climate regions, and provided valuable findings on the relationship between microclimate and outdoor thermal comfort, thermal neutrality, comfort, and acceptable ranges in an outdoor environment [2–10]. Nikolopoulou and Steemers [11] and Huang et al. [12] pointed out that outdoor thermal comfort should be affected by not only microclimate but also experience, expectations, exposure time, and so forth. Improvements in the outdoor thermal environment will increase the use of outdoor spaces, and thus attract more people to cities.

In addition, outdoor thermal environment research is needed to improve pedestrians' safety. Heat-related illness has become a notable problem in Japan, which has a humid subtropical climate. Nakai et al. [13] examined the relationship between heat-related deaths and meteorological parameters in Japan, and demonstrated that the deaths were most likely to occur on days with a peak daily temperature above 38 °C. According to the Health Care Manual for Heatstroke by the Ministry of the Environment of Japan [14], the largest number of yearly heat-related deaths was 1745 in 2010. To reduce this level of mortality, the manual recommends several precautions including avoiding heat, drinking water, and so forth. Many countries also work on the prevention of heat-related illness. For instance, the nationwide Heat Illness Prevention Campaign has been conducted for outdoor workers in the US using three keywords, "water, rest, shade" [15]. These activities remind us that peoples' understanding of excessive heat is important to prevent heat-related illness.

Several researchers examined the relationship between a microclimate and use of outdoor spaces in different climate regions. Nikolopoulou et al. [16] conducted field studies in the center of Cambridge, UK, during spring, summer and winter, and noted that the number of people sitting in outdoor spaces increased as globe

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temperatures increased. Eliasson et al. [17] performed meteorological measurements, structured interviews, and human activity observations in four urban public spaces in Gothenburg, Sweden, during four seasons, and demonstrated that the number of visitors increased when the air temperature rose. Lin [18] indicated that the number of people visiting the square increased as the thermal index value increased during the cool season, but decreased as the index value increased during the hot season in the hot and humid climate of Taiwan. In addition, the same findings were obtained from a study conducted in a park in central Taiwan [19,20]. De Montigny et al. [21] carried out observations using web-based cameras in nine cities across the northern hemisphere, and concluded that three weather variables of air precipitation, sunlight, and air temperature had significant associations with volumes of pedestrians; a 5 °C increase in temperature was associated with a 14% increase in pedestrians.

As regards peoples' behavior in selecting sunlit and shaded areas, several researchers have conducted microclimatic measurements and observations at urban public squares and parks in different climatic regions. Zacharias and Stathopoulous [22] investigated the relationship between microclimatic conditions and human presence and activity in seven open spaces in the built-up downtown of Montreal, Canada. They found that people increasingly positioned themselves in sunlit areas as the temperature dropped, and there was a tendency to move into the shade or out of direct sunshine at the higher temperature of 20 °C. Thorsson et al. [23] compared the results of outdoor research in Japanese parks with those in Swedish parks, and indicated that 80% of park visitors sought shade in Japan, whereas only 14% in Sweden at temperatures higher than 20 °C. Nikolopoulou and Lykoudis [24] performed microclimatic monitoring, structured interviews, and observations in open spaces in the Mediterranean climate of Athens. They reported a strong relationship between microclimatic conditions and use of open spaces; the visitors preferred to sit in shaded areas in summer, whereas sunlit areas were more popular in autumn and winter. Kántor and Unger [25] conducted thermal comfort investigations in a park in Szeged, Hungary, and marked subjects' exact location and observation data within GIS application. They concluded that the momentary attendance was near to zero in lower air temperature, while it showed greater numbers and a remarkable scatter in warmer conditions; despite hot conditions (PET > 35 °C) more than 50% of subjects lingered in the sun. Lin et al. [26] emphasized that moving to a shaded area was the most vital behavior for the participants in adapting to severely hot weather through field investigations in a public park in Taiwan. Martinelli et al. [27] assessed daily shading patterns, attendance, and thermal comfort during summer in San Silvestro square in Rome, Italy, and revealed that the majority of visitors sought shaded locations when sitting. Additionally, they indicated that the maximum difference in the median of PET between shaded and unshaded areas was 7 °C. Huang et al. [28] performed microclimate measurements, image recordings, and dynamic behavior observations at the outdoor garden in Taichung City, Taiwan. They found that the number of people present decreased as temperatures increased during the hot season, and more than 75% of users preferred shaded areas.

