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Pinnae Movement of Captive Asian Elephants Weakly Affected by Environmental Factors

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Abstract. Ear flapping is believed to be a behavioural mechanism to reduce heat in elephants. We examined the effects of temperature, humidity and body size on pinnae movement of elephants. Percentage of elephants flapping ears and individual ear flapping rate was determined every 10 minutes. Both factors were positively correlated with the ambient temperature and negatively correlated with relative humidity. Larger elephants flapped ears more frequently than smaller elephants.

Introduction

Heat dissipation is a concern for large terrestrial mammals living in tropical environments. Elephants have sparse body hair and no sweat glands, except for inter-digital sweat glands in Asian elephants (*Elephas maximus*). Thus, evaporative heat loss in elephants occurs by trans-epidermal water loss (Wright & Luck 1984; Lamps *et al.* 2001). The wrinkled skin of an elephant holds moisture and facilitates its movement on the body surface, which creates an evaporative cooling effect (Lillywhilte & Stein 1987).

Elephants use several behavioural mechanisms to reduce their heat load. They cover themselves with soil by dusting or wallowing, thereby absorbing less and reflecting more radiation, or dip in water to lose heat through conduction (Hiley 1975). It is believed that a large ear surface area and ear fanning is important for thermoregulation in elephants, under warm environmental conditions (Wright 1984). The constant motion of the pinnae expose the medial sides and corresponding vessels to air currents and increase heat loss from ears as well as from the fanned body surface (Wright 1984).

Infrared thermography has demonstrated that in elephants, pinnae act as thermal windows

(Weissenbock *et al.* 2010). Their ears are equipped with specialized motor control (Phillips & Heath 1992). Depending on ambient temperature, thermal windows regulate heat exchange via vasoconstriction and vasodilatation (Sumbera *et al.* 2007; Weissenbock *et al.* 2010). Temperature distribution across the ear changes with ambient temperature and heat loss is amplified by the movement of the pinnae (Phillips & Heath 1992).

The African elephant (*Loxodonta africana*), is the largest land mammal and has the largest thermoregulatory organ of any animal; the pinna or external ear, which it uses as a radiator-convector (Phillips & Heath 1992). The combined surface area of both sides of the ears of an African elephant is about 20% of its total surface area and the calculated heat loss from the ears is a significant proportion of the total heat lost (Buss & Estes 1971; Wright 1984). The pinnae of Asian elephants are approximately one third the size of African elephants (Carrington 1959). Therefore theoretically, heat loss from the pinnae in Asian elephants is one-third that of African elephants (Phillips & Heath 1992).

Weissenbock *et al.* (2010) reported the existence of thermal windows on the whole body surface indicating that the elephants' skin has regional concentrations of vascular networks. Although

91% of the heat produced by an elephant can be dissipated via its pinnae (Phillips & Heath, 1992), heat transfer across the ears represented less than 8% of the total heat loss (Williams 1990). Myhrvold *et al.* (2012) revealed that elephant hair significantly enhances thermoregulation ability by over 5% under all scenarios considered and by up to 23% at low wind speeds where thermoregulation needs are greatest. However, Benedict (1936) claimed that a large animal such as the elephant has no need for special heat regulating mechanisms in its ears and if it did possess one, it would be a singular provision in nature. Hiley (1975) found that the temperature of the ear skin, especially the back of the ear where the prominent blood vessels are located, was cooler than that of the body during midday. Together with the fact that water loss from the ears was not significantly greater than that from the rest of the body, Hiley (1975) concluded that elephants do not use ears for cooling.

A number of studies have demonstrated the significance of ear flapping in African elephants (Buss & Estes 1971; Wright 1984; Phillips & Heath 1992). However few studies have been carried out on Asian elephants. The objectives of our study were to examine the effects of temperature, humidity and body size on ear flapping rate and the variation in ear flapping with time of day in captive Asian elephants.

