ECOLOGY

Fluorescent Signaling in Parrots

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Fluorescent pigments appear to glow because ultraviolet (UV) light is absorbed and reemitted at longer wavelengths. Humans use fluorescence as a highlighter, but it remains a mystery whether naturally occurring fluorescence functions as a signal or is a by-product of pigment structure. Here, we test for evidence of signaling using the fluorescent plumage of parrots (*1*).

We performed mate choice experiments on wild-type budgerigars (*Melopsittacus undulatus*), in which both sexes have fluorescent yellow plumage on their crown and cheeks (Fig. 1, A and B) that is used in courtship displays. "Focal" individuals of each sex were given a choice between two "stimulus" birds of the opposite sex, one retaining fluorescent plumage on its crown (F^+ treatment) and the other with experimentally reduced fluorescence on its crown (F^- treatment) (*2*). We reduced fluorescent emission by applying sunblock to the crown. This decreased the amount of UV, which is needed for excitation (Fig. 1C), reaching the fluorescent pigment. In the F^+ treatment, petroleum jelly alone was applied. This does not specifically absorb UV, so it does not prevent fluorescent reemission. These treatment groups differed substantially in terms of fluorescence, but not in UV reflectance because neither fluorescent nor manipulated crown feathers reflect UV. To confirm that preferences were sexual mate choice rather than social signaling, we also performed trials in which the stimulus birds were of the same sex as the focal birds.

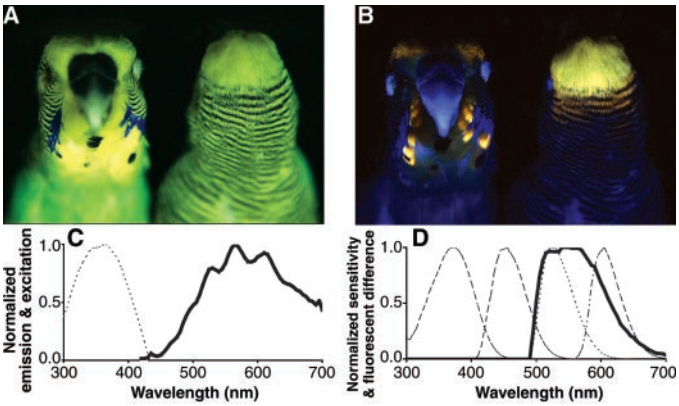

Fig. 1. Budgerigar's head (**A**) under white light and (**B**) under UV illumination to induce yellow fluorescence. (**C**) Crown irradiated with UV light only (dashed line), resulting in human visible fluorescent emission (solid line). (**D**) Normalized visual difference between the emission spectrum of plumage, measured as radiant emission from feathers (solid line) and the spectral sensitivities of the four single cones classes of the budgerigar's retina (dashed lines) (*4*).

Our experiments revealed strong evidence for fluorescent sexual signaling. When stimulus birds were of the opposite sex to the focal individual, both females (Fig. 2A) and males (Fig. 2B) showed a significant sexual preference for fluorescent stimulus birds. Mutual mate choice is expected in monomorphic, socially monogamous species, such as the budgerigar, in which both sexes provide parental care. Conversely, when stimulus birds were of the same sex as the focal birds, neither sex (Fig. 2, C and D) showed a significant social preference for F^+ or F^- birds. Given these results, we calculated the effect of fluorescence on the "color" of their plumage as perceived by another budgerigar. By measuring the reflectance spectra of the feathers (*3*) and using the known spectral sensitivities of budgerigar cone cells (*4*) (Fig. 1D), we calculated the signal difference (in relative photons) imparted by fluorescent yellow plumage (F^+ treatment) versus yellow plumage in which fluorescence was prevented (F^- treatment). Fluorescent plumage adds 14% extra "chromatic signal" to the crown region, as perceived by the visual system of another budgerigar (Fig. 1D). Moreover, the peak of the fluorescent contribution is not only ideally placed for chromatic detection by the budgerigar's middle two visual cones (or a combination of the two short cones versus the two long cones) but also coincides with the sensitivity peak of avian "double cones," thought to play a role in perceiving overall "brightness" (*5*).

These findings show that the fluorescent plumage of parrots is an adapted sexual signal, rather than a by-product of plumage pigmentation. Given the elaborate biochemical pathway by which fluorescent pigments are produced (*6*), they may be costly and thereby honest indicators of individual quality.

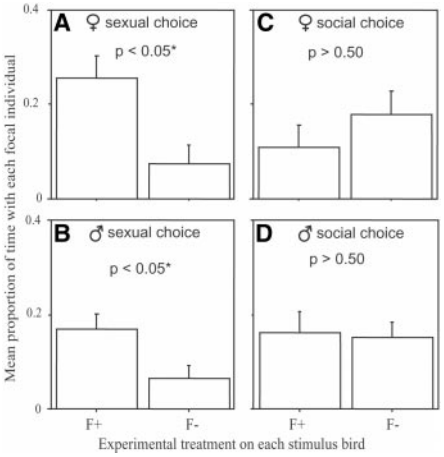

Fig. 2. Results of mate choice trials, showing mean proportion of time (± SE) spent by focal individuals with fluorescent (F^+) and fluorescent-reduced (F^-) stimulus birds. (**A**) Females show a significant sexual preference for fluorescent males ($z = 1.99$, $N = 10$, $P < 0.05$). (**B**) Males show a significant sexual preference for fluorescent females ($z = 1.99$, $N = 10$, $P < 0.05$). (**C**) Females show no social preference for fluorescent females ($z = 0.66$, $N = 10$, $P > 0.5$). (**D**) Males show no social preference for fluorescent males ($z = 0.42$, $N = 10$, $P > 0.5$).

References and Notes

1. W. E. Boles, *Birds Int.* **3**, 76 (1990).
2. We used a two-way choice apparatus, with the focal bird in a central compartment separated from stimulus birds by Perspex transparent between 300 and 700 nm. Illumination was provided by Daylight tubes and UV-rich light tubes to mimic natural conditions. Focal birds had 13 hours to acclimatize to the apparatus. Each trial lasted 4 hours. Stimulus birds were swapped between end compartments half-way through. F^- treatment was obtained by daubing feathers with 40/60% (w/w) mixture of petroleum jelly and unscented, UV-absorbing chemicals (*7*). F^+ treatment was petroleum jelly alone.
3. Under experimental light conditions, reflectance spectra were measured normal to the crown with illumination at 45° to the feather surface. Ten measures from each of ten individuals were taken. There was no fluorescent sexual dimorphism. "Fluorescent contribution" was estimated with spectral sensitivities of the budgerigar's "short" (S) and "medium" (M) wavelength cones (*4*) combined with reflectance measurements of the F^+ and F^- crown feathers. The percentage of fluorescent contribution is then given by $\{[(M \times F^+ - S \times F^+) - (M \times F^- - S \times F^-)]/(M \times F^+ - S \times F^+)\} \times 100$ (= 14.3%).
4. J. K. Bowmaker, L. A. Heath, S. E. Wilkie, D. M. Hunt, *Vision Res.* **37**, 2183 (1997).
5. D. Osorio, A. Miklósi, Zs. Gonda, *Evol. Ecol.* **13**, 673 (2001).
6. R. Stradi, E. Pini, G. Celentano, *Comp. Biochem. Physiol. B.* **130**, 57 (2001).
7. S. Andersson, T. Amundsen, *Proc. R. Soc. London Ser. B* **264**, 1587 (1997).
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