VARIATION IN THE HEARTBEAT OF THE WHITE TERN *GYGIS ALBA* DURING INCUBATION

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ABSTRACT

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Rapid global heating is a particular danger to tropical birds already near their thermal maximum. White Terns *Gygis alba* are important to tourism in the Seychelles Islands, where, in 1974, we took an unexpected opportunity to measure the heart rate of two incubating adults. We found that the birds had higher heart rates at night compared to during the day, and their heart rates increased rapidly when approached by people. Local temperatures have risen considerably since these data were collected nearly 50 years ago and are predicted to rise even further by 2100. Given the importance of White Terns as a resource for ecotourism, and the likelihood that they will move closer to their thermal maxima as climates warm, an urgent re-evaluation of their thermoregulatory responses to approach by people is warranted.

Key words: thermoregulation, heat stress, disturbance, climate warming

INTRODUCTION

The White Tern *Gygis alba* is a tropical seabird famous for laying its single egg in a precarious site without the benefit of nest or adhesive. Formerly known as the Fairy Tern, its behaviour was first studied by Moynihan (1962), Dorward (1963), Ashmole (1968), and Howell (1978). Incubating birds will often allow an observer to approach within a few yards while showing no obvious reaction. This extreme tameness is the basis for its success as a tourist attraction on Cousin Island, one of its main breeding stations in the Seychelles (Diamond 1975).

Many seabirds, from penguins to albatrosses, nest on islands that have historically had few human visitors; accordingly, the birds show few anti-predator responses to approaching humans. Where such colonies are now commonly visited, by researchers or tourists, the difficulty of assessing the risks to the birds can become critical. The challenge is to identify a physiological or stress response in the absence of a behavioural response (such as fleeing or attacking). Stress is often manifested physiologically by an increase in metabolic rate, but this is hard to measure directly. For over 80 years (Odum 1941), heart rate has been used as a proxy for metabolic rate in studying the effects of stress on birds (and other vertebrates) because it can be measured in their natural environment, without the need to take the animal out of the wild and into a laboratory.

Measuring heart rate is particularly important in assessing the effects of disturbance on animals such as seabirds, which do not exhibit obvious behavioral responses. The chief method used to measure heart rate involves data loggers, either attached to (Bisson *et al*. 2009) or implanted in the bird (Weimerskirch *et al.* 2002), or in an artificial egg substituted for the bird's own egg (Ellenberg *et al*. 2002; Nimon *et al*. 1995, 1996). The first two methods impose some added stress on the bird, whereas using dummy eggs does not, apart from the stress imposed by the brief exchange of eggs by the researcher. The first loggers for measuring heart rate of free-ranging wild animals, employed in the 1960s and 1970s (Holter *et al*. 1976, Kanwisher *et al*. 1978), were too big to be used on small birds. Another method—placing a miniature microphone under the egg to amplify the sound of the incubating bird's heart rate—appears to have been among the earliest methods used for studying incubating birds, as described by Odum (1941, 1945). This was the only method available to us in 1974 when we had the opportunity to address the metabolic impact of close approach by tourists to White Terns in the Seychelles.

METHODS

Cousin Island (4°20′S, 55°40′E) is a small (27 ha; 0.27 km^2) nature reserve in the Republic of Seychelles in the tropical Indian Ocean, hosting large colonies of seabirds, including White Terns (Diamond 1975a, 1975b). The occasion of this study was the visit by a film crew to document the research and conservation work of the senior author as Resident Scientific Administrator for the British Section of the International Council for Bird Preservation (now BirdLife International). Data collection for the project reported here had to be inserted into the already busy schedules of all participants, including island management (Diamond 1975a), landing and guiding tourists (Diamond 1975b), filming (A. Studer-Thiersch), and conducting research (Diamond 1976a, 1976b, 1976c, 1983; Diamond & Prys-Jones 1986). Only one microphone was available due to filming duties, and it became unavailable when the junior author departed on the final day of observations.

