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Research article

Heart rate patterns of captive Asian elephant (*Elephas maximus*) in their natural habitat at Wild Elephant Valley, Xishuangbanna of China

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ABSTRACT

There are few studies on the changes of heart rate of the Asian elephant (*Elephas maximus*), one of the largest tropical terrestrial mammals, with its self-factors and external environment. By measuring the heart rate of 35 Asian elephants, ranging in age from 4 months to 52 years, using a non-invasive electrocardiogram sensor in their natural habitat at Wild Elephant Valley, Xishuangbanna of China, we found factors that significantly influenced the HR were season, phase of the day, age, body weight, and the interaction between some of the above factors. We also observed that Asian elephants had lower resting heart rate in the morning of hot season than the cold and mild season, and the differences were significant, but the heart rate increased to similar levels in the afternoon regardless of the season. HR also decreased with age in all seasons and phases of the day. However, there was no significant effect of sex. This study reveals the adaptability of Asian elephant to tropical environment, and provides a basic reference for heart rate of Asian elephant under various natural conditions.

1. Introduction

The Asian elephant (*Elephas maximus*) is one of the largest terrestrial mammals that distribute in tropical and subtropical zone. Thus, it is an ideal model to research how large thermostatic animals adapt to tropical environment. Xishuangbanna (Yunnan, China) is in the natural distribution area of Asian elephants, where the physiological research of elephants can reflect their natural adaptation mechanism to the environment. However, its geographical position is close to the Tropic of Cancer where the temperature variation range is relatively large. The annual average temperature of Xishuangbanna is 18.43 °C, the temperature on warm days can be higher than 30 °C, and the temperature on cold nights can be lower than 6 °C [1]. Therefore, it could be more obvious in Xishuangbanna that how Asian elephants adjust their physiological characteristics to adapt to weather changes.

Heart rate (HR) measurement is an important method of thermophysiology research. Although affected by many factors and has

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certain errors, HR can reflect the real-time changes of metabolic intensity. Studies on some thermostatic animals showed that HR was positively correlated with metabolic heat production, and there was a linear relationship [2,3]. Generally, larger mammals have slower HR and longer life span [4,5]. However, more researches are needed to verify whether body weight affects HR in the same species. As one of the largest land animals, the HR of Asian elephants has attracted much attention, but it is difficult to hear the heart sounds of Asian elephants with stethoscope [6]. A feasible method of HR measurement for Asian elephants is to use electrocardiogram system. Average HR of 37 adult female Asian elephants when they stood was 30 bpm, ranging from 22 to 39 bpm, and after lying down, the HR increased by 8–10 bpm [6]. The HR of healthy newborn Asian elephants were 93 ± 25 bpm (range: 70–140 bpm), which were much higher than those of adult elephants [7]. The weight of the young elephant is much smaller than that of the adult Asian elephant. However, the existing research has not specifically studied the relationship between the HR and age or body weight of the Asian elephant. Study on humans have found that gender and temperature may also be factors affecting HR [8]. Therefore, this study intends to explore the effects of internal and external factors on HR of Asian elephants.

2. Materials and methods

2.1. Study area and animals

This study was conducted at Wild Elephant Valley scenic area in Xishuangbanna, Yunnan, China (100°51′ E, 22°10’ N, altitude of 795 m). 35 captive Asian elephants, including 21 females and 14 males, aged 4 months to 52 years old, weighed 200–3280 kg, were used in HR measurement (Table 1). All the elephants are well habituated to get in touch with humans.

2.2. Data collection

HR of elephants were recorded in the morning (7 a.m.–9 a.m.) and afternoon (4 p.m.–6 p.m.) at 3 seasons (Table 2). The mild season data was recorded in March. The cold season data was recorded in December to January. The hot season data for the morning was recorded in August and that for the Afternoon was recorded in May, as the morning temperature in August was higher than that in May, but it was reversed in the afternoon.

