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Short communication

Exposure to tourism reduces stress-induced corticosterone levels in Galápagos marine iguanas

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Abstract

Unstressed and stress-induced plasma corticosterone levels in Galápagos marine iguanas (*Amblyrhynchus cristatus*) were compared in animals from a site heavily exposed to tourism to animals from a site undisturbed by humans. Initial corticosterone levels not only did not differ between the two groups, but they were 50% of levels in iguanas known to be chronically stressed. These data suggest that iguanas in tourist areas are not chronically stressed. Both groups of iguanas exhibited elevated corticosterone levels after 30 min of capture and restraint, indicating that they can physiologically respond to stressful stimuli. The stress response was lower, however, at the tourist site. This result indicates that iguanas are physiologically affected by tourism, although it is presently unknown whether these changes are ultimately beneficial or harmful.

Keywords: Glucocorticoids; Stress; Reptiles

1. Introduction

Successful physiological coping mechanisms are vital for ensuring individual, and thus species, survival in the face of adverse environmental conditions created by human disturbances. For vertebrates, a major coping mechanism is the stress response, and one of the hallmarks of the stress response is the release of the glucocorticoid steroid hormones (Wingfield et al., 1997; Romero et al., 2000; Sapolsky et al., 2000). Short-term glucocorticoid release is considered beneficial in helping animals survive stressful conditions primarily by helping mediate adaptive responses such as stimulating gluconeogenesis, inhibiting glucose utilization in non-essential tissues, mobilizing fat stores, and redirecting behavior (Sapolsky et al., 2000; Wingfield and Romero, 2001). Prolonged stress leading to chronically elevated glucocorticoid concentrations, however, can lead to a multitude of problems including reproductive failure and neuron death (Sapolsky, 1992; Sapolsky et al., 2000).

Several recent studies indicate that human activities can result in elevated glucocorticoid concentrations. For example, deforestation of spotted owl habitat (*Strix occidentalis*, Wasser et al., 1997), heavy metal contamination in trout (*Salmo trutta*, Norris et al., 1997), and coal waste pollution in ponds supporting toad populations (*Bufo terrestris*, Hopkins et al., 1997), have all been shown to result in increased glucocorticoid levels in the affected species. Tourist visitation of animal breeding grounds, especially common with increases in ecotourism, also has been postulated to be stressful to visited animals (e.g. in the neotropical hoatzin, *Opisthocomus hoazin*; A. Müllner and M. Wikelski, in preparation). One recent study in magellanic penguins (*Spheniscus magellanicus*), however, suggests that in some circumstances animals can habituate to human visitation so that their glucocorticoid concentrations are lower in tourist-visited areas (Fowler, 1999). Some forms of tourism, therefore, may not be stressful, or species might vary in their physiological responses. Given the economic importance of ecotourism to many threatened ecosystems (Giannecchini, 1993), it is important to determine whether human visitation can be continued without harming threatened species.

The Galápagos Islands are a popular destination for ecotourists. The Parque Nacional Galápagos, however,

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restricts tourists to well-defined trails for animal viewing. In the present study, we examine the corticosterone (the primary glucocorticoid in reptiles, Greenberg and Wingfield, 1987) responses in Galápagos marine iguanas (*Amblyrhynchus cristatus*) living either next to or far away from a major tourist trail to ascertain whether tourism is stressful to these animals.