Methods

The study was carried out at the Pinnawala Elephant Orphanage (PEO), the Millennium Elephant Foundation (MEF) and the Elephant Safari (ES) in Sri Lanka.

PEO is located in a 10 ha coconut estate close to the Maha Oya River at Rambukkana, 80 km northeast of Colombo. It consists of a free ranging area for daytime activities and sheds to house elephants. During the study a total of 86 captive elephants of varying ages were housed at the PEO.

MEF and ES are located close to the PEO and keep elephants for providing tourist rides. Elephants are tethered under a tree canopy except

when giving rides or bathing. At night, elephants are tethered in a different location under a tree.

Observations for the study were based on 8 elephants at the PEO, 2 elephants at MEF and 2 elephants at ES (Table 1). Data were collected from February to September 2010.

Elephants at the PEO were allowed free movement during daytime. At night, adults were tethered in sheds, while calves were unfettered. The elephants were released at 8:00 h to move to an open area with little shade. Food was placed in the open yard and consisted mainly of foliage of coconut (*Cocos nucifera*), kithul (*Caryota urens*), jak (*Artocarpus heterophyllus*) bread-fruit (*Artocarpus nobilis*), banyan (*Ficus bengalensis*) and bo (*Ficus religiosa*). Elephants were moved across the main road and down a path lined by trade stalls to the Maha Oya at 10:00 h. At the river, elephants were allowed to drink, bath and play. At noon, the herd returned to the yard. They remained there till taken to the river once again at 14:00 h. They were washed by the mahouts while in the river and taken back to the orphanage at 16:00 h and tethered in the sheds.

At MEF and ES, elephants were untied at about 8:00 h and bathed in a stream, which ran through the facilities. After that they were tethered in an exhibit area. The elephants were fed mainly with coconut, kithul and jack branches and food was provided intermittently throughout the day. The elephants were bathed several times a day in the

Table 1. Composition of elephants in the study.

| Site | Elephant | Sex | Age |
|------|----------|-----|----------|
| PEO | Kanaka | M | 6 months |
| | Dinuda | F | 6 months |
| | Wasamba | M | 10 years |
| | Surangi | F | 12 years |
| | Sanka | M | 20 years |
| | Saama | F | 22 years |
| | Mathali | F | 39 years |
| | Anusha | F | 64 years |
| MEF | Pooja | F | 23 years |
| | Luxmi | F | 40 years |
| SF | Manika | F | 38 years |
| | Kumari | F | 50 years |

stream, with or without the presence of tourists. Elephants were taken back to their night quarters at about 17:00 h.

Each elephant was observed twice a month from 9:00 to 16:00 h and earflaps were counted for 3 minutes at every 10-minute interval for the entire period. The ear-flapping rate (EFR) was calculated as the average number of earflaps per minute over the 3-minute period. An 'earflip' was defined as the partial or full movement of pinnae, once forward and once back. Ambient temperature and relative humidity data were obtained using a digital weather station (Sensor Tech®, USA). No EFR counts were obtained while elephants were moving between the yard and the river at PEO or during tourist rides at MEF and ES.

Scan sampling (Altmann 1974) of the PEO herd (n = 66) was performed to count the number of elephants flapping ears at 10 minute intervals from 9:00 to 16:00 h twice a month. Daytime variations were determined by plotting the average number of elephants flapping ears at a particular time of the day with temperature and relative humidity.

Eight elephants at PEO were observed to examine the effect of body size on EFR. Data were collected from elephants representing three body sizes; juveniles (n = 2), sub-adults (n = 2) and adults (n = 4). Earflaps were counted when the elephants were in the herd.

All data analyses were performed with MINITAB 15 (Minitab Inc. PA, USA). Effect of

temperature and humidity on EFR was analyzed using Pearson product moment correlation. Effect of body size on ear flapping rate was evaluated using ANOVA followed by the Tukey's multiple range test. All statistical analyses were carried out with an a level of $P < 0.05$ as the significant level.