HR of Asian elephants were measured using Polar H10 Heart Rate Sensor (Polar Electro Inc.). Two electrode patches (6 cm × 9 cm) with viscous conductive silica gel were connected to the sensor with 1 m long wires. When the two electrode parches were attached to both side of the elephant’s chest, the real-time HR would be recorded by the sensor and uploaded to the network server at the same time. When the readings appeared, waited for 1 min to make sure the readings were stable. Then, recorded the HR for another 1 min, and took the minimum value (except failure in record when the reading was 0) as measurement result for further analysis. During the measurement, the elephants stood still under the control of mahouts. Therefore, the measured HR. was considered as resting HR.

2.3. Statistical analyses

Generalized estimating equations (GEE) was used in IBM SPSS Statistics 27 to test the influence of sex, age, body weight, season and phase of the day on HR of the Asian elephants. Because air temperature and humidity at a specific phase of the day are different across seasons, interaction between seasons and phase of the day (season*phase of the day) were included. As the body weight of an elephant grows with age, and there is difference between average body weights of male and female elephant, interaction between ages and sexes and body weights (age*body weight and sex*body weight) were also included.

Table 1
Information of Asian elephants for heart rate measurement.

Individual	Sex	Age[a] (year)	Body weight (kg)	Individual	Sex	Age (year)	Body weight (kg)
1	Female	4 months	200	19	Female	25	2315
2	Female	1	485	20	Female	26	2220
3	Male	2	500	21	Male	27	2700
4	Female	4	1000	22	Male	29	2290
5	Female	4	960	23	Male	30	2900
6	Male	5	890	24	Male	31	3050
7	Male	8	1550	25	Female	31	2700
8	Female	9	1550	26	Female	31	2830
9	Female	10	1530	27	Female	32	2270
10	Female	16	1800	28	Male	33	2900
11	Female	17	1760	29	Female	33	2155
12	Female	18	2250	30	Male	36	3050
13	Female	18	1900	31	Female	36	2105
14	Male	20	2645	32	Female	36	2300
15	Male	20	3280	33	Female	39	2405
16	Male	21	3060	34	Female	41	2550
17	Male	24	3100	35	Female	52	2530
18	Male	24	2575				

[a] Determined at the first time of heart rate measurement.

Table 2
Air temperature and humidity while the heart rate recording.

Season	Phase of the day	Air temperature (°C)	Relative humidity (%)
Cold	Morning	5.2–10.2	79.5–93.6
Cold	Afternoon	14.5–22.9	39.6–68.5
Mild	Morning	14.3–19.8	79.6–95.6
Mild	Afternoon	29.7–33.5	26.3–44.5
Hot	Morning	22.2–26.3	78.8–94.3
Hot	Afternoon	37.0–43.2	17.7–33.6

As repeated measures, individuals were selected as the subject variables, while seasons and the phase of the day were selected as the within-subject variables. Poisson loglinear was chosen as the type of the model. HR were selected as the dependent variable for response. For predictors, seasons and the phase of the day were factors, while sexes, ages and body weighs were covariates. Working correlation matrix structures were ranked by quasi-likelihood under the independence model criterion (QIC), and the model with the lowest QIC was the most appropriate, which was 5-dependent in the model with all predictors above plus season*phase of the day. Under 5-dependent working correlation matrix structure, each model included one or several predictors, and the model with the lowest corrected quasi-likelihood under the independence model criterion (QICC) was the most appropriate (Table 3).

3. Results

The average age ±SD was 22.54 ± 12.86 years, and the average body weight ±SD was 2123 ± 808.24 kg. Under the most appropriate, all predictors except sexes had significant effect on HR of Asian elephants using type III analysis (Table 4).

