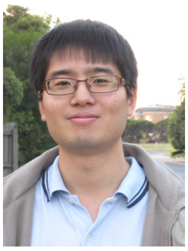

Visitor perception of thermal comfort in two contrasting public landscape gardens during extreme heat events

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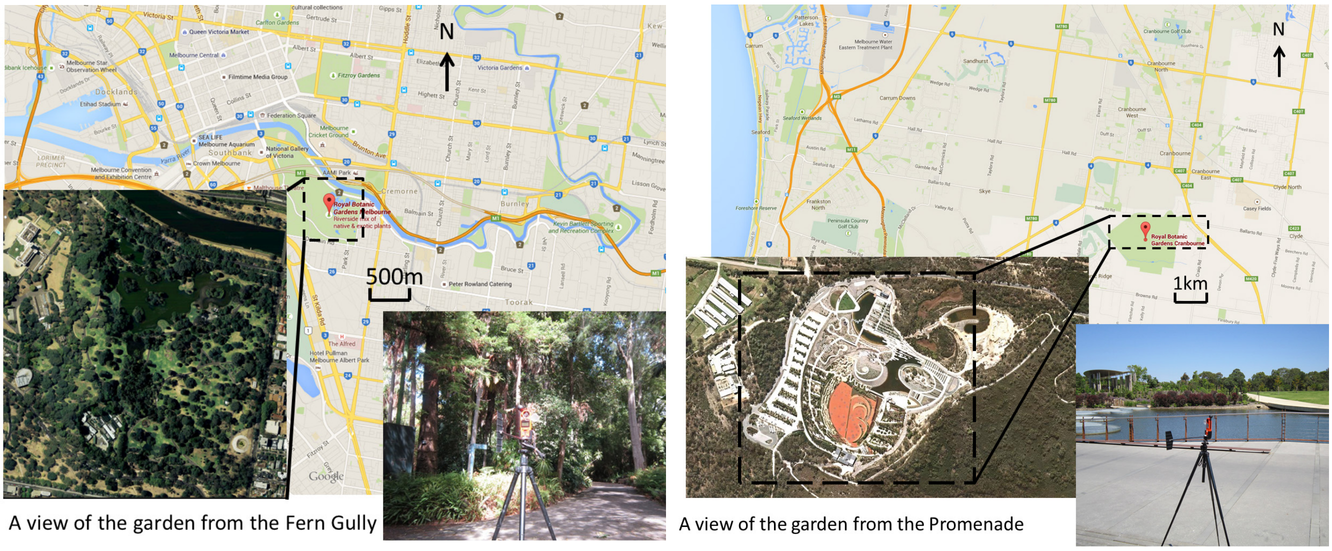
1. Introduction

Outdoor thermal comfort affects the number of visitors to tourist destinations. Previous outdoor thermal comfort field studies have mainly focused on analyzing local residents (Spagnolo and de Dear 2003; Lai et al. 2014; Oliveira and Andrade 2007; Ruiz and Correa 2015). Our study addresses this gap by comparing the thermal perceptions between local residents and overseas visitors to the Royal Botanic Garden (RBG) in Melbourne and Cranbourne. There have been also limited outdoor observational studies during heatwaves. Our study period coincided with two heatwaves during the Australian summer from January to February 2014. In addition, our study tests the hypothesis of thermal alliesthesia by comparing visitors' thermal perceptions before and after the 2014 heatwave in the RBG Cranbourne.

2. Methods

The RBG Melbourne is situated near the central business district of Melbourne, Australia. It is located at 37°50'S, 144°58'E, bordering the Yarra River and the Melbourne and Olympic Parks to the north. Opened in 1846, the RBG Melbourne covers 38 hectares and it includes a mixture of native and exotic vegetation. The RBG Cranbourne is located at 38°7'S, 145°16'E, outside the central business district of Cranbourne, 45 km southeast of Melbourne. Opened in 2006, the Australian Garden in the RBG Cranbourne covers 15 hectares and specializes in Australian native vegetation. The study area is shown in fig. 1.



A view of the garden from the Fern Gully

A view of the garden from the Promenade

Fig. 1 The study area: the RBG Melbourne (left) and the RBG Cranbourne (right).

At each of the gardens, two main weather stations (including one near the visitor entrance) measured air temperature and relative humidity using a Vaisala HMP155 Probe in a radiation shield. Wind speeds were measured by Met One 014A-L anemometers. Globe temperatures were measured using a 150-mm diameter black globe thermometer. Solar radiation values were recorded by an Apogee SP-212 Amplified Pyranometer. The data were block averaged into 10-minute intervals and recorded by a data logger (CR211X, Campbell Scientific). In addition, a network of Kestrel 4400 heat stress trackers (1.3 m above ground) was used to measure air temperature, globe temperature, relative humidity and wind speed at 1-minute intervals at the sites where visitor surveys were conducted. Later the data were averaged into 10-minute intervals. All logging equipment was positioned at approximately 2 m above ground.

