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SHORT NOTE

Polar bear stress hormone cortisol fluctuates with the North Atlantic Oscillation climate index

Thea Ø. Bechshøft · Christian Sonne · Frank F. Rigét · Robert J. Letcher · Melinda A. Novak · Elizabeth Henchey · Jerrold S. Meyer · Igor Eulaers · Veerle L. B. Jaspers · Adrian Covaci · Rune Dietz

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Abstract Polar bears are heavily dependent on sea ice for hunting sufficient prey to meet their energetic needs. When the bears are left fasting, it may cause a rise in the levels of the stress hormone cortisol. Cortisol is the major corticosteroid hormone in most mammals, including polar bears. Production and regulation of this stress hormone are vital for the body as it is part of a myriad of processes, including in relation to metabolism, growth, development, reproduction, and immune function. In the present study, we examined the correlation between East Greenland polar bear hair cortisol concentration (HCC), a matrix that reflects longer-term hormone levels, and the fluctuations of the North Atlantic Oscillation (NAO) index, a large-scale climate phenomenon applied as a proxy for sea ice extent in the Greenland Sea along the coast of East Greenland. In doing so, a significant positive correlation ($r = 0.88$; $p = 0.0004$) was found between polar bear hair cortisol and the NAO, explaining 77 % of the variation in HCC observed between years over the period 1989–2009. This result indicates that interannual fluctuations in climate and ice cover have a substantial influence on longer-term cortisol levels in East Greenland polar bears. Further research into the implications and consequences inherent in this correlation are recommended, preferably across multiple polar bear populations.

Keywords Polar bear · Hair · Cortisol · Climate · NAO · Glucocorticoids · Stress

T. Ø. Bechshøft (✉) · C. Sonne · F. F. Rigét · R. Dietz
Department of Bioscience, Aarhus University, Box 358, Frederiksborgvej 399, 4000 Roskilde, Denmark
e-mail: thbe@dmu.dk

C. Sonne
e-mail: csh@dmu.dk

F. F. Rigét
e-mail: ffr@dmu.dk

R. Dietz
e-mail: rdi@dmu.dk

R. J. Letcher
Wildlife and Landscape Science Directorate, Environment Canada, National Wildlife Research Centre, Carleton University, Raven Road, Ottawa, ON K1A 0H3, Canada
e-mail: Robert.Letcher@ec.gc.ca

M. A. Novak · E. Henchey · J. S. Meyer
Department of Psychology, University of Massachusetts, Tobin Hall, 135 Hicks Way, Amherst, MA 01003-9298, USA
e-mail: Mnovak@psych.umass.edu

E. Henchey
e-mail: Elizabeth.Henchey@baystatehealth.org

J. S. Meyer
e-mail: jmeyer@psych.umass.edu

I. Eulaers · V. L. B. Jaspers
Department of Biology, University of Antwerp, Universiteitsplein 1, 2610 Wilrijk, Belgium
e-mail: Igor.Eulaers@ua.ac.be

V. L. B. Jaspers
e-mail: veerle.jaspers@ua.ac.be

A. Covaci
Toxicological Center, University of Antwerp, Universiteitsplein 1, 2610 Wilrijk, Belgium
e-mail: adrian.covaci@ua.ac.be

Introduction

Cortisol is the major glucocorticoid (GC) hormone in most mammals and as such responsible for a wide range of vital functions in the body, as well as responses to stress influencing metabolism and the physiology and endocrinology of the reproductive and immune systems (Hiller-Sturmhöfel and Bartke 1998). Of interest to the present study, cortisol helps control carbohydrate, protein, and lipid metabolism, primarily by stimulating various steps of the gluconeogenesis process (Hiller-Sturmhöfel and Bartke 1998). Cortisol (and corticosterone, another GC) has been used for assessing physiological and psychological stress in a wide range of animals, in matrices such as blood, bird eggs, feces, saliva, urine, feathers, and more recently hair (Koren et al. 2002; Constable et al. 2006; Van der Staay et al. 2007; Bortolotti et al. 2008; Lupica and Turner 2009; Okuliarová et al. 2010; Bechshøft et al. 2011, 2012a, b). Feather and hair samples have the advantage that they express chronic stress rather than short-term hormonal fluctuations caused by circadian rhythms or the stress of hunting or live capture (Koren et al. 2002; Bechshøft et al. 2011). Measuring hair cortisol concentration (HCC) in polar bears is a relatively new venture (Bechshøft et al. 2011), and one that is gaining interest (Vongraven et al. 2012). The polar bear is a protected species, although strictly regulated hunting is legal in some places, often limited by quotas to native hunters (Obbard et al. 2010). Thus, noninvasive methods for assessing stress and the causes behind it are valuable tools when examining the health of the entire circumpolar polar bear population. One such biomarker tool could be polar bear hair, a noninvasive matrix which can even be obtained remotely by the use of hair traps.