For estimated marginal means, there was no significant difference between HR in the cold and mild season, while HR in the hot season were 4.72 ± 1.39 bpm (Mean value difference ± SE) lower ($P < 0.001$) than the cold season, and 1.61 ± 1.58 bpm lower ($P = 0.005$) than the mild season. HR in the afternoon were 6.40 ± 1.12 bpm higher than the morning ($P < 0.001$). When considering the interaction between seasons and phase of the day, the mean HR of Asian elephants n each specific category ranged from 26.96–38.22 bpm (Table 5). In paired comparison, significant differences of HR exist between cold morning and hot morning (the former was 8.08 ± 1.91 higher than the latter, P < 0.001), cold afternoon and mild morning (the former was 6.07 ± 1.88 higher than the latter, P = 0.001), cold afternoon and hot morning (the former was 10.13 ± 1.83 higher than the latter, P < 0.001), mild morning and mild afternoon (the former was 7.19 ± 1.51 lower than the latter, P < 0.001), mild morning and hot morning (the former was 4.06 ± 1.27 higher than the latter, P = 0.001), mild morning and hot afternoon (the former was 5.39 ± 1.99 lower than the latter, P = 0.001), mild afternoon and hot morning (the former was 11.25 ± 1.50 higher than the latter, P < 0.001), hot morning and hot afternoon (the former was 9.46 ± 1.69 lower than the latter, P < 0.001).

Parameter estimates showed that ages had significant negative effect on HR of Asian elephants (b = −0.0.027, SE = 0.001, 95 % Wald confidence interval from −0.041 to 0.014, $\chi^2 = 16.765$, P < 0.001). In the scatter plot of ages and HR, HR showed decreasing trends with age in all combination of seasons and phase of the day (Fig. 1). From calf to adult, the mean HR of each age group decreased sequentially (Table 6). The effect of body weights on HR was also significant, but the partial regression coefficient was closed to 0 (b < 0.001, $\chi^2 = 12.498$, P < 0.001).

Table 3
Goodness of fit for models based on different predictors explaining heart rate of Asian elephants.

Model	ΔQICC[a]
Intercept only	236.184
Season	218.345
Phase of the day	172.396
Season + phase of the day	154.814
Season + phase of the day + season[a]phase of the day	138.199
Season + phase of the day + season[a]phase of the day + sex	136.454
Season + phase of the day + season[a]phase of the day + sex + age	48.892
Season + phase of the day + season[a]phase of the day + age + body weight	29.802
Season + phase of the day + season[a]phase of the day + sex + body weight	31.242
Season + phase of the day + season[a]phase of the day + sex + age + body weight	31.365
Season + phase of the day + season[a]phase of the day + sex + age + body weight + sex[a]body weight	21.933
Season + phase of the day + season[a]phase of the day + sex + age + body weight + age[a]body weight	**0**
Season + phase of the day + season[a]phase of the day + sex + age + body weight + sex[a]body weight + age[a]body weight	1.504
Season + phase of the day + season[a]phase of the day + age + body weight + age[a]body weight	0.696
Sex + age + body weight + age[a]body weight	98.355
Season + phase of the day + sex + age + body weight + age[a]body weight	17.676

The scatter plot of the heart rate changing with age was drawn by Microsoft Excel. The Asian elephants were divided into four age groups [9]. Arithmetic mean and standard error of all HR samples were calculated for each age groups, ignoring other factors.

[a] Corrected quasi-likelihood under the independence model criterion (QICC) of the model minus QICC of the model with the lowest QICC.

Table 4
Model effect test of predictors on heart rate of Asian elephants.

Predictor	Wald χ^2	*df*	*P*-value
Intercept	7340.335	1	<0.001
Season	17.73	2	<0.001
Time	34.894	1	<0.001
Season * phase	11.69	2	0.003
Sex	1.82	1	0.177
Age	16.765	1	<0.001
Body weight	12.498	1	<0.001
Age * body weight	12.472	1	<0.001

Table 5
Estimated heart rate (bpm) of Asian elephants in different seasons and phases of the day.