Over 40 volunteers were recruited to conduct surveys with visitors over the age of 18 years about their thermal comfort. The thermal perception of visitors was identified using a seven-point scale called the actual sensation vote (ASV), ranging from hot (+3) to cold (-3), with 0 being neutral (Nikolopoulou et al. 2001). A total of 2198 and

1122 valid surveys were conducted at the RBG Melbourne and Cranbourne respectively. The survey was conducted from 10am to 3pm on Fridays and weekends between 8 and 19 January (RBG Cranbourne) and 5 and 16 February 2014 (RBG Melbourne). For the period 14-17 January 2014 and 7-9 February 2014, the survey ended at 12 pm because of heat-health concerns for the volunteers, with the temperatures reaching over 40 °C.

The Universal Thermal Climate Index (UTCI) was calculated based on the FORTRAN code provided on the UTCI website (http://www.utci.org/utci_doku.php). The FORTRAN code was converted to a VBA code which could be run in Microsoft Excel. This VBA program was provided on the ClimateCHIP website (http://climatechip.org/node/78). The UTCI was calculated with an assumption for a 35-year-old male, as well as a clothing insulation value of 0.9 and activity rate of 80 W. The input factors for calculating UTCI were air temperature, relative humidity, wind speed at 10 m above ground, as well as mean radiant temperature, which was derived from globe temperature.

The following formula was used to convert the wind speed (ws) to 10 m above ground (Bröde et al. 2012).

$ws_{10m} = ws_{xm} \times \mathrm{LOG}(10/0.01) / \mathrm{LOG}(x/0.01)$

where x is the height of the weather station.

The following formula was used to calculate the mean radiant temperature according to Ramsey and Bernard (2000).

$WF1 = 0.4*(|Tg - Ta|)^{0.25}$

$WF2 = 2.5*ws^{0.6}$

If WF1 > WF2, then WF = WF1, otherwise WF = WF2

$Tmrt = 100*\{[(Tg + 273)/100]^4 + WF*(Tg - Ta)\}^{0.25} - 273$

where Tg is the globe temperature, Ta is the air temperature, ws is the wind velocity (m/s), and Tmrt is the mean radiant temperature.

Statistical analysis was performed using SPSS 22. A one-way between-groups analysis of variance (ANOVA) was conducted to explore the impact of visitors' area of origin on their thermal perception in the RBG Melbourne. In addition, an independent-samples t-test was conducted to compare the thermal perceptions of Melbourne visitors to the RBG Cranbourne, both before and after the January 2014 heatwave in Melbourne.

3. Results and Discussion

3.1 Cultural differences in thermal perception

Our study reveals that visitors from different origins had different thermal perceptions in the RBG Melbourne. Fig.2 shows the visitor's mean ASV across different UTCI ranges according to various areas of origin. Chinese and European tourists were selected to compare with local Australian visitors. In general, as UTCI increased, the mean ASV increased accordingly. Visitors' thermal sensation changed from 'slightly warm to warm' when UTCI was between 21.7 and 37.7 °C, to 'warm to hot' between 37.71 and 49 °C (UTCI). When UTCI was from 21.7 to 37.7 °C, the mean ASV of Chinese visitors (0.77 ± 1.17, n = 131) was significantly lower than that of Australian visitors (1.18 ± 1.04, n = 999), North American visitors (1.28 ± 0.97, n = 80) and European visitors (1.47 ± 0.95, n = 323), as determined by one-way ANOVA (F (4, 1599) = 12.36, $p < 0.001$). However, when UTCI exceeded 37.7 °C, the mean ASV of Chinese visitors (2.64 ± 0.792, n = 47) was significantly higher than that of Australian visitors (1.92 ± 1.02, n = 266), as shown by one-way ANOVA (F (4, 442) = 7.07, $p < 0.001$). The mean ASV of Chinese visitors did not differ significantly from either European or North American visitors.

Fig. 3 shows that Chinese visitors generally wore more clothing than other visitors, as indicated by higher mean clothing insulation value (clo). While Chinese visitors wore more clothes, it is interesting to note that they only felt hotter than other visitors once UTCI exceeded 37.7 °C. In particular, the mean clo value for Chinese visitors (0.42 ± 0.13 clo, n = 47) was significantly higher than that of European visitors (0.33 ± 0.10 clo, n = 103) and North American visitors (0.30 ± 0.75 clo, n = 10) visitors, as determined by one-way ANOVA (F (4, 442) = 7.60, $p < 0.001$).