During the time period covered in the present study (1988–2009), overall sea ice extent and concentration in East Greenland have decreased substantially (Vinje 2001; Bader et al. 2011 and references therein). Polar bears rely mainly on seal blubber as their main source of energy and so are heavily dependent on sea ice for hunting sufficient prey to meet their energetic needs (Stirling et al. 1999; Cherry et al. 2009). The bears are thus especially vulnerable to a diminished and/or fragmented ice cover, a fact supported by an ever increasing number of studies (as reviewed by Stirling and Derocher 2012). Among other, the changes in sea ice and less easy access to prey have been found to lead to a larger portion of bears fasting in the spring months, lowered reproductive rates, lowered survival, and a decrease in general body condition (Stirling et al. 1999; Cherry et al. 2009; Regehr et al. 2010). In addition, there are indications that the bears spend more energy on swimming and navigating in a fragmented terrain (Stirling and Derocher 2012). Fluctuations in climate as well as ice cover of course affect not just the bears, but also their prey, especially the all-important ringed seal pups (Ferguson et al. 2005).

In the present study, the North Atlantic Oscillation (NAO) winter index was applied as a proxy for sea ice extent in the Greenland Sea along the coast of East Greenland (based on Vinje 2001; Hurrell et al. 2003; Bader et al. 2011). The NAO is a large-scale climate phenomenon, its index value depending on the difference of atmospheric pressure at sea level between the Icelandic Low and the Azores High, as well as on the time scale on which it is calculated (monthly, yearly, etc.). Among others, the NAO winter index has been shown to correlate with changes in temperature, sea ice distribution, and precipitation patterns (Hurrell 1995; Hinkler et al. 2008). A number of studies have even found the more general NAO index a better overall climate indicator than more locally based measures (Hurrell et al. 2003). In the Greenland Sea off the coast of East Greenland, the focus area of the present study, a negative correlation has been found between the NAO index and the sea ice extent (Vinje 2001; Hurrell et al. 2003; Bader et al. 2011), meaning that a high NAO index value would generally imply less ice along the East Greenland coast.

The aim of the present study was to assess, for East Greenland polar bears, the relationship between a climate and ice cover proxy indicator (NAO index) and physiological stress levels in the bears (HCC).

Materials and methods

All hair samples were collected in East Greenland during 1988–2009. Hair from 88 polar bears (42 female and 46 male) was analyzed for cortisol according to the procedure described by Bechshøft et al. (2011), an article which also includes more details on the sampling itself. Age estimation was conducted according to Calvert and Ramsay (1998), and bears were categorized into age groups according to Rosing-Asvid et al. (2002). Female mean age was 10.5 years (range 3–26, $n = 42$), and male mean age was 8.0 years (range 3–19, $n = 46$). A single three-way ANOVA was applied to test for differences between log (cortisol) in relation to gender (male vs. female) and age (subadults vs. adults) ($n = 88$). Data were also analyzed using multivariate statistics. However, the results were the same as with the ANOVA (see below).

Hair growth in polar bears is seasonally harmonized, with a partial molt occurring over the summer months and a subsequent renewal of the fur that primarily happens during the late fall months (Pedersen 1945). The correlation between mean annual HCC of the samples and the NAO index was analyzed using Pearson's correlation test.

Only years with cortisol results from at least two individuals were used in this analysis, which meant a total of 11 years and 84 individuals (Fig. 1). We used the NAO December–March winter index available at the National Centre for Atmospheric Research (Hurrell 2012).

Results

Hair cortisol concentration was not dependent on sex (male, female; $F_{(1,86)} = 1.44$; $p = 0.23$) or age (adult, subadult; $F_{(1,77)} = 1.38$; $p = 0.22$). Therefore, no age or sex classification of the data was done in the ensuing analysis. Mean HCC of all individuals was 12.75 pg mg^{-1} (range: 3.98–24.42, $n = 88$). Mean annual HCC and the NAO index were positively correlated ($p = 0.0004$, $r = 0.88$) (Fig. 1), with the NAO explaining approx. 77 % of the variation in hair cortisol across the period of 1989–2009.

