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Emotion estimation using a wearable heart rate monitoring device in Asian elephants (*Elephas maximus*) during veterinary clinical procedures

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ABSTRACT. Fatal accidents in captive elephants occasionally occur because humans are unable to gauge elephants' emotions solely by their behavior. The intellectual capacity of elephants makes them capable of understanding circumstantial changes and associated emotions, allowing them to react accordingly. Physiological markers, such as heart rate variability, may be effective in determining an elephant's emotional state. In this study, a wearable heart rate monitor was used to determine the emotional state of a female Indian captive elephant (*Elephas maximus indicus*). The average heart rate was higher when the elephant underwent painful treatment than when it underwent non-painful treatment. In addition, the heart rate increased both before and after the treatment, which included radiography and blood collection.

KEY WORDS: blood collection, *Elephas maximus*, radiography, stress, training

The elephant is the largest terrestrial animal in the world and can be categorized based on the species into the Asian elephant (*Elephas maximus*; *E. m.*), African savanna elephant (*Loxodonta africana*), and African forest elephant (*L. cyclotis*) [20]. The Asian elephant is categorized as "endangered" (EN) in the International Union for Conservation of Nature's (IUCN) Red List. The elephant is characterized by extraordinary intelligence and complex social behavior, indicative of cognitive and emotional functions. Corroborating such claims is the fact that the elephant has the largest brain among terrestrial animals [7, 15], and the ratio between the body weight and the brain capacity of the elephant is close to that of the chimpanzee [9]. Behavioral evidence of such functions include the ability for self-recognition [13] and signs of sympathy and empathy [6]. Based on these characteristics, it is likely that elephants possess the ability for complex thoughts and emotions.

Elephants have been worshipped as gods, used as working animals, and admired in zoos and circuses worldwide [18]. The life span of a captive elephant is approximately 60 years [19]. For the good health of elephants under human control, daily care and/or occasional intensive treatment are required. This is challenging because it is difficult for humans, even for traditional elephant keepers (known as mafoo), to gauge an elephant's condition and emotions by its behavior. Such lack of or limited insight into an elephant's behavior has been reported to precede some fatal accidents. Furthermore, elephants can become extremely dangerous because of their strength, speed, and intelligence [18]. Given the risk, strategies and systems to ensure the safety of elephant handlers should be developed. An alternative method is to determine the elephant's emotional state.

Various methods have been reported for grasping animal emotions. To identify the cause of directly observable animal behavior, the underlying emotions must be estimated. Facial expression and voice changes in animals are key factors used to gauge their emotions [5, 12]. Furthermore, physiological changes associated with emotions, such as changes in skin temperature, can be used as emotional markers in both humans and animals [8, 10, 11, 17]. Its disadvantage is that the outside environment also affects the results of skin temperature examination [4, 10]. Particularly for elephants, such measures might not be suitable because of sudden, unexpected behaviors, unclear changes in facial expression, and thick skin. The heart rate variability is another factor used to estimate an animal's emotional state. A previous study described that the heart rate in rhesus monkeys (*Macaca mulatta*) changed depending on the situation [1]. In addition, Smith *et al.* [16] described that horses' heart rates were affected by human facial

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expressions. Therefore, heart rate variability may be an effective tool for estimating an animal's emotional state, provided that the heart rate measuring device can be applied to the animal without causing additional stress. This has been made possible with recent innovations in the design and manufacture of wearable heart rate measurement devices that are used to estimate the animal's emotional state. Therefore, the aim of this study was to estimate emotional changes in an elephant by monitoring changes in its heart rate during a veterinary clinical procedure that was stressful for the elephant.