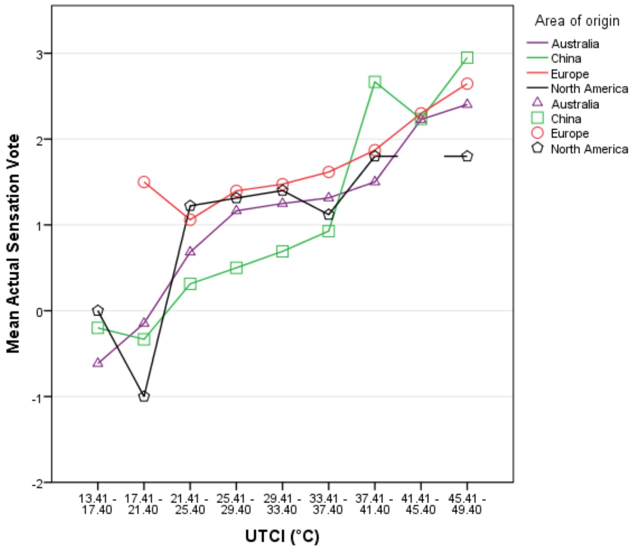


Fig. 2 Visitors' thermal perception from selected area of origin in the RBG Melbourne.

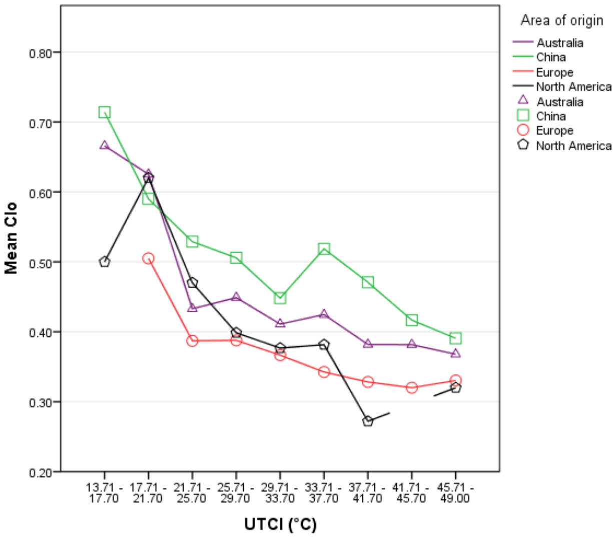


Fig. 3 Clothing insulation (clo) of visitors from different origins for each UTCI range in the RBG Melbourne.

When UTCI was between 21.7 and 37.7 °C, the mean ASV of European, North American and Australian visitors was significantly higher than that of Chinese visitors. This finding is in agreement with a Melbourne study conducted by Kenawy and Elkadi (2013), which stated that people from America, NW Europe and Australia had a higher mean ASV than Asians in summer. It is likely that Europeans, North Americans and Australians have greater body and muscle mass, which lead to higher metabolism (de Boer et al. 1988) and subsequently higher ASV. However, 37.7 °C (UTCI) appears to be a threshold temperature in which Chinese visitors started to feel much hotter. Chinese visitors had a consistent mean clo between 0.4 and 0.5 when UTCI was from 25.7 to 49 °C. Once UTCI passed this threshold (37.7 °C), it is possible that Chinese visitors' relatively high clo values had a greater influence on their mean ASV than their relatively low metabolism rate. This factor could explain why Chinese visitors perceived the environment to be hotter than other visitors in higher UTCI values.

3.2 Changes in thermal perception after a heatwave

Our study indicates that the thermal perceptions of Melbourne visitors to the RBG Cranbourne changed after the heatwave in January 2014. For the Melbourne visitors, overall there were statistically significant differences in the mean ASV between the visitors before the heatwave (group 1) (0.73 ± 1.02, n = 342) and after the heatwave (group 2) (0.51 ± 0.99, n = 297), t (637) = 2.796, p = 0.005 (fig. 4). The magnitude of the differences in the means (mean difference = 0.23, 95% *CI*: 0.07 to 0.38) was small (eta squared = 0.012). In particular, the mean ASV of group 1 was significantly higher that of group 2 at air temperature between 19 and 22.9 °C. However, there were no statistically significant differences between the ASV of group 1 and 2 for the temperature ranges 18 – 18.9 °C and 23 – 24.9 °C, possibly due to small sample size.

