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Short Communication

Effect of Luminance on Visual Performance by Secondary Cavity and Non-Cavity Nesting Passerines

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HW conceived and designed the study. HW sampled bird. NB conducted the experiments. NB, HW and FJ analysed the data and wrote the manuscript.

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ABSTRACT

The great majority of avian species is diurnal and thus endures variation in light intensities, associated with daily, seasonal or lunar cycles. These diurnal birds search their food in light abundant environment and raise their broods in dark cavities. However their visual performance in dim light conditions is largely unknown. Here, we compared light intensity threshold of activity in two groups of passerines, *i.e.* secondary cavity and non-cavity nesting. For this purpose, different species of secondary cavity and non-cavity nesting passerines were subjected to two phases of trials: in the first trial birds were released in an experimental cage and allowed them to accommodate themselves in darkness for 10 min. In the second trial we turned on the dimmer to a given luminance for 2 min. We found that activity threshold for secondary cavity nesting passerines ranged from 0.05 to 0.2 cdm^{-2} and non-cavity nesting passerines from 22.00 to 16.00 cdm^{-2}. Our results shed light on the question about potential effect of luminance on visual performance by secondary cavity and non-cavity nesting passerines.

Light has an enormous influence on several aspects of bird biology, ecology and physiology (Oishi *et al*., 2001). In birds, the eyes, pineal organ and hypothalamus regulate circadian rhythms and photoperiodism (Oishi *et al*., 2001). Likewise, the duration of singing, development of reproductive system, level of testosterone, and molting in male birds are largely influenced by period of illumination (Dominoni *et al*., 2013). Intensity of light differs from low light conditions to brighter sunny days. Several diurnal bird species can be active in low light conditions for instance tree holes, dense forest, dawn and dusk and depend on optical system for vital behavior (Gomez *et al*., 2014).

It is evident that avian species may be highly dependent upon vision, and vision is used to control many behaviors (Martin *et al*., 2004). Generally, birds depend heavily on vision and particularly on color; however, it remains unknown if any avian species has a multifocal optical network or not (Lind *et al*., 2008). Majority of diurnal birds have circular pupils and relatively high minimum f-numbers with little exception *e.g.* owls (Lind *et al*., 2008). The avian eyes have two main refractive elements; the cornea and the lens are separated by an aperture. This basic concept embodies a number of degrees of freedom, which are capable of generating a variety of visual performance (Martin and Osorio, 2008).

Most species of birds use rods for brightness detection under low light conditions and cones for color vision (Podkowa *et al*., 2019). However, it has been documented in previous studies that the tendency to encounter with this rapidly fluctuating level of light has evolved only in cavity nesters (Zhang *et al*., 2019; Larsen *et al*., 2020). Several former studies investigated that globally over 1700 and in Australia over 300 avian species use tree cavities (van der Hoek *et al*., 2017).

Several former studies investigated that many avian species either can orient or forage in lightless conditions by touch and/or sensory information (Corfield *et al*., 2015). Some of the avian species though develop invariably particular behavioral, physiological and anatomical adaptations, allowing them to effectively use these senses in the lightless conditions (Dominoni *et al*., 2020). The cave-dwelling species like oilbird (*Steatornis*

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caripensis) spend their days in dark caves maneuvering via echolocater or bat like sonar system found in their ears. Unlike the supersonic scream of the bat, the oilbird emits a clicking sound at an audible frequency of 7,000 cycles per sec. Therefore, the human ear can easily detect the pulsations of the oilbird when the bird is in flight. The bird relies on its large and highly light-sensitive eyes for night flying (Martin *et al*., 2004). Kiwis (*Apteryx* sp.) use their nostrils at the end of their long beak to detect prey before they ever see it (Martin, 2011).

In tree cavities, however, nothing is known about avian vision, which offers essential information for understanding animal communication. Several species of birds can either see and work under low light conditions, or use sensory modalities (Dominoni *et al*., 2020). However, there is no known use of specific sensory adaptations in cavity nesters and these birds are likely to rely on vision to direct their behavior within their dark cavities. This is supported by the variability in parent feeding behavior in response to manipulation of chick mouth flanges brightness and color (Wiebe and Slagsvold, 2009). When cavity nesters do not use their vision to work in total darkness, there must be a certain illumination limit beyond which sensing is difficult, as nest cavities are very dark to use (Land and Nilsson, 2002). There are therefore reasons to expect that light conditions inside dark cavities may limit both the selection of nesting sites and the evolution of nesting habit in cavity nesters (Wesołowski and Maziarz, 2012). There are however restricted data on light conditions within cavities. To provide more information on luminance, in the present study we compared light intensity threshold of activity *i.e.* movement or foraging in two groups of passerines *i.e.,* secondary and non-cavity nesting. Secondly, we also measured the feeding latency between two groups of birds.

