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Contaminants and energy expenditure in an Arctic seabird: Organochlorine pesticides and perfluoroalkyl substances are associated with metabolic rate in a contrasted manner

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ABSTRACT

Basal metabolic rate (BMR), the minimal energetic cost of living in endotherms, is known to be influenced by thyroid hormones (THs) which are known to stimulate *in vitro* oxygen consumption of tissues in birds and mammals. Several environmental contaminants may act on energy expenditure through their thyroid hormone-disrupting properties. However, the effect of contaminants on BMR is still poorly documented for wildlife. Here, we investigated the relationships between three groups of contaminants (organochlorines (OCs), perfluoroalkyl substances (PFASs), and mercury) with metabolic rate (MR), considered here as a proxy of BMR and also with circulating total THs (thyroxine (TT4) and triiodothyronine (TT3)) in Arctic breeding adult black-legged kittiwakes (*Rissa tridactyla*) from Svalbard, during the chick rearing period. Our results indicate a negative relationship between the sum of all detected chlordanes (ΣCHLs) and MR in both sexes whereas perfluoro-tridecanoate (PFTrA) and MR were positively related in females only. MR was not associated with mercury. Additionally, levels of TT3 were negatively related to ΣCHLs but not to PFTrA. The findings from the present study indicate that some OCs (in both sexes) and some PFASs (only in females) could disrupt fine adjustment of BMR during reproduction in adult kittiwakes. Importantly, highly lipophilic OCs and highly proteinophilic PFASs appear, at least in females, to have the ability to disrupt the metabolic rate in an opposite way. Therefore, our study highlights the need for ecotoxicological studies to include a large variety of contaminants which can act in an antagonistic manner.

1. Introduction

Understanding the concept of energy allocation toward maintenance requirements, activity, growth and reproduction is a central goal which integrates both ecology and physiology. Usually considered as the minimal energetic cost of living, basal metabolic rate (BMR) is defined as the lowest rate of energy expenditure in a post-absorptive, adult endotherm at rest in its thermoneutral zone (Bligh and Johnson, 1973; Ellis and Gabrielsen, 2002; McNab, 1997). BMR is by far the most widely assessed parameter in vertebrate energetics (Danforth and Burger, 1984; Ellis, 1984) and has been described for a large variety of species from a wide geographical range (Bryant and Furness, 1995; Ellis, 1984; Ellis and Gabrielsen, 2002; Scholander et al., 1950). Although subject to circadian and seasonal fluctuations (Aschoff and Pohl, 1970; Kendeigh et al., 1977), a significant part of BMR variation within and between species can be attributed to adaptations either to specific environmental conditions or to particular behavioral traits of the species (Bech et al., 1999; Burton et al., 2011; Gabrielsen, 1994; Verreault et al., 2007).

Thyroid hormones (THs) are involved in a multitude of physiological traits and are known to regulate metabolism. Specifically, thyroxine (T4) and especially triiodothyronine (T3) are considered as the major controllers for the regulation of tissue oxygen consumption, thermogenesis and metabolic activity in endotherms (Bobek et al., 1977; Danforth and Burger, 1984; Freake and Oppenheimer, 1995; Hulbert, 2000). The roles of THs in the regulation of metabolism have been well

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documented in laboratory studies (Hulbert, 2000; Kim, 2008; Silvestri et al., 2005), and several investigations conducted in domestic as well as in free-living animals have highlighted strong and positive associations between total T3 (TT3) levels and BMR (Bobek et al., 1977; Chastel et al., 2003; Elliott et al., 2013; Vézina et al., 2009; Welcker et al., 2013; Zheng et al., 2013).

Over the last few years, a significant amount of studies have led to the hypothesis that exposure to environmental contaminants could be the cause of disruption of thyroid function or BMR and several studies have reported abnormal TH concentrations and thyroid gland structure in birds exposed to contaminants under controlled laboratory conditions, as well as in free-ranging populations (Cesh et al., 2010; reviewed in Dawson, 2000; Haugerud, 2011; reviewed in McNabb, 2005; reviewed in McNabb and Fox, 2003; Melnes, 2014; Nøst et al., 2012; reviewed in Rolland, 2000; reviewed in Scanes and McNabb, 2003; Smits et al., 2002; Verreault et al., 2004, 2007, 2013; Wada et al., 2009). Besides, circulating levels of THs appear to be suitable biomarkers as measures of contaminant-associated effects in wildlife (Fox, 1993; McNabb, 2005; Peakall, 1992; Rolland, 2000). Effects of contaminants on metabolic activity are still poorly known and largely debated in the literature, since the few studies that have investigated this topic in adult birds and mammals are limited and somewhat contradictory. Briefly, decreased metabolic rate was observed in mourning doves (*Zenaida macroura*) exposed to the polychlorinated biphenyl mixture (PCB) Aroclor 1254 (Tori and Mayer, 1981) and in pigeons (*Columba livia*) fed with high doses of dichlorodiphenyltrichloroethane (DDT, Jefferies and French, 1971). Similarly, a previous study conducted in an Arctic seabird, the glaucous gull (*Larus hyperboreus*), revealed negative associations between BMR and plasma concentrations of PCBs, DDTs, and particularly chlordane and its metabolites (CHLs, Verreault et al., 2007). In contrast, other studies have reported an increased metabolic rate in response to contamination, as in DDT-exposed short-tailed shrews (*Blarina brevicauda*, Braham and Neal, 1974) and PCB-exposed white-footed mice (*Peromyscus leucopus*) (Voltura and French, 2000).