Results

Ear-flapping rate (EFR)

The mean EFR of studied elephants was 8.19 ± 0.19 and EFRs of individual elephants ranged from 1.97 ± 0.18 to 15.79 ± 0.62 during the study period. EFR was positively correlated with the ambient temperature ($r = 0.30$, $P < 0.05$, $df = 1810$, Fig. 1) and negatively correlated with relative humidity ($r = -0.36$, $P < 0.05$, $df = 1810$, Fig. 2).

Percentage of elephants flapping ears (PEFE)

A positive correlation was observed between PEFE and ambient temperature ($r = 0.18$, $P < 0.05$, $df = 251$, Fig. 3) while a negative correlation was observed with relative humidity ($r = -0.33$, $P < 0.05$, $df = 251$, Fig. 4). Two peaks in PEFE were observed at 10:20 h and 14:20 h (Figs. 5 & 6). PEFE decreased from 12:00 to 14:00 h when ambient temperature reached a peak and the mean relative humidity was 69 - 70%. PEFE was 6 - 9% during the hottest part of the day, when many elephants were observed to stand still with their ears spread. PEFE was less than 10% before 10:00 h and after 15:30 h.

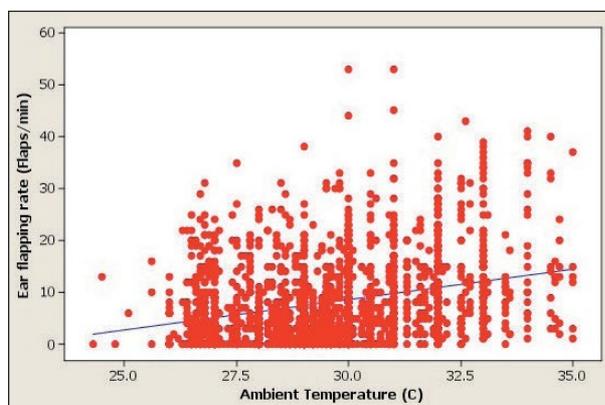


Figure 1. The effect of ambient temperature on individual EFR.

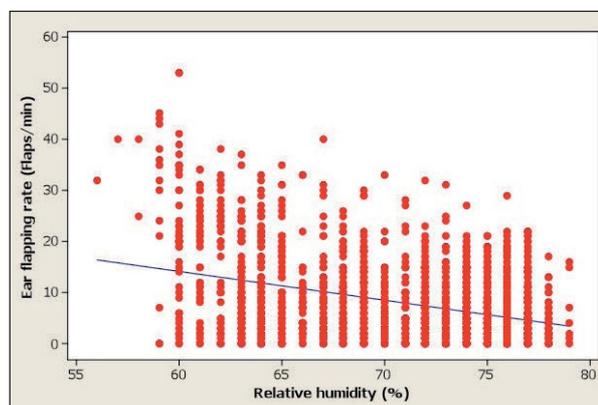


Figure 2. The effect of relative humidity on individual EFR.

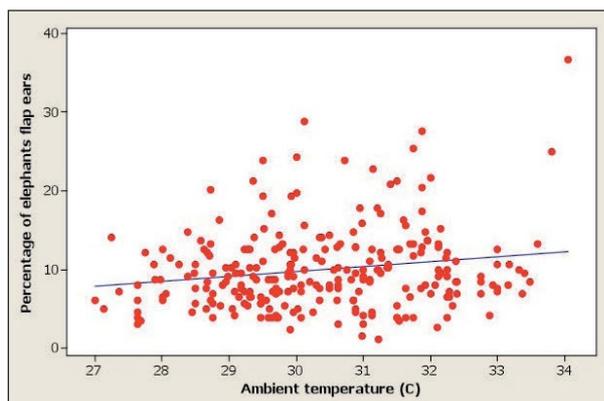


Figure 3. The effect of ambient temperature on PEFE.