Materials and methods

In this study, secondary and non-cavity nesting birds were caught with trapping cages in Jilin city and the adjacent areas in Jilin Province, China, between May and June 2016 and January and February 2017. We used 7 adult birds of each selected species. Secondary cavity nesting birds included great tit (*Parus major*) and sparrow (*Passer domesticus*), and non-cavity nesting birds included red-billed leiothrix (*Leithrix lutea*) and Eurasian siskin (*Spinus spinus)*. Within 4 h individuals of these species from various populations were transported to the laboratory. On arrival at the research facility, individuals were housed in 0.9 m×0.4 m×0.5 m cages under a 12:12 h photoperiod, each with side and back walls, compact upper and lower surfaces, wire netting and three small perches (Bibi *et al*., 2019). The worms, commercial seed mixtures, sunflower seeds and water were provided to the birds *ad libitum*. Sex of all the birds was determined following Svensson (1992). Exposure to humans was minimized, and the individuals were left undisturbed overnight. The individuals were released back to their natural habitat after completion of the experiment.

Individuals were placed in a light safe testing room, with walls covered with black curtain (H×L×W: 4.0×2.4×2.3 m) (Dingemanse *et al*., 2002). We placed two feeders in the experimental cage and monitored bird's activity with two cameras in the side walls. The two groups of birds were trained to hunt for prey in the experimental cage at varying luminance level 0-22 cdm^{-2} until they reached a constant latency to search and capture rate. Each test contained two blocks. In the first block, we released the birds in the experimental cage and allowed them to accommodate darkness for 10 min, then turned on the dimmer to a given luminance for 2 min and observed whether the test bird foraged or moved to engage in other activities and then the trial was terminated. Birds were trained according to the Lind and Kelber (2009) protocol for parrots (Gomez *et al*., 2014). A white paper placed horizontally just below the feeders and a luminance meter (LMT 1009) were used to calculate the luminance. Luminance meter (LMT 1009) has an angular field 3°, 1°, 20', 6' selectable. Photometer head with Si-photoelement, fine V (lamda)-approximation. It could measure distance approx. 0.50 m to infinity. During the trial we switched on the dimmer, a single detector on the luminance meter detected and measured the brightness displayed on the screen. We also recorded the readings for further use. When evaluating the light sources, we can calculate the luminance or illuminance of the source. Luminance (L) is also referred to as brightness of light source and measured in candela per square meter (cd/m^2). Illuminance (E) is the volume of light on a surface per unit, expressed in lux or lumen per unit $meter^2$, lm/m^2. The third unit of light is luminous intensity (I) which is amount of light radiating in a specific direction. It expresses itself in candela (cd). However, amount sum of light emitted by light source is denoted as luminous flux (LM). It is measured in lumens (lm).

During trial, only worms were provided to testing individual to increase their desire to feed the feeders.

Individuals were first trained at varying luminance levels. Individuals were considered as efficiently trained when they started using feeders in one trial out of two at given luminance resulting to P = 0.05 (two tailed binomial test) (Gomez *et al*., 2014). We then continued testing from decreased luminance to maximum point. Upon acclimatization for at least 10 min, individuals were presented with one feeder and we observed whether the test bird foraged or moved to engage in other activities and then the trial was terminated. Feeding latency and light intensity were recorded, however maximum latency was given to the birds that did not move or forage. After the trial, testing individuals were taken back to their aviary before release (Gomez *et al*., 2014).

Comparison between the secondary and non-cavity nesting birds were made using the independent sample t test. Difference in feeding latency between secondary and non-cavity nesting birds were calculated using generalized linear model. Individual identity was used as random factor and trial as fixed factor. We checked data for normality, and transformed variables to meet the assumptions of generalized linear model (GLM). All tests were two tailed and alpha level was set at 0.05. All data were analyzed in SPSS (V. 20 IBM). Descriptive statistics with the first and third quartiles (Q25–75%) were viewed as a mean ± standard deviation or as a median (Me) (Fernández-Juricic *et al*., 2007).