2. Methods

Marine iguanas were captured on Fernandina Island on 22 and 23 May 1999. Twenty-one animals exposed to tourism were captured at Punta Espinosa and 13 not exposed to tourism were captured along the coast approximately 2 km south of Punta Espinosa. Our previous extensive research indicates that marine iguanas are extremely site faithful, thus iguanas 2 km off the tourist site are indeed naive to humans (Wikelski et al., 1997; Wikelski and Trillmich, 1997; Wikelski, 1999). Adult iguanas were captured by hand within 30 s of approaching the animal without controlling for sex or size. Previous work indicates that corticosterone does not vary by sex in this species (Romero and Wikelski, 2001) and only three females were captured. Consequently, sex was ignored in the statistical analyses. Immediately upon capture, approximately 2 ml of blood were collected from the tail vein into Vacutainer tubes (Becton Dickinson, Franklin Lakes, NJ) containing sodium heparin. Initial blood samples were all taken within 3 min of capture, and all but four samples were taken within 2 min of capture. In most species studied to date, glucocorticoid concentrations do not start to increase until approximately 3 min after the initiation of an acute stressful stimulus (Sapolsky et al., 2000; Wingfield and Romero, 2001), but by 10 min corticosterone concentrations can increase dramatically in at least one lizard species (*Urosaurus ornatus*, Moore et al., 1991). Iguanas were then subjected to 30 min of restraint stress by placing them into opaque cloth bags, after which a second blood sample was collected. These procedures were approved by the Tufts University Institutional Animal Care and Use Committee and conducted with permission of the Parque Nacional Galápagos.

Samples were stored on ice for up to 12 h and then centrifuged at approximately 400 ***g*** for 6 min. Plasma was removed, frozen, and transported to Tufts University for analysis. Corticosterone was analyzed by radioimmunoassay after extraction of corticosterone with dichloromethane (described in detail in Wingfield et al., 1992). Each sample was assayed in duplicate with a small amount of radiolabeled steroid added to determine recovery. The intraassay variation was 8%. Differences in the stress response between tourist and undisturbed sites were compared by repeated measures ANOVA.

To further test for potential chronic stress, initial corticosterone concentrations were compared to the previously reported (Romero and Wikelski, 2001) initial corticosterone levels of 28 iguanas sampled during an El Niño. These animals were captured at Punta Espinosa near the end of the 1998 El Niño that resulted in wide spread mortality, and were sampled using the same techniques. Differences in initial corticosterone levels between tourist-exposed iguanas, undisturbed iguanas, and iguanas affected by El Niño were compared by factorial ANOVA followed by Fisher's protected least squares difference (PLSD) post hoc tests.

3. Results

Iguanas at both tourist-exposed and undisturbed sites responded to the stress of capture, handling, and restraint (Fig. 1). Corticosterone concentrations increased after 30 min of restraint in both groups ($F_{1,\ 32} = 14.74$, $P < 0.001$). The magnitude of this response, however, differed at the two sites. Although initial (unstressed) baseline concentrations are indistinguishable between sites, stress-induced corticosterone concentrations were significantly lower at the tourist site ($F_{1,\ 32} = 4.481$, $P < 0.05$).

Initial corticosterone levels at both sites were significantly lower than equivalent samples taken during an El Niño ($F_{2,\ 59} = 5.77$, $P < 0.005$). Initial levels during El Niño were approximately double at 11.5 ng/ml (as reported in Romero and Wikelski, 2001). Post hoc tests indicated that levels at both the tourist and non tourist sites differed from El Niño levels ($P < 0.03$ for each) but not from each other ($P = 0.67$).

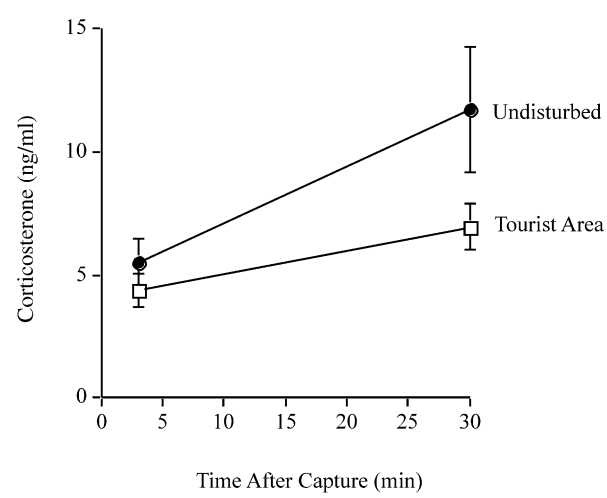

Fig. 1. Initial and stress-induced corticosterone concentrations in marine iguanas from an undisturbed and a tourist-exposed area. Each point represents the mean ± SEM for $N = 21$ and 13 for tourist-exposed and undisturbed sites, respectively.