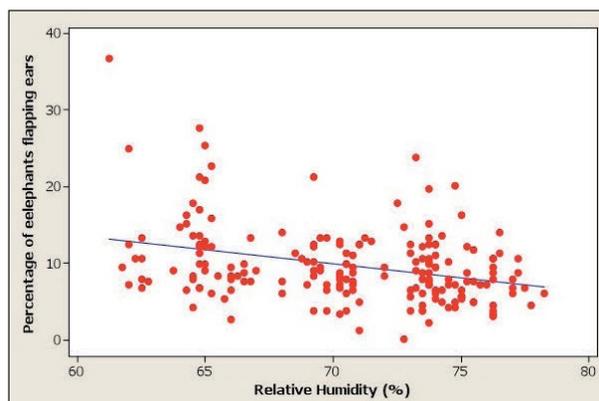


Figure 4. The effect of relative humidity on PEFE.

The highest EFR and the PEFE were recorded at 30 - 31°C and a relative humidity of 59 - 61%. Temperature ranged from 24 - 35°C while relative humidity ranged from 56 - 76% during the study period.

Effect of body size

EFR was significantly different among large, medium and small elephants ($P^{a,b,c} < 0.05$, $F = 164.78$, $df = 779$). EFR was highest (10.7 ± 0.5^a) in large elephants while it was lowest (1.6 ± 0.1^b) in small elephants. EFR of medium sized elephants was 5.4 ± 0.3^c .

Other observations

Some elephants had unique patterns of ear flapping. Elephant MEF-1 flapped 4 times followed by an interval, whereas it was 2 - 3 flaps in elephants MEF-2 and MEF-3. On the

other hand, elephant PEO-1 flapped 10 - 15 times continuously at a particular bout.

EFR of some elephants increased with approach of their preferred social partners. Elephant PEO-1 flapped ears more when elephant PEO-2 moved towards her. Elephant ES-1 flapped her ears considerably faster when she saw her mahout in the morning. She displayed this behaviour every morning, accompanied by voiding of urine. Ear spreading followed by rapid flapping was observed in elephants at the PEO when they were excited or alert. Higher EFR were also observed after a safari ride in ES and MEF elephants and before and after a fight or arriving at the river in PEO elephants. Ear flapping gradually decreased with most of the elephants moving to shade a few minutes after they reached the river. However, there was no increase in PEFE after they walked back to the yard at 12:20 h, in which they exert more, as they have to walk uphill.

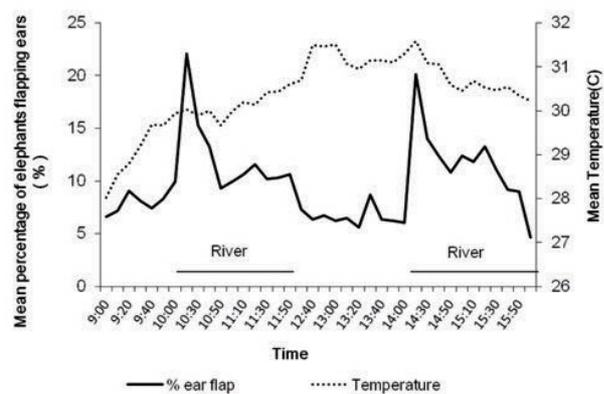


Figure 5. Variation in PEFE with ambient temperature. Elephants are in the river twice a day from 10:00 - 12:00 h and 14:00 - 16:00 h.