While filming White Tern behaviour on Cousin Island (Hufschmid 1975), it was important to predict the hatching date of eggs in order to film the chick's emergence. The high rate of egg mortality (*ca*. 70%; AWD unpubl. data) made it impractical to record the laying dates of a sample of eggs and wait for them to hatch. Instead, sounds made by the chick before hatching were monitored using a piezo-electric microphone placed beneath the egg and connected to a tape recorder and earphones. While testing this method, we found that when the adult tern settled back on the egg, we could clearly hear the heartbeat of the adult. The heart rate varied with time of day and disturbance, so we investigated the influence of these two factors, and the approach of visitors, on heart rate. The film crew had priority for the equipment, so it was possible to monitor only two birds, at different sites, over a period of eight days (22–29 November 1974).

The first site (Fig. 1) was a wooden T-piece 1.5 m above the ground, with a slight hollow carved in the top in which a tern had laid its egg about four weeks before. This site was fully exposed to sun throughout the day. The second site was a beam above the patio of the laboratory building, about 2.5 m above the ground, and was partially shaded at different times of the day. To install the microphone beneath the egg, the adult had to leave the egg temporarily. Unattended eggs were vulnerable to depredation by Seychelles Fodies *Foudia seychellarum* and skinks *Mabuya seychellensis* and *M. wrightii*, so the microphone was installed at night when these predators were less active.

The microphone was a flat piezo-electric crystal, 13 mm square and 1 mm thick, attached to delicate silver leads soldered to an extension cord connected to a tape recorder (Uher 4000 Report). The microphone was placed exactly where the egg contacted the site beneath it and was secured with a ring of colourless grafting wax to prevent the egg rolling off (Fig. 2). The egg was then carefully replaced after less than 5 min off the site.

Heartbeats were clearly audible through earphones and could be tape-recorded simultaneously. Using a stopwatch, we counted the number of beats heard in intervals of 5 s or (mostly) 10 s and made at least 10 measurements on each occasion. All measurements were later converted to beats per minute. Diastole and systole, while distinguishable on the oscillograph, could not be heard separately, so each beat recorded corresponds to one complete contraction of the heart (Fig. 3).

We were unable to measure the ambient temperatures to which our study birds were directly exposed, but we recorded shade temperatures in a Stevenson screen located 20 m away whenever possible.

We encountered two main challenges. First, in the heat of the day, the bird often stood over the egg, shading rather than incubating it, which resulted in losing contact between the bird and the egg and an inability to detect the heartbeat. On these occasions, we would alarm the bird by waving at it, causing it to sit back down on the egg. We then allowed a few seconds for the heart rate to return to an undisturbed rate (i.e., similar to the rate before it stood up), and then we continued readings before the bird relaxed sufficiently to stand up again. Readings between 11h00 and 14h00 may, therefore, be slightly higher than those from a completely undisturbed bird.

Second, disturbance from people, passing lizards, and nearby White Terns were obvious causes of temporary rises in heart rate, but less obvious stimuli could have similar effects. We noticed increases in heart rate at night when the moon appeared from behind clouds, and in the day when clouds obscured the sun. We excluded readings with identifiable causes for changes in heart rate, but we included those with anomalous values for which no obvious reason could be determined.

In this way, routine measurements were made to measure diel variations in heart rate. Changes due to disturbance could not be measured by stopwatch because heart rate became too fast to count; instead, we transcribed recordings from tape onto an oscillograph and measured the rate from the transcription.

The advantage of this method over more sophisticated telemetric techniques is that it does not require handling the bird or attaching any equipment to it. Because the recording system does not touch the bird, it does not affect the parameter being measured. There is also no need to replace the egg with a dummy containing the instrument (e.g., Kneis & Kohler 1977, Nimon *et al*. 1996), so our method minimizes disturbance to both the bird and its egg.

Fig. 1. Adult White Tern *Gygis alba* incubating egg on a wooden T-piece 1.5 m above the ground. The cable to the microphone can be seen running up the right-hand side of the vertical support.

Fig. 2. View from above of piezo-electric microphone that was placed on top of the wooden T-piece where one of the White Terns *Gygis alba* incubated its egg. Wood chips embedded in paste protect the leads to the microphone from damage by the bird's feet.