High latitudes are considered as a sink for environmental pollutants due to atmospheric long-range transport and oceanic currents in combination with a cold climate (Burkow and Kallenborn, 2000). Given their properties (i.e. high volatility and/or persistence), organic pollutants and heavy metals can reach remote areas such as the Arctic (AMAP, 2010, 2011). Once deposited in the marine ecosystem, most of those chemicals bioaccumulate in birds *via* food intake. Due to biomagnification, this exposure will then increase in severity throughout food webs (Atwell et al., 1998; Blévin et al., 2013; Kelly et al., 2009; Letcher et al., 2010). Several Arctic seabirds occupy relative high trophic levels and are consequently particularly exposed and sensitive to high concentrations of environmental contaminants. They are thus relevant biological models to investigate the influence of contaminant exposure on energy expenditure in wildlife (Gabrielsen and Henriksen, 2001; Letcher et al., 2010). In Svalbard, black-legged kittiwakes (*Rissa tridactyl*a, hereafter "kittiwakes"), are exposed to a complex mixture of harmful halogenated compounds and heavy metals which correlates with impaired fitness and population dynamic through their endocrine-disrupting properties (Goutte et al., 2015; Tartu et al., 2013, 2014, 2015, 2016). Among them are (1) toxic trace elements of both human and natural origins such as mercury (Hg) which tends to decrease in the Arctic (Cole et al., 2013); (2) the globally decreasing legacy persistent organic pollutants (POPs) which have been extensively used in the past and now banned by the Stockholm convention (Helgason et al., 2008; Rigét et al., 2010); and (3) poly- and perfluoroalkyl substances (PFASs) such as the long-chained perfluoroalkyl carboxylic acids (PFCAs) which currently are the most prevalent PFASs in Arctic biota (Butt et al., 2007, 2010; Tartu et al., 2014). Kittiwakes are thus potentially exposed to a broad cocktail of contaminants with many possible additive, synergistic, as well as antagonist effects.

In kittiwakes, significant relationships between concentrations of OCs, PFASs, Hg and several hormones (e.g. THs, corticosterone) involved in energy metabolism have been observed (Ask, 2015; Tartu et al., 2014, 2015, 2016). Because THs are known to exert a strong control on the regulation of metabolic functions in kittiwakes (Elliott et al., 2013; Welcker et al., 2013), individuals exposed to high concentrations of those chemicals may experience altered metabolic activity in response to disrupted thyroid function. We tested this assumption by investigating the relationships between three groups of contaminants (OCs, PFASs, and Hg) with metabolic rate (MR), considered here as a proxy of BMR and also with circulating concentrations of total THs (TT3 and TT4) in a kittiwake population from Svalbard (Norwegian Arctic). Because BMR is considered as a life-history component (reviewed in Burton et al., 2011), such relationships between contaminants and basal energy expenditure could potentially be related to the decreased survival rate, lower hatching success and breeding probabilities as previously reported in the most contaminated kittiwakes in Svalbard (Blévin et al., 2016; Goutte et al., 2015; Tartu et al., 2014).

2. Material and methods

2.1. Study area and sampling collection

Fieldwork was carried out in 2012, from July 12th to 27th in a colony of black-legged kittiwakes at Kongsfjorden (78°54′N; 12°13′E), Svalbard. A total of 44 individuals (22 males and 22 females) were caught on their nest with a noose at the end of a 5 m fishing rod during the chick rearing period (when raising chicks). At capture, a 2 mL blood sample was collected from the alar vein using a heparinized syringe and a 25-gauge needle to assess contaminant concentrations, TT3 and TT4 levels (when enough blood) and to determine the sex of individuals. Blood samples were stored on ice in the field. Whole blood and both, plasma and red blood cells obtained after centrifugation were kept frozen at −20 °C until subsequent analyses in the lab.

2.2. MR measurements

MR measurements were performed on 23 individuals (12 males and 11 females) among the 44 kittiwakes that have been caught in total. After capture and blood sampling, birds were kept in an opaque box and rapidly transported by boat (within 20 min) to the laboratory in Ny-Ålesund to measure MR by open-flow-through respirometry measurements of at least two hours duration. Outside air was drawn into the lab and dried in indicator silica gel before entering a 41 L plexiglass chamber holding the bird. Air was drawn past the bird and into a Sable Systems FoxBox® analyzer at a rate of 1.92 ± 0.04 (sd) L/min. CO_2 was measured by the FoxBox, after which the air was scrubbed of CO_2 with indicator soda lime and dried again with indicator silica gel before returning to the FoxBox where O_2 was measured. Prior to and following each MR measurement, the bird was weighed to the nearest 0.1 g on an electronic balance and its body temperature was taken with a Schultheis fast-reading reptile mercury thermometer accurate to 0.2 °C. During metabolic measurements, the chamber was covered with a towel to allow diffuse light while preventing the bird from observing its surroundings. This was necessary because the chamber was not in a temperature cabinet but on a lab bench where it was exposed to room temperatures. Chamber temperature (T_a) was monitored continuously by a probe connected to the FoxBox and averaged 19.2 ± 1.8 °C (sd; ranged from 15.1 to 22.7 °C). Body temperature (T_b) averaged 40.5 ± 0.7 °C (sd; ranged from 38.8 to 41.9 °C). Readings of all gases, flow rate, and T_a were made every 20 s by the FoxBox and recorded with a time stamp on a laptop computer. Most kittiwakes caught on their nest had been there for an unknown period of time, so it was not known if they were entirely post-absorptive. For that reason, metabolic measurements were not typically begun until about 4 h post-capture. By itself, that did not guarantee a post-absorptive condition, but the time