Seasons	Phase of the day	Mean	SE	95 % Wald Confidence Interval	
				Lower	Upper
Cold	Morning	35.04	2.36	30.70	39.98
	Afternoon	37.10	2.07	33.25	41.39
Mild	Morning	31.03	1.59	28.07	34.30
	Afternoon	38.22	1.78	34.89	41.86
Hot	Morning	26.96	1.06	24.96	29.12
	Afternoon	36.42	1.89	32.90	40.31

Covariates appearing in the model are fixed at the following values: 40 % males and 60 % females; age = 22.54 years; body weight = 2123.00 kg.

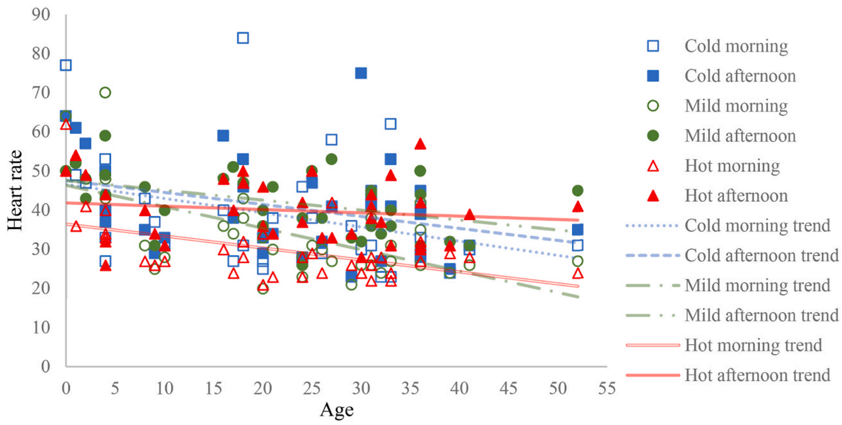

Fig. 1. Heart rate of Asian elephants of different ages in different combination of seasons and phase of the day. Trend lines are linear.

Table 6
Heart rate of Asian elephant in different age groups.

Age group	Age range (year)	N	Body weight (kg, mean ± SE)	Heart rate (bpm, mean ± SE)
Calf	under 1 year	1	200	61.16 ± 4.15
Juvenile	1 to 5 (excluding) years	4	736.25 ± 141.00	45.92 ± 2.26
Sub-adult	5 to 15 (excluding) years	4	1380.00 ± 163.40	35.13 ± 1.40
Adult	15 years and above	26	2524.62 ± 82.31	35.56 ± 0.83

4. Discussion

The heart rate measurement technology based on electrocardiogram used in this study has been applied in wildlife for about a hundred years [6]. The Asian elephants in this study were well trained, so it was easy to get them to work together and stick the electrodes on both sides of the chest cavity with the help of mahouts. However, when applied to Asian elephant, the sensor was not as sensitive as those applied to human bodies. Generally, the real time measurement value could be read immediately when the sensor was attached to human bodies, but it might take several minutes to run successfully after attached to elephant bodies. Measurement readings interruption also occurred, though there was no observable interference. The sensitivity of sensors varies across different measured individuals. A 27-year-old male elephant was the most difficult to get the result, which usually took more than 3 min, despite its good cooperation in measurement. After the sensor was just connected, the measured value was generally high, and gradually decreased and tended to be stable within 1 min. It is uncertain whether this is caused by the stress of the Asian elephant, or by the inaccuracy of the sensor at the beginning of the connection. Thus, we took the minimum value after stabilization as the result. In some cases, it is found that even though the electrode had been removed from the Asian elephant, data was still upload to network server. This indicated that there might be a delay in data upload, so we extended the interval between two measurements to prevent data overlap.