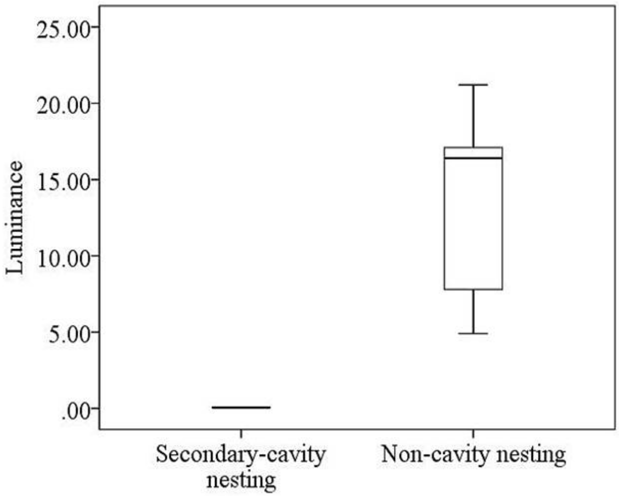

Fig. 1. Comparison between the secondary (great tit and sparrow, n = 14) and non-cavity nesting passerines (Eurasian siskin and red-billed leiothrix, n = 14) on the onset of activity/ foraging. Medians are shown (a filled line, 25–75% quartile).

Results and discussion

Data represented in this context showed the intensity threshold of vision ranged from 0.05-0.2cdm^{-2} in secondary cavity nesting passerines and 22.00 to 16.00 cdm^{-2} in non-cavity nesting passerines. Moreover, we found the significant difference in luminance between two groups of birds *i.e.* secondary cavity nesting (t = 2.897, df = 12, p-value < 0.001) and non-cavity nesting passerines (t = 3.402, df = 12, p-value = 0.05) (Fig. 1). It is also found that there is a significant difference in feeding latency in secondary cavity nesting passerines (W = 21.568, p < 0.001) and non-cavity nesting passerines (W = 19.664, p < 0.001) (Table I).

Table I.- Difference in feeding latency between secondary and non-cavity nesting birds.

Passerines	Parameter	DF	W	P
Secondary-cavity nesting	Feeding latency	13	21.568	<0.001
Non-cavity nesting	Feeding latency	13	19.664	<0.001

In this study intensity threshold of vision was tested between two groups of passerines. In our study range of luminance in secondary cavity nesting passerines is comparable to the similar values of about 0.4 and 0.1 cdm^{-2} which have been reported in budgerigars *Melopsittacus undulatus* and Bourke's parrots *Neopsephotusbourkii* (Lind and Kelber, 2009). Similarly, our results for secondary cavity nesting passerines are also comparable with Wesołowski and Maziarz (2012) for marsh tits *Poecile palustris* and great tits *Parus major*, where they reported the same figure of the range of luminance threshold (0.05 to 0.2 cdm^{-2}). Our study is also comparable with Podkowa and Surmacki (2017), where light in open nesting species like great tits *Parus major* was shown to be less important due to higher overall illumination compared to secondary cavity nesting birds constructing deeper nests.

Interestingly, several previous studies investigated chick coloration in cavities or egg in *Parus* species described variation in parental behavior manipulated a reflectance over a broad variety of wave lengths or UV ranges (Wiebe and Slagsvold, 2009; Dugas, 2009; Antonov *et al*., 2011). These earlier investigations did not, however, determine which indications were used, except in one case where birds might use brightness (Antonov *et al*., 2011).

As these cavity nesting birds have additional issues to address *i.e.* their optical system adapts to rapidly fluctuating light rates, aside from the need to be able to see in low light conditions (Cassey, 2009). Apparently, these cavity nesting birds can adapt even to fluctuating light levels, but it remains uncertain how do they do that? Certain mechanism and function of highly dynamic pupil may be involved (Lind and Kelber, 2009). Like other vertebrates, the process of dark full adaptation is relatively low also in bird's eyes, taking up to 40 min (Reynolds *et al*., 2009). It might also be possible that vision of these cavity nesters is not well adapted to the luminance level within cavities or they employ some additional but unexplained light/ dark adaptation mechanisms. A detailed investigation to highlight and uncover these mechanisms will definitely be worthwhile.

In summary, the current research has shown that the tree cavities may be really dark spots and open nesting places have higher luminance but, both secondary and non-cavity nesting birds must be able to see in low light only under certain threshold. However, for cavity nesters tending broods within the dark cavities may be possible with sustainably poorer spatial resolution relative to local foraging. Our analysis also shows that under certain natural conditions of illumination, enough light availability would be unlikely in the cavities to make vision of birds while non-cavity nesters possess a greater luminance. It means that using cavities by cavity nesters possess real sensory challenges. Therefore, we propose that it would be very instructive to record these measurements with different species; living in contrasting environments.

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Statement of conflict of interest

The authors have declared no competing interests.

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