Title: Seasonality in Amniotes: an introduction to the Special Issue on seasonal rhythms in birds and mammals

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Introduction

Seasonal rhythms are pervasive across the animal kingdom. There is remarkable diversity in how mammals and birds integrate environmental factors to time seasonal transitions in life history events. Both use the annual change in day length, or photoperiod, as the primary predictive cue to entrain endogenous circannual cycles (Wingfield, 2018). Other supplementary environmental cues such as temperature and social context often have robust sex-dependent impacts on neuroendocrine substrates to fine-tune annual cycles (Tolla and Stevenson, 2020). The aim of the Special Issue “Seasonal Rhythms in Amniotes” was to provide a series of manuscripts that covered the proximate mechanisms that control seasonal rhythms in mammals and birds. The selection of manuscripts focussed on the role of deep brain photoreceptors and melatonin for light-dependent regulation of physiology, neuroplasticity, and behavior.

In birds, light detection by the brain has been known for almost 100 years (Benoit, 1934). A series of opsins receptors are distributed across multiple regions in the brain with high expression of vertebrate ancient opsin, neuropsin and melanopsin present in the hypothalamus (Perez et al., 2019). In this issue, Jonathan Perez described the criteria required for opsin-dependent light detection deep in the hypothalamus. Current evidence suggests that vertebrate ancient opsin and neuropsin are the candidates for light detection and met most of the criteria for the avian photoperiodic response. The findings indicate that multiple opsins are likely involved in the photoperiodic regulation of seasonal reproduction in birds. However, photoperiod cycles entrain endogenous rhythms in reproductive physiology in birds (Gwinner and Dittami, 1990). The molecular and cellular basis of endogenous circannual timing of reproductive physiology is poorly understood. External coincidence timing was used to describe the roles of photoperiodic cues and endogenous circannual programs to time seasonal reproduction (Dawson et al., 2001). Liddle and colleagues proposed an updated mechanism in which pituitary cell types, consisting of thyrotropes and gonadotrophs, possess circannual timers that independently track time of year. Light pulses during a restricted period, called the photoinducible phase requires the action of both pituitary cell types to drive the avian photoperiodic response (Liddle et al., 2022).

Most photoperiodic studies used temperate zone animals. The contribution from Sharma and colleagues (2022) describes the role of photoperiodic cues to time seasonal transitions in latitudinal migration by palearctic-Indian birds. The authors show that a suite of molecular changes including thyroid hormone catabolism achieved by the deiodinase enzymes type-2 and type-3, and circadian clock genes, period 2 and cryptochrome 1 in the mediobasal hypothalamus are key molecular correlates of transitions from spring to winter migration. However, the neural and molecular substrates that control the autumnal transition and onset of migration is not the same. This issue describes the contribution of circannual programs, the circadian clock and seasonal changes in circulating hormones to orchestrate organismal wide functional changes to synchronize peripheral tissues in anticipation of breeding and non-breeding states. Most tropical birds are non-migratory and show seasonal, non-seasonal, or opportunistic breeding. Renthlei and colleagues (2022) highlight the role of molecular changes in the hypothalamo-pituitary gonadal, and adrenal axes in the timing of reproduction in tropical birds. The authors show that thyroid-hormone dependent molecular switches in the mediobasal hypothalamus occur in tropical birds, similar to temperate zone amniotes.

The final manuscript to discuss seasonality in birds incorporates exciting advances from *in vivo* imaging brain circuits in European starlings (*Sturnus vulgaris*). A discrete neural circuit called the 'song system' is critical for the perception, production and learning of complex vocalizations and birdsong (Tramontin and Brenowitz, 2000). Orije and Van der Linden (2022) outline the significance of *in vivo* magnetic resonance imaging of male and female starling brains and illustrate that microstructural changes can be identified to monitor neuroplasticity over seasonal timescales. The research described uncovered new patterns of seasonally programmed morphological changes in both male and females in response to hormones (e.g., testosterone, thyroid hormone) and revealed a heightened level of multisensory neuroplasticity across the year.

Unlike birds, mammals do not use brain photoreceptors to regulate seasonal physiology. Instead, mammals detect light via the retina and use the nocturnal duration of melatonin secretion from the pineal gland to orchestrate seasonal physiology (Stevenson et al., 2017). Melatonin actions have a powerful effect on multiple neural substrates involved in reproduction. Munley and colleagues (2022) focussed on photoperiod induced changes in melatonin signalling to drive physiological and cellular changes involved in aggressive and non-aggressive social behavior. The authors cover recent findings indicating that melatonin-dependent changes in steroid enzymes and receptors in localized brain regions, such as the lateral septum and medial amygdala, are critical for increasing the intensity and probability of male and female aggression. The authors propose that melatonin also stimulates the production of other prohormones, such as adrenal androgen dehydroepiandrosterone (DHEA) which is converted by steroid enzymes to increase aggressive behavior in rodents. In addition to steroid-dependent signalling pathways, melatonin action also induces a change in regional blood flow in the brain. Annual changes in localized blood availability achieved via angiogenesis in the testes was proposed to be a major contributor to seasonal changes in testes growth and involution (Young and Nelson, 2000). Recent findings outlined by Tortonese indicates that melatonin also impacts angiogenesis in the pituitary and suggest that hormone-driven changes in vascular endothelial growth factor isoforms are a critical step in the photoperiodic timing of reproduction in sheep (Tortonese, 2022). Finally, lactotrophs were previously established as circannual timers in sheep (Lincoln et al., 2006). Research advances in mouse genetic analyses and comparative histological studies in rodents and ungulates indicates a common neural circuit provides both short- and long-term control over prolactin secretion. Calum Stewart and Christopher Marshall (2022) describe prolactin signalling in both mammals and birds and argue for cell autonomous circannual timing in lactotrophs.

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