HR will increase with dynamic exercise [10,11]. It was also found in this study that when the elephant was moving, the sensitivity of the sensor would be improved. This may be because during exercise, the heart beats more powerfully and electrocardiogram signals were also enhanced. However, we only use the HR measured when the elephant was standing still, as exercise might increase heart rate, and skeletal muscle activity could also generate electrical signals, which might interfere with the results [12]. During the measurement, mahouts gave instructions to the elephant frequently. This might put the Asian elephant under stress, which would affect the HR [13]. We also found in this study that when the mahout's voice was loud, the HR of the elephant might suddenly increase for 1 or 2 bpm. Implantable HR measuring devices has been applied in both small and large animals, which could record HR without disturbing animals while measurement, but the implantation process was invasive [14–16]. Swallowable biotelemetry devices have been applied in ruminants, as the unit would remain in the rumino-reticular tract [17]. It is possible to feed a small measuring device to an elephant, while it could be excreted through the gut soon [18,19]. Similar techniques can be applied in further elephant HR studies, which can also record HR in a longer time scale.

Research on the garden dormouse (*Eliomys quercus*) has shown that animals have lower HR at the optimal temperature, when they are in thermoneutral condition, and higher or lower temperatures can cause an increase in heart rate [20]. The thermoneutral zone for Asian elephants has not been reported in previous studies. According to the morning HR, the hot season was the optimal for Asian elephants than the cold and mild season. Therefore, we hypothesize that Asian elephants are closer to thermoneutral condition at this time. This seasonal rhythm is different from those of animals living in temperate zone, such as red deer (*Cervus elaphus*) and Alpine ibex (*Capra ibex*), who have higher HR in the hot season than in the cold season [21,22]. This may reflect the adaptability of Asian elephants to tropical climate. Although the air temperature relative humidity was also different in the afternoon among three seasons, there was no significant difference among the HR of Asian elephants. We speculate that the impact of circadian rhythm flattens out the impact of weather. It has been demonstrated that the phase of the day-night cycle affects human HR, and light increases resting HR [23]. In this study, the circadian activity rhythm of captive elephants was similar to humans, whose most activities were at daytime and which were restricted in enclosures at night. Besides, animals with different circadian activity rhythm have similar circadian rhythm of HR that HR at daytime are higher [21,24–26]. HR were only measured in two phases in a day in this study. Measuring the continuous changes in HR throughout the day are required in further research.

The effect of sexes was included in the most appropriate model of GEE, but was not significant. However, females have a higher HR than males in humans [8]. Ages had a significant negative effect on HR of Asian elephants, which was consistent with the study on humans [27]. It might be due to sample limitations that the effect of weight was not significant, as it was difficult to find enough individuals with the same age and different body weights. Nevertheless, there is also the study that does not support a correlation between HR and body weight within the same species [28].

5. Conclusion

This study, to a certain extent, shows the seasonal and daily rhythm of HR of Asian elephant of different ages in the natural habitat. Our data suggest that Asian elephants are more adapted to the hot season, showing lower HR during that time, and their HR increases during daylight hours. Younger Asian elephants have higher HR than the elders, and this is mainly determined by age rather than body weight based on our model analysis. It was also observed that the sensitivity of electrocardiogram sensors varied among individuals. These findings enrich the primary data of Asian elephant physiology, and provides a reference for monitoring the health of Asian elephants. The data of this study was taken from the selected time point. In further research, the influence of more factors on HR of Asian elephants needs to be explored to understand the adaptability of Asian elephants to diverse environment.

Declaration of ethical approval

This study was reviewed and approved by the Ethic and Animal Welfare Committee, College of Life Science, Beijing Normal University, with the approval number: CLS-EAW-2019-004.

Data availability statement

Original data of this study are available at Mendeley Data (doi: 10.17632/m8s3hf85tr.1).

CRediT authorship contribution statement

Fangyi Zhou: Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Mingwei Bao:** Project administration, Data curation. **Xianming Guo:** Resources, Project administration. **Qingzhong Shen:** Resources, Project administration. **Jiming Chen:** Resources, Data curation. **Duo Li:** Data curation. **Hong Bao:** Data curation. **Li Zhang:** Writing – review & editing, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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