4. Discussion

There is good evidence that elevated corticosterone concentrations can disrupt normal physiological functions in reptiles (reviewed in Guillette et al., 1995). For example, corticosterone has been shown to inhibit normal functions of reproductive hormones (Dunlap and Schall, 1995; Mahmoud and Licht, 1997; Nijagal and Yajurvedi, 1999), disrupt immune function (Dunlap and Schall, 1995; Morici et al., 1997), inhibit growth (Morici et al., 1997), disrupt normal social and territorial behaviors (DeNardo and Licht, 1993; DeNardo and Sinervo, 1994; Knapp and Moore, 1997), and may be involved in body length shrinkage (Wikelski and Thom, 2000). Clearly, there is the potential for a multitude of adverse effects if marine iguanas were chronically stressed by tourism. Furthermore, we know that chronic stressors in marine iguanas, such as famine conditions during El Niño (Romero and Wikelski, 2001) and exposure to an oil spill (Wikelski et al., 2001), result in elevated corticosterone levels that are correlated with survival (Romero and Wikelski, 2001). Baseline corticosterone concentrations, however, were not only indistinguishable in animals at tourist-exposed and undisturbed sites, but were 50% of levels in known chronically stressed iguanas. In fact, stress-induced corticosterone levels in animals exposed to tourists never reached baseline levels in chronically stress animals. These data indicate, therefore, that tourism is not chronically stressing the iguanas.

Corticosterone concentrations in iguanas at both sites respond to the stress of capture and handling. Observed increases were consistent with data from other reptile species (e.g. Cash et al., 1997; Tyrrell and Cree, 1998). Iguanas in tourist-exposed areas, however, had significantly lower corticosterone concentrations after 30 min of stress. Corticosterone release in reptiles is controlled by a hypothalamic, pituitary, adrenal pathway that is similar to pathways in other taxa (Guillette et al., 1995). Therefore, to damp stress-induced corticosterone release, iguanas at the tourist-exposed site must downregulate some aspect of this pathway. This is potentially a result of iguanas habituating to the presence of tourists, as has been reported for megallanic penguins (Fowler, 1999), but the exact mechanism controlling habituation is unknown. The reduction of stress-induced corticosterone release is not necessarily beneficial. Attenuated glucocorticoid release has been documented in several species affected by contaminants and has been proposed to impair their ability to survive (Hontela, 1998; Hopkins et al., 1999). For example, during periods of environmental stress, higher corticosterone concentrations may be required to optimize energy regulation (Sapolsky et al., 2000). However, there may be parallel mechanisms (such as modulating corticosterone receptors) that could compensate for the lowered corticosterone concentrations. Whether or not damped stress-induced corticosterone concentrations will ultimately aid or hinder the survival of these iguanas remains to be determined, but a central fact is that the stress response has been physiologically altered by tourism.

One potential problem with these conclusions, however, is that by only measuring corticosterone release at 30 min, we cannot exclude a lengthening or shortening of the corticosterone response in the iguanas exposed to tourists. If it takes longer for corticosterone to return to baseline levels after a stressful stimulus, even though the initial corticosterone response is lower, the overall response could be higher. Evidence for this kind of effect has been demonstrated in free-living baboons where a modest but lengthy stress response in subordinate males ultimately results in more glucocorticoid release than an intense but short response in dominant males (Sapolsky, 1992). Conversely, if it takes a shorter time for corticosterone to return to baseline it could hinder the iguana's ability to respond to future stressors. Future studies will be required to determine whether iguanas show either of these patterns as well.

Overall, these data provide a mixed message for wildlife managers. On the one hand, both the lack of a difference in initial corticosterone concentrations and the low levels compared to animals affected by El Niño conditions indicates that marine iguanas are not being chronically stressed by current levels of tourism, thereby avoiding the negative effects chronically elevated corticosterone can cause. This good news should be tempered with the potential that the tourist-exposed iguanas' long-term survival may be compromised, since their lowered corticosterone response to a stressful stimulus may limit the beneficial effects of acute corticosterone release.

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