A female Indian elephant (*E. m. indicus*) aged 40 years in 2018 and weighing 3,800 kg had been housed at the Kanazawa Zoological Gardens, Japan since 1985, when she was transported from the Mumbai Zoo, India. The elephant was managed using the direct contact method. It underwent routine training for health checks and daily treatment. The heart rate of the elephant was sporadically measured during this training period between January and October, 2018, amounting to a total of twelve measurements. The examinations were numbered C-1 and 2 for the control trials and E-1 to 9 for the examination trials. During E-1 to 9, the elephant received daily treatment for her hoof because of pododermatitis in her left forelimb since 2014. Intensive treatment corresponding to severe pain was provided between intervals E-1 and 6 while either no treatment or minor treatment without pain was provided between intervals E-7 and 9. Routine treatment consisted of preparation for the hoof treatment, placement of her left forelimb on a steel stand, securing photographic images of the hoof lesion, trimming of the lesion, and finally, removing her forelimb from the stand. Though not a usual procedure, radiography was required for the diagnosis and was therefore performed before the treatment at E-1. For this, the elephant keepers and veterinarians approached the elephant with the radiographic instrument, acquired the photograph, and finally tidied up the instrument before leaving. In E-7 and 8, blood was collected (a monthly routine procedure for health check) before trimming and treatment. For this, the keepers and veterinarian first positioned themselves to collect the blood sample, and the veterinarian then inserted the needle and performed astriction. Finally, the keepers and veterinarian left the area. The control was measured 6 months after completion of the hoof treatment.

The heart rate was monitored in the standing position using a wearable heart rate monitoring device, a stretchable conductive film (COCOMI^{TM}, Toyobo STC Co., Ltd., Osaka, Japan), and a wearable heart rate sensor (myBeat, Union Tool Co., Tokyo, Japan). The wearable heart rate device was placed on a cut bicycle rubber tube. This apparatus was then secured on to the elephant's chest with an elastic band (Fig. 1). All data were collected by a smart phone application and exported to a Windows computer as a CSV file. Data were then analyzed using Microsoft Excel (Japan Microsoft Co., Tokyo, Japan).

The heart rate (beats per minute [bpm]) was calculated using the time between two waveforms (R-R interval). However, the heart rate waveform included some noise secondary to muscular electric waves reflective of body movements. Therefore, this study evaluated the heart rate measurement ratio, calculated from the area of the heart rate waveform without noise for that specific time period. The statistical difference between the average heart rate of E-1 to 6 and E-7 to 9 was determined using the Student's *t*-test.

This study adheres to the Japanese Association of Zoos and Aquariums Ethics and Welfare Guidelines and Caring for Wildlife: The World Zoo and Aquarium Animal Welfare Strategy. It was approved by the Kanazawa Zoological Gardens ethical and welfare assessors (reference number: Kana-1136, March 20, 2018).

The total measurement time was 3 hr, 28 min, and 13 sec, and the average measurement time for each examination was 17 min and 21 sec. As seen in Table 1, the average heart rate of E-1 and 6 was significantly higher than that of E-7 and 9.

As seen in Fig. 2, the average heart rate increased during E-1 to 6, when the elephant placed her foot on the steel stand. From treatment to post-treatment, the heart rate gradually increased during both E-1 to 6 and E-7 to 9 time periods.

As seen in Fig. 3(a), the heart rate measurement ratio increased during radiography. As seen in Fig. 3(b), the heart rate measurement ratio increased during astriction.

Thus, this study revealed that an elephant's emotional state might be estimated by its heart rate and the heart rate measurement ratio change. In the past, an elephant's heart rate was recorded using electrocardiograms [2, 3]. This study showed several advantages to alternatively using wearable heart rate measurement devices. The wearable device used in this study seemed to be accurate in measuring the elephant's heart rate, as the average heart rate in this study was within the previously reported range (25–35 bpm) [18]. It is also easier to use smaller wearable devices to record the heart rate rather than an electrocardiogram. In addition, if the elephant gets used to wearing the device, it might be possible to record its heart rate for the whole day. Therefore, this method has the potential to become a common way of monitoring an elephant's heart rate in the future.

