General and Comparative Endocrinology 197 (2014) 65–72

Contents lists available at ScienceDirect

General and Comparative Endocrinology

journal homepage: www.elsevier.com/locate/ygcen

Seasonal variations of basal cortisol and high stress response to captivity in *Octodon degus*, a mammalian model species

Rene Quispe [a,1], Camila P. Villavicencio [a,1], Elizabeth Addis [b,2], John C. Wingfield [b,3], Rodrigo A. Vasquez [a,*]

[a] Instituto de Ecología y Biodiversidad, Departamento de Ciencias Ecológicas, Facultad de Ciencias, Universidad de Chile, Casilla 653, Santiago, Chile
[b] Department of Biological Sciences, University of Washington, 24 Kincaid Hall, Box 351800, Seattle, WA 98195, USA

ARTICLE INFO

Article history:
Received 10 June 2013
Revised 10 December 2013
Accepted 16 December 2013
Available online 22 December 2013

Keywords:
Degus
Cortisol
Stress
Mammals
Season
Captivity

ABSTRACT

Across vertebrates, the hypothalamic–pituitary–adrenal axis is a conserved neuroendocrine network that responds to changing environments and involves the release of glucocorticoids into the blood. Few studies have been carried out concerning mammalian adrenal regulation in wild species either in the laboratory or field, and even fewer have been able to determine true glucocorticoid baselines. We studied the South-American caviomorph rodent *Octodon degus*, a diurnal and social mammal that has become an important species in the biological research. First, we determined the plasma cortisol baseline and the acute stress concentrations during the non-reproductive and mating seasons in free-living individuals. Second, using the same protocol we assessed the impact of long-term captivity on the adrenal function in wild-caught degus and degus born in laboratory. Third, we examined laboratory groups formed with degus taken from two distant natural populations; one of them originally occurs at the Andes Mountains in high altitude conditions. The data revealed seasonal modulation of basal cortisol in the wild associated with mating. In laboratory, degus presented higher cortisol stress responses, with greater magnitudes shown in degus born and reared in captivity. No differences between populations were found. The results suggest differential regulatory mechanisms between basal and stress-induced cortisol levels, and context dependence of cortisol modulation in a mammalian species.

1. Introduction

The vertebrate adrenocortical response to acute stress is a highly conserved physiological process common to all vertebrates and involves the release of glucocorticoids (GCs) into the blood. This "stress response" is controlled by the hypothalamo–pituitary–adrenal (HPA) axis, which is a hormonal communication network sensitive to environmental perturbations (Sapolsky et al., 2000; Wingfield and Sapolsky, 2003). The HPA axis is activated when the hypothalamus is stimulated and secretes arginine, vasotocin, and corticotropin releasing factor to regulate pituitary release of adrenocorticotropin hormone (ACTH), which stimulates the synthesis and secretion of GCs by the adrenal gland. The GCs (cortisol and corticosterone) are steroid hormones with pleiotropic actions, exerting multiple effects from embryonic development and through adult life (Fowden et al., 2006; Seckl, 2004). Among other functions GCs adjust and maintain homeostasis and energy balance by regulating gluconeogenesis, glucose use, and fat and protein metabolism (Cole and Mollard, 2007; Reeder and Kramer, 2005; Sapolsky et al., 2000).

Variations in the energetic demands of animals occur seasonally, paralleling seasonal changes in basal GCs blood concentration (Wingfield, 2005). On the other hand many stressful events are unpredictable and followed by an acute elevation of GCs above basal levels (Sapolsky et al., 2000). Therefore, plasma baseline levels of GCs indicate the daily and seasonal energetic demands in an animal, and stress-induced levels of GCs represent the intensity of the stress response and the sensitivity to adverse events (Wingfield et al., 1998). Seasonal changes in overall adrenocortical function throughout the course of the year have been documented in several free-range animals (Kenagy et al., 1999; Romero et al., 2008; Vera et al., 2011). However, little data are available for baseline and stress-induced GC levels in mammals as compared with data collected for other wild species. The acute increase of GCs concentrations as a result of capture and human handling constitutes a good method for estimating the magnitude of the stress response. The true baseline concentrations can only be obtained by collecting plasma immediately after capture (Kenagy and Place, 2000; Reeder et al., 2004; Romero et al., 2008). Chronic plasma GC elevation because of continuous exposure to stress involves deleterious

* Corresponding author.
E-mail address: rvasquez@uchile.cl (R.A. Vasquez).
[1] Present address: Abteilung für Verhaltensneurobiologie, Max-Planck-Institut für Ornithologie, Seewiesen, Germany.
[2] Present address: Biology Faculty, Gonzaga University, Spokane, WA 99258, USA.
[3] Present address: Department of Neurobiology, Physiology and Behavior, University of California, Davis, CA 95616, USA.

0016-6480/$ - see front matter © 2013 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.ygcen.2013.12.007

consequences like impaired resistance to disease, infertility, neuronal damage and atrophy of body tissues (McEwen and Wingfield, 2003; McEwen, 2000; Romero and Wikelski, 2001; Sapolsky and Pulsinelli, 1985). Under laboratory settings, animals can be exposed to both persistent stressors and consecutive acute stress due to captivity conditions themselves (confinement, reduced retreat space, abnormal social groups and monitoring procedures). Profound effects of captivity on the function of the HPA axis have been described and can persist for generations (Matthews and Phillips, 2010; Romero and Wingfield, 1999). This aspect is particularly important because it emphasizes the caution that must be used when extrapolating biological captivity data to natural conditions (Calisi and Bentley, 2009; Kunzl and Sachser, 1999; Marra et al., 1995).