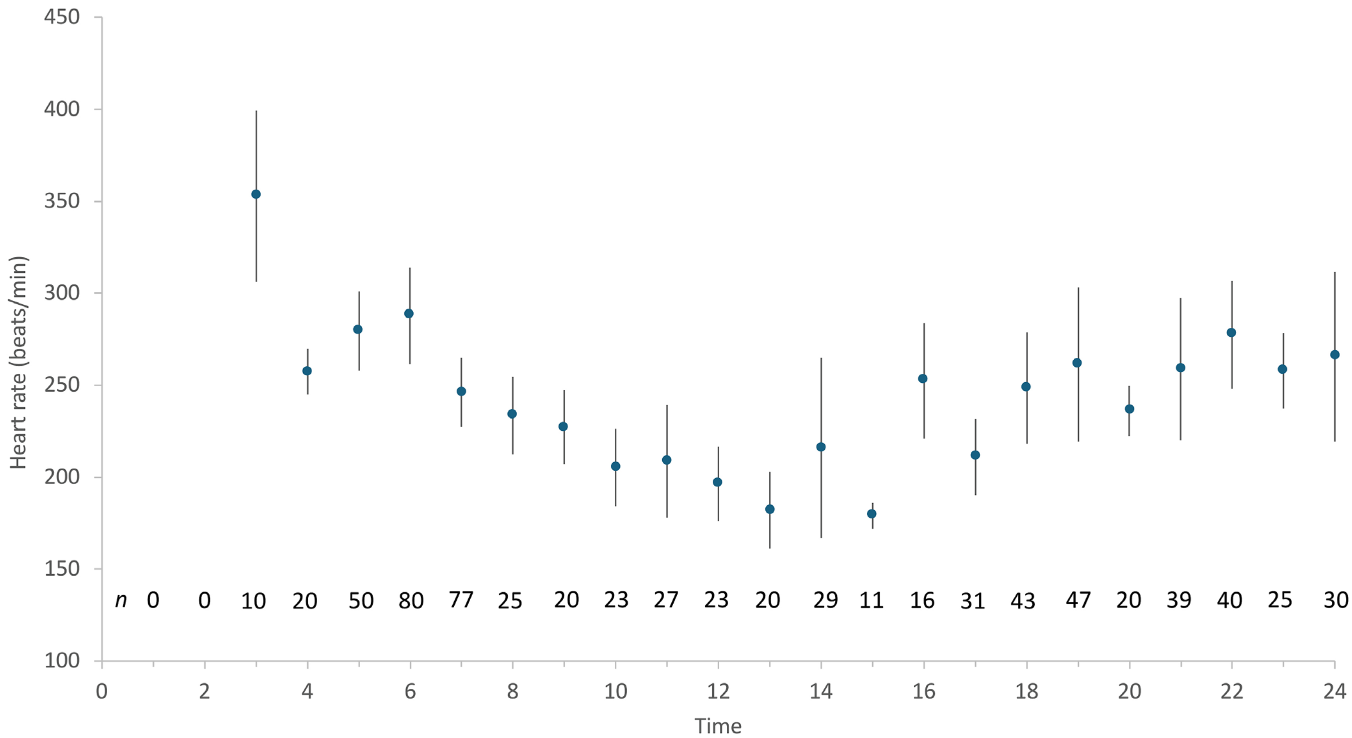

Fig. 3. Diel changes in heart rate over 24 hours (00h00–24h00) in two incubating adult White Terns *Gygis alba*. Each point represents the mean heart rate (± standard deviation) based on data collected over the previous hour; e.g., the point at 06h00 represents data collected from 05h01–06h00. Sample sizes are shown above the horizontal axis. The gap in readings between 24h00 and 03h00 is due to observers' need to sleep.

Although Odum (1941, 1945) described a similar method using a piezo-electric microphone, the technique does not appear to have been further developed or widely used.

RESULTS

Diel rhythm

Figure 3 illustrates the mean heart rates over 24 hours, showing a clear rhythm with the lowest rates occurring between 06h00 and 18h00. The unusually high reading between 02h01 and 03h00 comes from the smallest sample size (n = 10); sample sizes at other times averaged 35. On average, nighttime rates (19h00–06h00) were significantly higher (mean 272 beats/min) than daytime rates (mean 217 beats/min) (t-test, df = 16, t = -5.04, P < 0.01). The gap in readings between 24h00 and 03h00 is due to observers' need to sleep.

Shade temperatures nearby, mostly around the time of maximum heart rate but also at midday, are shown with corresponding heart rates in Table 1. Sample size is too small for analysis, but the highest temperatures generally correspond with lowest heart rates.

