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Age class and sex-specific ultraviolet signal enhancement in a sexually dimorphic gecko

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Animal visual signals serve highly diverse roles, where in some instances throughout ontogeny signals can change (Wilson et al., 2007). In visual ecology, recent interest has aimed to clarify how a signal can be both cryptic and conspicuous simultaneously, based on differences in perception (Bohlin et al., 2008). In many instances viewing distance influences perception where up close a signal can be perceived as highly conspicuous yet at greater distances, cryptic (Barnett et al., 2017). Contrast can also be influenced by the combinations of adjacent colour patches, and to a lesser extent the addition of wavelengths not universally visible such as those extending into ultraviolet (UV; Yeager and Barnett, 2020). The use of calibrated photography has facilitated research into animal colour pattern function and evolution (Stevens et al., 2007; Troscianko and Stevens, 2015), though when it comes to UV photography, equipment costs can be prohibitive, potentially impeding researcher's ability to discover and document such signals. Therefore, opportunely documenting visual signals that are not universally visible to viewers such as humans, is a valuable addition to natural history literature.

The few studies of *Gonatodes* colouration that exist emphasise sexually dimorphic visual signals, particularly highlighting the male head ornamentation in species such as *G. albogularis* (Ellingson, 1994). The vision of diurnal gecko species like *G. albogularis* has been assessed and found to include visual discrimination of human-visible wavelengths, as well as UV sensitive photoreceptors (Ellingson et al., 1995). Interestingly, *G. albogularis* was not found to display any UV reflectance in yellow male visual signals, suggesting that although UV photoreceptors were found, they likely would not serve a role in sexual selection. Here we afford preliminary evidence of UV+ signal contrast among juvenile and adults of a different sexually dimorphic *Gonatodes* gecko, *G. caudiscutatus* (Fig. 1). Throughout its distribution *G. caudiscutatus* shows considerable phenotypic divergence, varying in colouration and pattern most notable in males, and to a lesser extent females (see Sturaro and Avila-Pires, 2013), although the causes and consequences of phenotypic divergence remain untested.

An adult male, an adult female, and a juvenile *G. caudiscutatus* were opportunistically photographed in natural lighting following identical methodologies detailed in Yeager and Barnett (2020) using a tripod mounted full-spectrum quartz converted Canon EOS 7D camera paired with a Nikkor EL 80mm metal body lens (known for high UV transmission). In brief, two photographs were taken using a series of 2” pass filters to permit collection of human-visible and secondly UV images, where all photos contained 10% and 77% reflectance standards. To estimate how adjacent UV+ and UV- gecko colour pattern elements contributed to contrast we modelled perception in the MICA toolbox (Troscianko and Stevens, 2015) in ImageJ v1.52k (Schneider et al., 2012) using the models of the blue tit (*Cyanistes caeruleus*, Paridae). Two distinct models were used, one of which included UV wavelengths (300-700 nm), the second excluded them and included only the human visible spectrum (400-700 nm) following previous studies (Yeager and Barnett, 2021). For full, detailed methods see Yeager and Barnett (2020). We calculated chromatic and achromatic (luminance) contrasts between adjacent patches of grey/white coloured patches which showed some UV+ reflectance in UV images, against their nearest alternative (grey/black) coloured patch. For the male the white ocellus was compared to the black ring surrounding the ocellus, female middorsal white/grey patches were compared against surrounding grey patches, and in the juvenile white caudal rings were compared against alternating

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grey/black rings. Although patches were not located in the same body regions, and therefore direct patch-to-patch comparisons cannot be drawn, these locations were chosen to include the strongest UV reflectance. Contrast measurements are reported in just-noticeable differences (JNDs) where a threshold of 1= JND is theoretically discernible, and JND > 3 are more likely to discernible (Vorobyev and Osorio, 1998; Nokelainen et al., 2019).

All contrast differences due to the including of UV were found in chromatic contrast (Fig. 1). Adult female and juvenile contrasts differences resulting from the addition of UV+ elements would be highly detectable to a potential avian predator (11.14 and 16.48 JNDs respectively), and male elements likely detectable (2.62 JNDs). The addition of UV+ elements to contrast has previously been shown to only contribute to chromatic contrast in aposematic frogs and butterflies (Yeager and Barnett, 2020; Yeager and Barnett, 2021). Overall chromatic contrast was highest (Fig. 1) in the juvenile tails (white vs. black) than male (white vs. black) and female (grey/white vs. grey). The addition of UV+ elements had no effect on achromatic contrast (all achromatic JND values << 1).

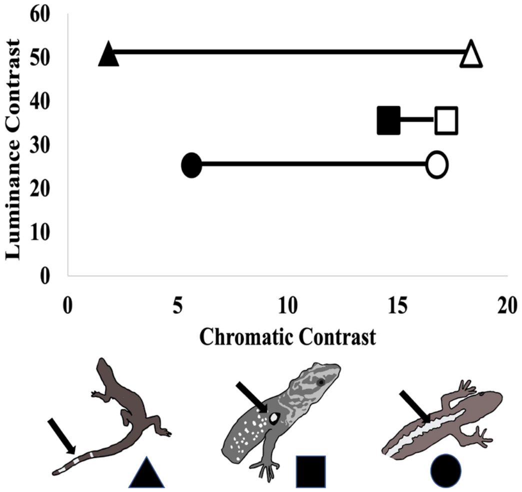

Figure 1. Contrast distances estimated using tetrachromatic avian visual models for UV+ (open shapes) and UV- models (filled shapes) representing contrast estimates (reported in just-noticeable differences (JNDs) between adjacent colour pattern patches found on juveniles (triangles), males (squares) and females (circles). Locations of UV+ reflecting regions illustrated in white, UV+ regions measured in study indicated by arrows.

Future studies are needed to resolve if, and what functional role(s) exist for contrast enhancement from UV+ elements. If one exists, perhaps the most probable function would be if juveniles are utilising a form of caudal luring, using the more highly salient and contrasting tail band consisting of UV+ and melanistic elements to deflect predatory attacks (Murali et al., 2018). Snake species such as death adders use caudal luring in juvenile age classes, which are ultimately lost throughout ontogeny as tails blend to match body colouration as adults (Crowe-Riddell et al., 2021). Though requiring explicit testing, this is a compelling potential explanation for the white caudal bands in juveniles which are subsequently absent in adults of the population we sampled.

Surprisingly, the contrast gain in the white ocellus (surrounded by black) that is found in males was the lowest of all body regions we measured. Sexual dimorphism with conspicuous head colouration in males (Pazmiño-Otamendi and Carvajal-Campos, 2019), which changes due to breeding condition suggests the presence of potentially strong sexual selection. *Gonatodes* photoreceptors are predicted to be able to resolve the colours present in nuptial displays (Ellingson et al., 1995) and conspicuous white ocelli represent obvious visual signals which would likely be highly salient even when viewed from distances. However, UV+ gains in male visual signals were the smallest of any patch measured. Benefits attributable to UV+ gains in female contrast are further not immediately clear. Females are more cryptic than males as they lack highly conspicuous nuptial colouration (Figure 1), and therefore high contrast would not be expected. High middorsal contrast could perhaps serve some disruptive colouration function (Stevens and Merilaita, 2008). While we find contrast differences due to the addition of UV+ elements, they are most pronounced in juveniles and females than in males. However further studies are needed to clarify the evolution and function of various colour pattern patches in *Gonatodes*.

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