It is hypothesized that GCs are mediators that balance internal physiological dynamics with external environmental conditions (Romero, 2004; Sapolsky et al., 2000). Habitat characteristics and climatological variables influence the physiological stress of animals (Bauer et al., 2013; Breuner et al., 2003; Busch et al., 2011; Mueller et al., 2007; Wingfield et al., 2008). The particular harsh conditions existing at high altitude regions, such as, a higher degree of seasonality, longer winter seasons, lower temperatures, lower partial pressure of oxygen, and lower atmospheric pressure, among others, might be challenging for the organism's homeostasis. Accordingly, previous studies demonstrated that populations occurring at high altitude sites express differences in the sensitivity of their adrenocortical responses (Addis et al., 2011; Beehner and McCann, 2008; Li et al., 2008, 2011; Pereyra and Wingfield, 2003; Sheriff et al., 2012). Although these findings have been essential to elucidate how vertebrates deal with high altitude conditions, the cause that originates differences between populations remains unclear. In general, divergences in the adrenocortical activity between populations could appear because of: (i) physiological adjustments to the prevailing environmental conditions, (ii) differences in developmental processes, (iii) or different genetic backgrounds. Experiments conducted in common garden conditions can be useful to disentangle this assumption (Angelier et al., 2011; Dahl et al., 2012; Dunlap and Wingfield, 1995). Exploring the origin of population's differences in the HPG axis activity can broaden our notion about the adaptive nature of GCs release. As far as we know, common garden experiments addressing divergences in the adrenocortical responses have never been done in wild mammals.

In the present work the study subject is the degu (*Octodon degus*), a diurnal, social, and endemic caviomorph rodent (~180 g), which occupies a wide distribution throughout north-central Chile. Degus are noted as seasonal breeders typically mating in late autumn (Fulk, 1976). Because of its diurnal behavior, social system, and physiological characteristics, the degu is a species that has become increasingly important in different research fields, including ecology (Ebensperger et al., 2012; Vasquez et al., 2002), animal behavior (Vasquez et al., 2006; Villavicencio et al., 2009), ecophysiology (Bozinovic et al., 2004, 2009), chronobiology (Mohawk et al., 2005; Vivanco et al., 2007), neurobiology (Helmeke et al., 2009; Suarez and Mpodozis, 2009), cognitive sciences (Abraham and Gruss, 2010; Popović et al., 2010), and Alzheimer and Atherosclerosis research (Homan et al., 2010; Inestrosa et al., 2005). Just like guinea pigs (Hennessy et al., 1995) and humans (Gunnar and Donzella, 2002), the principal measurable plasma GC of degus is cortisol (Gruss et al., 2006; Kenagy et al., 1999). Despite the information available about degus, the modulation patterns of their HPA axis are not well described. Previous studies on plasma cortisol levels have suggested seasonal (Kenagy et al., 1999) and environmental-dependent responses (Bauer et al., 2013; Soto-Gamboa et al., 2005). The impact that the long-term laboratory housing has on the HPA function of degus is not clear. In general, the glucocorticoids responses have been reported for a variety of vertebrate taxa, but remain unknown for most mammals.

We investigated the concentration of plasma cortisol at basal levels and during the stress response. We assessed variations in the magnitudes of cortisol elevation in: (1) Free living individuals of one natural population during two different life history stages, the "non-reproductive season" and the "mating season". During the mating period degus typically show a strong increase in the agonistic interactions with high social instability (Soto-Gamboa et al., 2005). Hence, our first aim was to assess how seasonal demands affect HPA axis regulation, and also to obtain a parameter of stress responsiveness under natural condition. (2) One laboratory group of captive-wild degus and one group of first generation individuals raised in a laboratory. Degus were related to the same natural population studied in the first aim. (3) Laboratory degus from a different high altitude population. This population occurs in the Andes Mountains and is geographically separated from the population studied in the previous aims. In the same way, we used one group of captive-wild degus and one group of first generation individuals raised in laboratory. The laboratory groups of the two populations described were maintained under the same controlled conditions for 1 year and were measured only at the non-reproductive state (i.e. neutral physiological state). We tested whether the plasma cortisol profiles differ between populations when individuals are held in identical laboratory conditions for 1 year. And also, when individuals from both populations were born and grown for 1 year at the same condition. We experimentally controlled for the influence of environment by conducting a common garden experiment.

We present these results in an effort to establish a plasma cortisol profile in degus as a physiological parameter under natural and captivity contexts. We expect this work to contribute to a broader understanding of mammalian cortisol modulation and its link to behavioral ecology, biomedicine, and animal welfare.

2. Materials and methods

2.1. Subject

The degu is an endemic caviomorph rodent of central Chile with a unique evolutionary lineage, long life, and manageable body size. Moreover they are diurnal, highly social, and relative easy to care for in captivity. Because of these and other characteristics, degus have become an important experimental model that can be bred for many generations (Lee, 2004).

2.2. Free living animals

We investigated a typical natural population of degus in central Chile, Rinconada de Maipú (33°29′S, 70°53′W, 480 m a.s.l.) a field station of the Universidad de Chile located 30 km south-west from Santiago. This population is situated in the Chilean "matorral" zone characterized by marked seasonality with hot and dry summers and cool and moist winters (Fulk, 1976; Vasquez, 1997; Vasquez et al., 2002). In order to assess the seasonal variation of the plasma cortisol baseline, one adult group of six males and five females was caught and sampled during the summer (non reproductive stage) during the first 2 weeks March 2007, and another adult group of five males and nine females was sampled in fall (mating season) during the last week of May and the first week of June 2007. We used 80 Sherman live traps with a grid structure that allowed us to look inside. All traps were located along frequently traveled paths of degus and were within 30 m radius. We were positioned at a concealed location for constant monitoring, so that, we could hear the degus being caught, and could remove them immediately.