In this study, the elephant's average heart rate increased and was relatively higher when she underwent painful treatment in comparison with trials where she had not been subjected to pain-inducing treatments, suggesting that the elephant endured painful treatment. In addition, when the elephant's foot was placed on the stage before treatment, the heart rate increased, particularly between E-1 and 6, in comparison with her heart rate between E-7 and 9. The elephant's heart rate increased when the keepers and veterinarians approached the elephant with the radiographic instrument. The radiographic examination was not a standard procedure and therefore caused some anxiety. Taken together, these observations suggest that the elephant might have felt tense or anxious in anticipation of both the painful treatment and the non-standard procedure, and her heart rate might have reflected her emotional state. Given the previous studies on physiological markers of emotional experiences in other species [1, 14, 16], it is not surprising that the elephant's heart rate was affected by negative stimuli.

This study demonstrates that the heart rate might also be affected by positive stimuli. When all procedures, including the hoof treatment, radiography, and blood sampling, were completed, the elephant's heart rate increased. Finalizing these procedures meant that the elephant was soon free from training with its associated restrictions, and this might have provided a positive stimulus for the elephant. A few reports described the heart rate change when the animal felt happy or positive. Some reports described a decrease in the heart rate during grooming in Rhesus Macaques, which might be an example of a positive stimulus [1]. However, as grooming means that the animal might feel relaxed and calm, this might be different from the animal feeling happy. In this study, a