The abovementioned studies provide valuable understanding regarding peoples' behavior in urban parks and plazas. Urban open spaces, however, consist not only of parks and plazas but also streets. Several researchers have discussed pedestrians' thermal comfort on streets [29–34]. Miranda-Moreno and Lahti [35] examined the impact of weather on pedestrian activity using automatic pedestrian counts in Montreal, Canada, and found that air temperature, humidity, wind speed, and precipitation are the main factors affecting pedestrian activity. Zeng and Dong [36] performed a thermal comfort survey in three pedestrian streets in hot and humid regions of Chengdu, China. They concluded that the number of pedestrians decreased as thermal indices increased in major alleys with multiple functions such as eating, drinking, resting, and performance areas, whereas more pedestrians were recorded when thermal indices increased in south-north alleys.

However, few studies have dealt with pedestrians' behavior, particular their selecting sunny or shaded areas when standing at traffic signals. To overcome this lack of knowledge, we performed microclimate measurements and unobstructed pedestrian behavior observations to determine the effect of outdoor thermal environment on their behavior in the street of a humid subtropical region. This study provides beneficial information on heat-related safety in an urban context to urban planners, architects, and policy makers, and contributes to improve safety and attract visitors to cities.

2. Material and methods

The target area is located in the center of Nagoya, Japan (35°9′N, 136°54′E), which is Yabacho intersection, consisting of eight east-west traffic lanes and six north-south lanes as shown in Fig. 1. The elevated Nagoya Expressway Route 2 runs east to west over the intersection and casts shadows on a pavement, thereby providing sunlit and shaded areas for pedestrians. A traffic signal cycle from a red light to the next red light was 120 s during the investigation. Unobstructed observations were performed by recording pedestrians' behavior on the pavement with a digital video camera (HANDYCAM HDR-CX270V, SONY). Focusing on pedestrians toward the south stopping at the traffic signals, the personal characteristics including pedestrians' location (sunlit or shaded areas), gender, and items worn to prevent heat (parasols, hats, and others) were encoded from the video images afterward.

Nagoya is categorized as a humid and subtropical region and the average climatic data from 1981 to 2010 of the Japan Meteorological Agency indicate that the monthly mean air temperature is highest in August at 27.8 °C and lowest in January at 4.5 °C. Additionally, the monthly mean relative humidity ranged from 59 to 74%. Microclimatic measurements and unobstructed observations were performed 18 times in two periods, July to October in 2012 and May to August in 2013, and all measured dates were weekdays excluding the national holiday of May 3, 2013. Meteorological data observed in measured periods and corresponding weather are

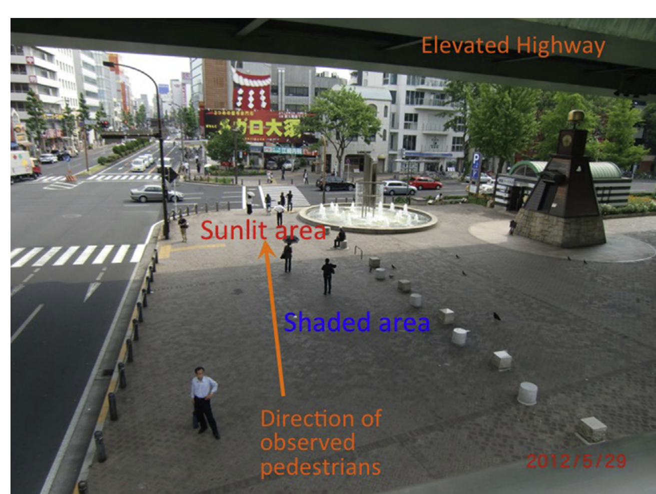

Fig. 1. The observation area (Yabacho intersection, Nagoya, Japan).