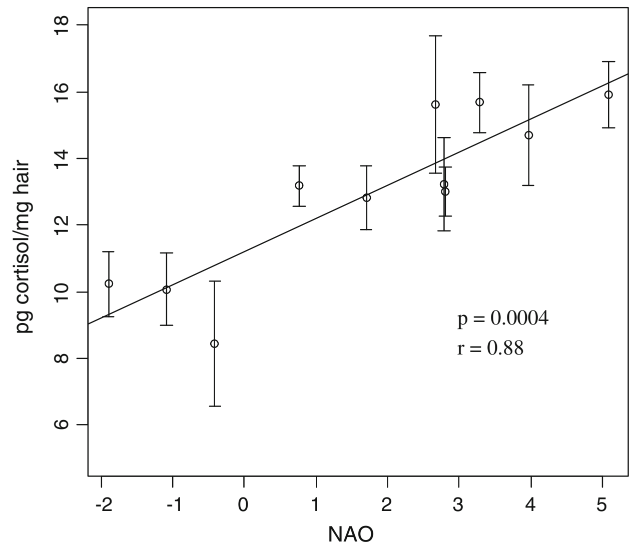

Fig. 1 Scatter plot of mean annual cortisol concentrations in East Greenland polar bear hair samples (pg mg^{-1} hair) versus NAO winter index values. ($p = 0.0004$, $r = 0.88$, $n = 11$ years/84 individuals). Circles represent the mean annual cortisol concentration ± 1 SE. From *left* to *right*, the years plotted are as follows: 2001 ($n = 7$), 2006 ($n = 14$), 2009 ($n = 7$), 2002 ($n = 2$), 1999 ($n = 13$), 1993 ($n = 7$), 2007 ($n = 7$), 2000 ($n = 8$), 1992 ($n = 9$), 1990 ($n = 6$), 1989 ($n = 4$)

Discussion

Hair cortisol concentration was not dependent on sex or age in the present study, which is in accordance with the hair studies by Bennett and Hayssen (2010; domestic dog, *Canis familiaris*) and Macbeth et al. (2010; grizzly bear, *Ursus arctos*). However, studies on cortisol in other matrices and different species have seemed more inconclusive in this regard (Handa et al. 1994; Tryland et al. 2002; Oskam et al. 2004). With regards to polar bears, a recent study by Macbeth et al. (2012) found significant differences in HCC between southern Hudson Bay (SH) bear sex-reproductive classes. The East Greenland hunter-collected samples of the current study were not divided into sex-reproductive classes, as females may only be hunted if alone (that is, not in company of cubs and hence not lactating). This also means that there are no dependent young among the sampled bears.

The East Greenland polar bear HCC and the NAO index were positively correlated, with the NAO explaining approx. 77 % of the variation in hair cortisol. If we take the NAO index to be a climate and ice cover proxy indicator (Vinje 2001; Hurrell et al. 2003; Bader et al. 2011), this indicates that the bears are under higher levels of physiological stress during years with less ice cover and thus less easy access to seals.

Increased cortisol levels have been associated with fasting in a number of mammal species, including humans (Ward et al. 1992; Faucitano et al. 2006), although reported results are not always consistent between sex and age classes (Faucitano et al. 2006; Bennett et al. 2012). With regards to polar bears, Hamilton (2007) found that the length of sea ice coverage and fasting was the strongest determinant of serum cortisol levels in Hudson Bay bears, in contrast to which Chow et al. (2011) found no difference in serum total cortisol concentrations between individuals in feeding and fasting states. This difference could perhaps be due to blood values being inconsistent across studies as they (unlike hair) are likely to reflect the acute stress response caused by the chase, darting, and anaesthetizing of the sampled bears. When analyzing hair, Macbeth et al. (2012) found that cortisol levels were significantly higher the more days had passed between the date of 50 % sea ice break-up and the time the bears were sampled (hair growth in SH bears is believed to occur during this onshore fasting period).

Chow et al. (2011) found a higher corticosteroid binding globulin (CBG) expression in fasting individuals compared to those feeding, suggesting a fasting adaptation that may include a decrease in the bioavailability of GCs either by reducing total GC levels and/or by elevating CBG content. To elucidate further on the issue of free versus bound cortisol in blood and serum, respectively, as well on how these levels relate to the ones measured in hair, it would be interesting to analyze the CBG content in blood samples from the East Greenland bears examined here. Further studies of how endogenous as well as xenoendocrine substances are incorporated into the hair of polar bears and how they relate to the levels in other matrices such as blood are much needed if we are to understand this process in its entirety (Sonne 2010).

The analyzed East Greenland samples unfortunately come from animals with no available data on body condition. However, a negative association was recently found in SH bears between HCC and bear length, mass, and body condition, all growth indices related to fitness (Macbeth et al. 2012).

Changes in the ecology of polar bears have also previously been associated with large-scale climate variation. For example, Derocher (2005) found that in Svalbard polar bears, litter production and natality declines were negatively correlated with the Arctic Oscillation index, a close relative of the NAO.

In conclusion, the observations in the present study indicate that interannual fluctuations in large-scale climate and ice cover have a substantial influence on longer-term HCC in East Greenland polar bears. This could be interpreted as the bears' inherent ability to maintain homeostasis under changing environmental conditions. However, it also raises the question of the limits in climate fluctuations that polar bears can survive and the extent to which they may be affected by the adverse physiological effects of chronically raised cortisol levels. Overall, a fuller understanding of polar bear endocrinology becomes ever more pertinent, as evidence mounts that levels of cortisol and other hormones in polar bears are also affected by the long-range transported contaminants found in the Arctic (reviewed by Sonne 2010; Bechshøft et al. 2012 a, b). In addition, the present study is an important step in assessing the uses of hair as a novel polar bear biomarker matrix. Further research into the implications and consequences inherent in the results presented here as well as in other polar bear HCC studies (Bechshøft et al. 2011, 2012a, b; Macbeth et al. 2012) are recommended, preferably across multiple polar bear populations.

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