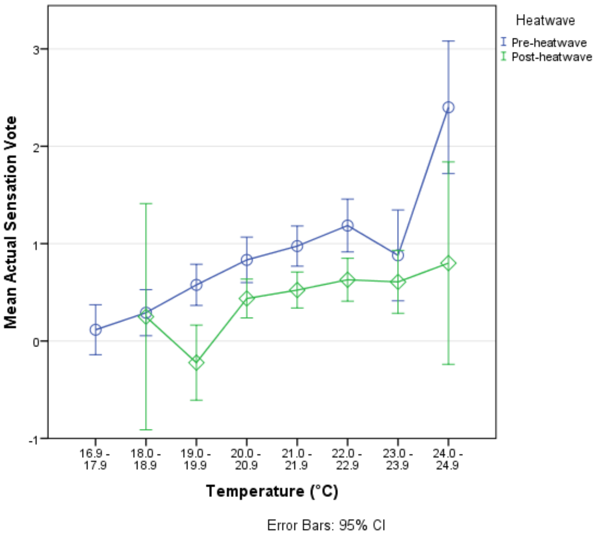


Fig. 4 Temperature and Melbourne visitors' thermal perceptions in the RBG Cranbourne before and after the January 2014 heatwave.

UTCI shows that the mean ASV also decreased after the heatwave (fig. 5), which is similar to the results from the temperature analysis. For the Melbourne visitors, overall there were statistically significant differences in the mean ASV between group 1 (0.95 ± 0.98, *n* = 96) and group 2 (0.53 ± 1.07, *n* = 161), *t* (255) = 3.10, *p* = 0.002 (fig. 5). The magnitude of the differences in the means (mean difference = 0.41, 95% CI: 0.15 to 0.68) was small (eta squared = 0.036). Most physiological adaptation to heat (heat acclimatization) requires at least a few days of exercising in a hot environment (Koppe et al. 2004, Schlader and Mündel 2012). It is plausible that many Melbourne visitors did not spend majority of their time outdoor during the 2014 heatwave. Therefore, psychological factors appear to be more important to explain the changes in visitors' thermal perceptions after the heatwave.

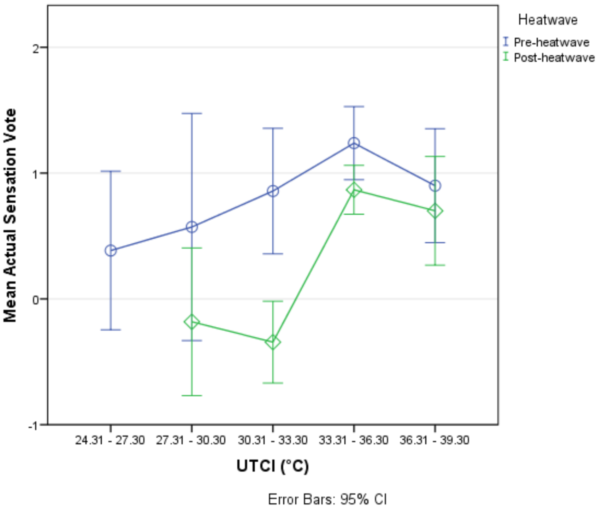


Fig. 5 UTCI and Melbourne visitors' thermal perception at the Promenade (RBG Cranbourne), before and after the January 2014 heatwave.

Alliesthesia has recently received revived interest in the thermal comfort research community. Alliesthesia refers to the phenomenon that 'a given stimulus can induce a pleasant or unpleasant sensation depending on the subject's internal state' (Cabanac 1971:1107). In the case of heat stress, any expectation of the prospect of a cooler environment could induce thermal comfort (Becker et al. 2003, de Dear 2011). This phenomenon is known as thermal alliesthesia. Thermal alliesthesia seems to explain the changes in people's thermal perception within the same day (Becker et al. 2003) and across different seasons (Nikolopoulou and Lykoudi 2006). However, there has been limited research on whether thermal alliesthesia occurs on a daily time scale, specifically its inter-daily variability. It has been difficult for researchers to investigate the impact of alliesthesia on outdoor human thermal perception because of the transient nature of outdoor environments. As neighboring days of substantial temperature differences are unusual, it is even more challenging to investigate the inter-daily variability of this phenomenon. Our study demonstrates that there is an inter-daily variability in people's thermal perceptions. After the heatwave, the visitors reported a lower mean ASV even within the same temperature and UTCI range. The January 2014 heatwave appears to desensitize local Melbourne visitors to heat.

4. Conclusion

Our research has examined the roles of culture and thermal alliesthesia on visitors' thermal perception in the RBG Melbourne and Cranbourne. By analyzing the weather and survey data, it has shown that Chinese visitors' perception of thermal comfort differed from European and Australian visitors in the RBG Melbourne. Moreover, we have demonstrated that visitors' thermal perception changed after the heatwave in the RBG Cranbourne. This finding suggests that thermal alliesthesia can provide a useful framework that explains the inter-daily variability of thermal perceptions. However, due to the scope of this research we have been unable to examine visitors' thermal perception in subsequent summers. As stated initially, the issue of visitors' thermal comfort remains of great importance to the sustainability of tourist destinations such as botanic gardens.

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