Disturbance

Heart rate increased when a bird was disturbed; it seemed to rise in proportion to the closeness of approach by the intruder, but we did not measure this systematically. Instead, we measured the maximum rate stimulated by a party of tourists by tape-recording the heart rate of an incubating bird while it was approached to within 3 m by 10 people who stayed near it for several minutes taking photographs and talking. One such sequence was filmed and appears in Hufschmid (1975) with the bird's heartbeat in the soundtrack (minutes 0530 to 0705 in the film). The heart rate rose from around 200 beats/min to a maximum of 570–600 beats/min, maintaining this level for at least 40 s before dropping to around 300 beats/min for an additional 50 s. It then returned to its original level as the people moved away. Fig. 4 shows an example oscillograph from a recording of the maximum heart rate. Thus, this incubating tern, while maintaining an outward appearance of total indifference, may have been experiencing a metabolic rate nearly three times the resting level (assuming that heart rate reflects metabolic rate; see Discussion below).

TABLE 1
Relationship between heart rate and ambient temperature recorded in a Stevenson screen located 20 m from incubating White Tern *Gygis alba*

Time	Temperature (°C)	Mean heart rate (beats/min)
03h45	25.8	255
04h20	25.5	311
05h00	25.3	270
05h15	25.3	270
06h15	25.5	241
07h00	26.5	227
11h15	29.4	215
17h40	27.5	226

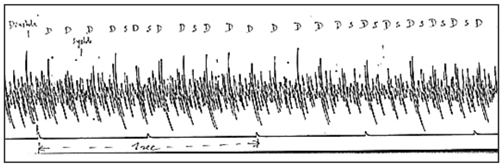

Fig. 4. Example output from oscillograph of maximum heart rate of a White Terns *Gygis alba* when disturbed (~600 beats/min.). Each notch on the horizontal scale represents 0.5 sec. Each 'D' on the figure represents the diastole of one complete heartbeat, and 'S' represents the systole.

DISCUSSION

Diel variation

Heart rate in birds is usually proportional to metabolic rate (Odum 1941, 1945, Owen 1969, Johnson & Gessamen 1973, Steiger *et al*. 2009), so the reduced heart rate we found during the daytime reflects a lower metabolic rate during that period. Metabolic rate in birds is typically higher during the day than at night (Whittow 1976). However, the limited data available on heart rate in incubating birds shows a pattern similar to that observed in White Terns, with higher heart rates at night (e.g., House Wren *Troglodytes aedon* and Gray Catbird *Dumetella carolinensis* [Odum 1941], and Common Gull *Larus canus* [Kneis & Kohler 1977]).

This pattern presumably reflects the need to keep the egg or eggs warm when ambient temperatures are lower than during the day; White Tern egg temperatures vary between 26 °C and 36 °C, or 2–6 °C above ambient temperature (Hart *et al*. 2016). House Wrens and Catbirds showed heart rate increases of 18% and 26%, respectively, over a temperature drop of 15 °F (8 °C), whereas White Terns showed a similar increase (19.5%) over only half the temperature difference (4 °C; Table 1). Thus, the difference in daytime and nighttime heart rates in White Terns is more than would be expected if it were due solely to the difference in ambient temperature, as Odum (1941) suggested in his study. We suggest that, in addition to a rise in heart rate at night to counter decreased ambient temperature and keep the egg warm, White Terns also lower their heart rate during the day to keep themselves cool and to avoid over-heating the egg, or to conserve their own body reserves during their incubation shift, which can extend over three days or more (Dorward 1963, AWD pers. obs.).

Incubating White Terns are often exposed to the full heat of the midday sun. Their brilliant and notably shiny white plumage likely reflects a significant amount of heat. However, unlike many seabirds, they do not use gular fluttering to keep cool and rarely pant, although small chicks do both. The only behaviour we saw that might have a cooling effect was the standing posture of incubating birds in the heat of the day (see Methods, above), which may dissipate some heat through the unfeathered legs, as legs are known to be a major avenue of heat loss in European Herring Gulls *Larus argentatus* (Baudinette *et al*. 1976). We suggest that it would be dangerous for an incubating White Tern to perform even the relatively small movements involved in panting, gular fluttering, or holding the wings away from the body, as in Sooty Terns *Onychoprion fuscatus* and other tropical seabirds (Drent 1972), because of the risk of losing the precariously balanced egg. Dorward (1963) noted that "the care with which a bird settled on, and rose from, its egg, was delightful to see".