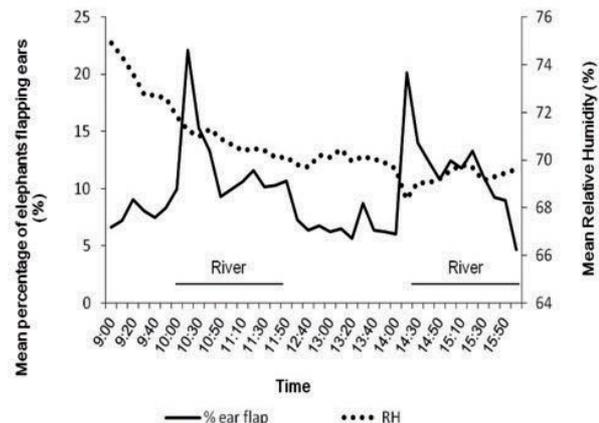


Figure 6. Variation in PEFE with relative humidity.

Discussion

Our results indicate that EFR and the PEFE were weakly associated with ambient temperature and relative humidity and strongly influenced by body size. PEFE decreased when the temperature was highest. Our findings are in contrast to some other studies in which strong relationships of EFR with ambient temperature were observed in wild African elephants (Buss & Estes 1971; $r = 0.85$) and captive Asian elephants (Vanitha & Baskaran 2010; $r = 0.59$).

The highest EFR was not associated with the highest temperature. Similarly, Buss & Estes (1971) observed that the three highest EFRs in their study occurred between 30 - 31°C whereas the highest temperature recorded was 34.4°C. Non-correspondence of highest temperature with highest EFR suggests that there may be an optimum temperature for efficient cooling by ear flapping of elephants. Consequently EFR and environmental factors may have a complex rather than a simple linear relationship.

A fall in the ear flapping percentage of the group was observed during the hottest periods of the day. Although wind velocity was not measured in our study, elephants standing still with the ears spread rather than flapping, during this part of the day suggests that they could be taking the advantage of wind to facilitate cooling. After the second peak at 14:20 h, percentage occurrence of ear flapping decreased as the temperature declined. A possible reason could be that elephants dissipate heat through non-evaporative heat loss at low temperatures and evaporative heat loss at high temperatures (>31°C). Kuhme (1963) also reported that captive African elephants hardly flapped their ears in the morning when it was cold. Benedict (1936) estimated that 20% of the metabolic heat was lost by evaporation divided equally between respiratory tract and body surface under experimental conditions.

Even though elephants walk around the yard at a normal pace, they moved faster when they walk down to river. The increase in EFR after arriving at the river is probably due to excitement or muscular work, similar to safari elephants that

had raised EFRs after a safari ride. Similarly, Benedict (1936) reported that ear temperature and ear flapping rate increased after a muscular work. However, it was not the case for the elephants at the PEO as there was no such increase in PEFE after walking back to the yard probably because they were well cooled off in the river.

Moving to a shady area was seen in PEO elephants when they were in the river, which may enhance heat dissipation by increasing the temperature gradient between the elephant's body and the environment. Besides, conduction through legs and drinking of water may assist them to lower the core body temperature when they are in the water. Similarly, Buss & Estes (1971) observed decreased rates of ear flapping when elephants were in the shade.

We observed that larger elephants flapped ears more frequently than smaller elephants. Larger size results in a smaller surface to volume ratio and hence a relatively smaller surface area for heat transfer (Williams 1990). Therefore, larger animals have a greater potential for heat retention and larger elephants can be expected to exhibit higher EFR to increase non-evaporative heat loss. Smaller elephants can be expected to lose more heat through evaporative heat loss and require less convective heat loss. Higher evaporative heat loss in young elephants compared to adults has been reported previously (Kumudinie *et al.* 2012; Kulasooriya *et al.* 2014).

Our observations also suggest that elephants may vary in pattern and timing of ear flapping reflecting individuality. Kuhme (1963) reported that the presence of a wild African female made a bull elephant increase his flapping rate and that the position of the ear is a signal to social partners. He further reported that superiority of the a male was demonstrated by flapping ears strongly. Likewise, Benedict (1936) stated that, changes in ear temperature and flapping were caused by nervousness, fright or apprehension. Our observations are compatible with EFR being influenced by communication, individual preferences, social environment and emotional state, in addition to environmental factors.

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