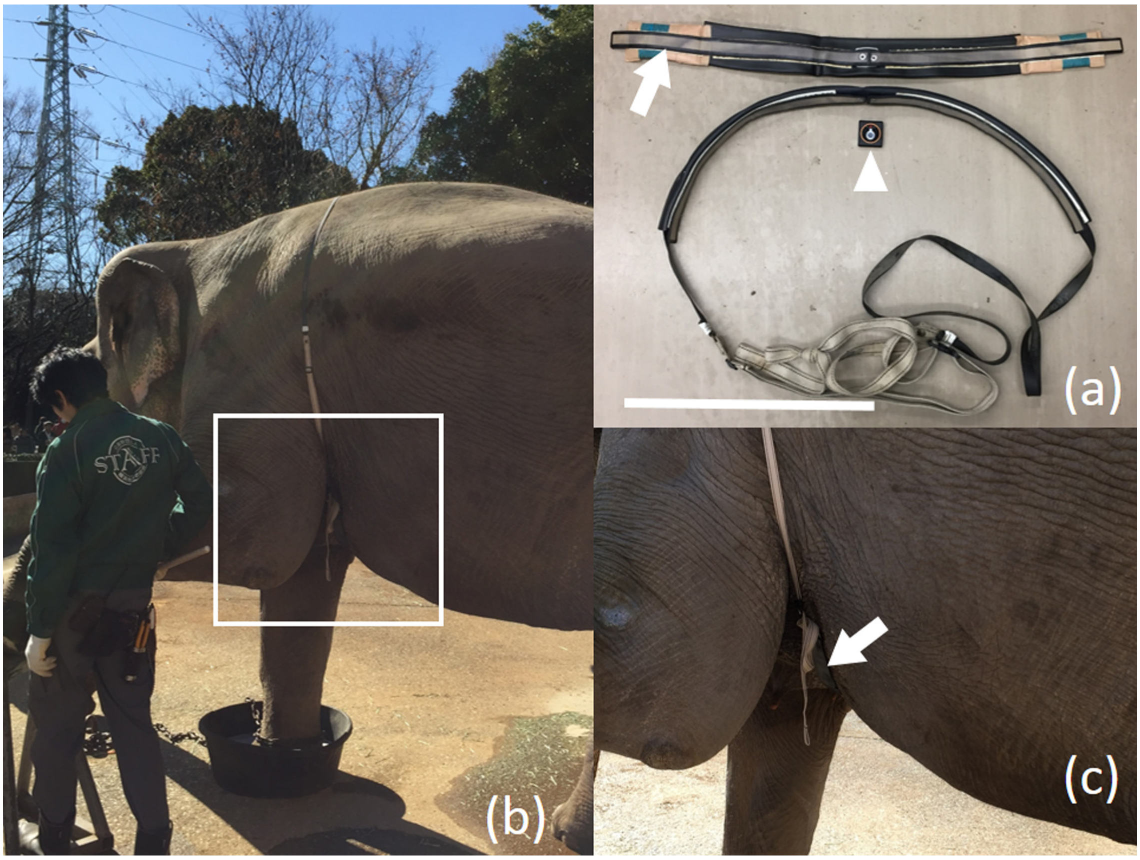

Fig. 1. The wearable heart rate monitoring device and position on which it was secured. (a) The stretchable conductive film (COCOMI^{TM}; arrow) and wearable heart rate sensor (myBeat; arrow head). The wearable heart rate monitoring device was placed on a cut bicycle rubber tube. Scale bar: 40 cm. (b) The rubber tube with the wearable device was secured on the elephant's chest with an elastic band. The square part is Fig. 1 (c). (c) The enlarged figure of the square part is Fig. 1 (b). The arrow indicates the part of the wearable device that was placed on the elephant's chest.

Table 1. The average heart rate and standard deviation and the heart rate measurement ratios in each examination

		Heart rate (bpm)		Heart rate measurement ratio (%)	
		Average S.D.	Average S.D.	Average	Average
C-1		36.0 ± 2.7	37.5 ± 3.5	67.2	58.5
C-2		39.7 ± 3.5		49.8	
E-1	Radiography	36.8 ± 2.9	36.6 ± 2.8[a)]	23.1	17.9
E-2		37.9 ± 3.8		7.4	
E-3		37.0 ± 2.6		18.0	
E-4		35.8 ± 2.7		24.3	
E-5		35.2 ± 1.9		11.5	
E-6		37.2 ± 2.7		23.2	
E-7	Blood Collection	35.6 ± 2.2	34.6 ± 2.5[a)]	37.2	22.7
E-8	Blood Collection	33.5 ± 2.3		18.4	
E-9		33.7 ± 2.7		12.5	

S.D.: Standard deviation. a) $P<0.01$ (the average heart rate between E-1 and 6 and E-7 and 9).

possibility is that the elephant's heart rate increased when she was feeling happy or positive.

Our study showed the possibility that the heart rate measurement ratio might reflect the elephant's change in emotion. The average heart rate measurement ratio mostly consisted of noise waveforms. Noise waveforms were usually the result of muscular electric waves or body movement. One hypothesis is that the elephant might stiffen or shake its body when faced with a stressful or anxiety-provoking situation because she could not escape these circumstances during training. Therefore, the noise waveforms might suggest that the elephant was experiencing negative or anxious feelings. In contrast, if the elephant was feeling relaxed or

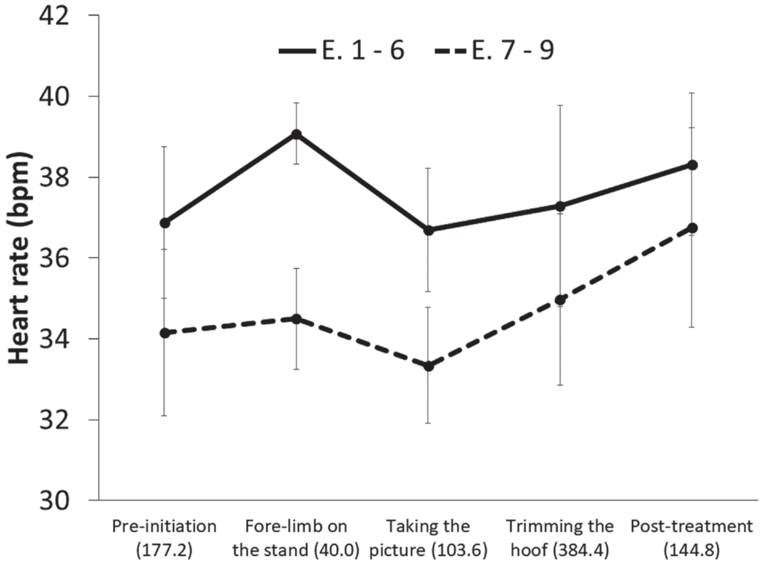

Fig. 2. The average heart rate from pre-initiation to post-treatment of the elephant's hoof in E-1 to 6, when the elephant received the aggressive treatment and E-7 to 9, when the elephant received no or minor treatment. The values in parentheses are for the average time required to conduct each procedure.