We suggest two possible reasons for the lower heart rate of White Terns during the day than at night. First, to maintain the egg at near-constant temperature throughout the 24-hour cycle would require the incubating bird to increase its metabolic rate at night to compensate for a lower ambient temperature. Second, the challenge of higher daytime temperatures is met by lowering the bird's metabolic rate (hence heat production) to prevent overheating in both adult and egg. These two influences on White Tern heart rate—the need to keep the egg warm at night, and the incubating adult cool by day—have the same effect on the diel cycle of heart rate. However, to quantitatively assess their relative importance will require measurements of heart rate in non-incubating birds, which was not possible with our technique.

The only other birds known to have higher heart rates at night than by day (see above) were also measured during incubation, supporting our explanation of this pattern in White Terns. The larger difference found in White Terns may be attributed to their limited cooling mechanisms, which likely reflects the hazardous egg-laying sites of this species.

Effects of disturbance

It is well known that the approach of a potential predator can induce heart rate changes in birds. Sometimes the rate will slow down (bradycardia), as in incubating Willow Ptarmigan *Lagopus lagopus* (Gabrielsen *et al.* 1977), but more often it will increase (tachycardia), as in Herring Gulls (Kanwisher *et al.* 1978, Ball & Amlamer 1980), two diving duck species—Common Pochard *Aythya farina* and Tufted Duck *A. fuligula* (Butler & Woakes 1979)—and several Galapagos seabird species (Jungius & Hirsch 1979). This is of obvious importance in situations such as those in Galapagos and Seychelles, where a bird which will tolerate close approach is a valuable economic resource. Jungius & Hirsch (1979) and Geise (1998) used measurements of heart rate in relation to proximity of approach to recommend minimum distances to which tourists should be allowed to approach nesting birds. The laboratory study of Ball & Amlamer (1980) showed that the speed at which a bird is approached can influence its response, with a slower approach inducing a delayed and smaller rise in heart rate. They also found that this response did not habituate over time.

It may be inferred that such high heart rates in birds, even when they appear outwardly unaffected, may be harmful to their fitness. White Terns on Cousin Island often nest close to paths used by tourists, and the results of this study suggest that they may be experiencing 'emotional tachycardia' (*cf*. Gabrielsen *et al.* 1977) despite their air of supreme indifference when approached. However, whether the induced tachycardia had a measurable negative effect on population viability is doubtful. Unpublished studies by J.R. Wilson and H.V. Bathe (*in litt.*), conducted in the late 1970s and early 1980s, respectively, found no difference in success between birds breeding on paths used by tourists and those on paths used only occasionally by staff.

However, as environmental temperatures increase with global heating, birds will experience increased heat stress (Oswald & Arnold 2012), making the stress from close approach by humans potentially more harmful. Mean annual temperature in the Seychelles has increased from 25.8 °C in 1974 (the year of our study) to 27.1 °C in 2021 (Climate Change Knowledge Portal 2023) and is predicted to rise by 2.01 °C by 2100 (Hart *et al*. 2016). This rate of increase threatens the ability of small endotherms such as White Terns to avoid lethal hyperthermia (McKechnie & Wolf 2019), especially in humid environments such as tropical oceanic islands where birds already live close to their thermal maxima (Oswald & Arnold 2012).

CONCLUSIONS

We observed a rapid increase in heart rate when the incubating birds were approached by people. Given the increased heat stress that White Terns and other seabirds are likely to experience in the foreseeable future, they may be less able to incubate successfully, especially at sites exposed to full sun and when approached closely by people. This has implications for both their survival and their economic value to the tourism industry in Seychelles, highlighting the need for further research on this topic in the context of rising environmental temperatures.

We also found that incubating White Terns had higher heart rates (and therefore metabolic rates) at night than during the day. We suggest that metabolic rate is lower by day in part to avoid hyperthermia of both the adult and the embryo. We recommend the method we used—a piezo-electric microphone under the egg and connected to a recorder—to measure heart rate. This method is less disruptive than other commonly used techniques, although it is limited to species that lay a single egg. The more common method for measuring heart rate, which involves the use of dummy eggs containing loggers, is appropriate for species that lay more than one egg.

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