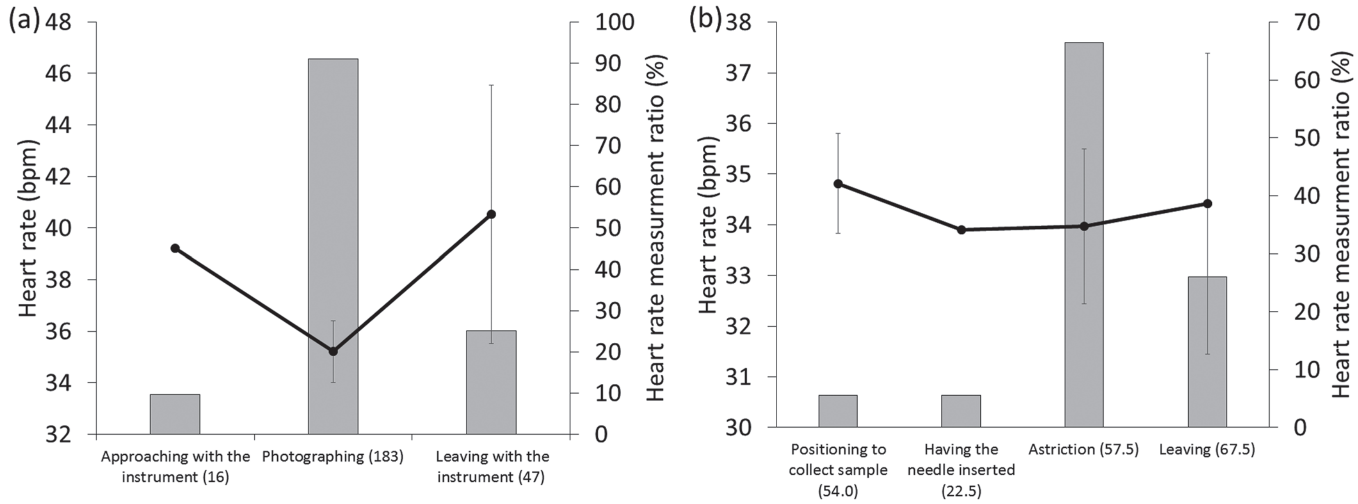

Fig. 3. The change in the heart rate and heart rate measurement ratio during radiography (a) and blood collection (b). The heart rate and heart rate measurement ratio are a line and bar graph, respectively. The values in parentheses are for the average time required to conduct each procedure.

comfortable, the heart rate waveform did not include the noise pattern. The heart rate measurement ratio decreased immediately before radiography and blood collection. Therefore, as radiography was a non-standard procedure and blood collection was painful, these procedures might have induced unhappy or negative feelings. The elephant might stiffen or shake its body under these circumstances.

The heart rate measurement ratio increased when the elephant might have felt comfortable or relaxed. In this study, the heart rate measurement ratio increased during the control, radiography, and astriction periods. In the control period, the elephant might have felt relaxed. During radiography, the elephant did not receive any painful stimulus or strong enforcement. During astriction, the elephant might have been relieved because she was now free from mooring and treatment. Therefore, during these circumstances, the elephant might have felt relaxed, leading to decreased muscular tension.

Finally, this study established the effectiveness of the wearable device in recording the elephant's heart rate. Thus, an elephant's emotional state may be estimated based on the change in the heart rate and heart rate measurement ratio. Using these methods, the elephant's emotional changes may be followed in real-time and may avert fatal accidents involving elephants, thereby decreasing their occurrence in the future.

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