distribution appears from the origin (*3*)]? This is tantamount, in the limit of complete reference to the origin, to substitution of the raw relationship

$$R = \left\{ \frac{[\Sigma x_i y_i]^2}{\Sigma x_i^2 \Sigma y_i^2} \right\}^{1/2}$$

for the correct definition of the correlation coefficient

$$r = \left\{ \frac{[\Sigma(x_i - \bar{x})\,(y_i - \bar{y})]^2}{\Sigma(x_i - \bar{x})^2\;\Sigma(y_i - \bar{y})^2} \right\}^{1/2}$$

in quantitative evaluation of linear association. It is well known, however, that R can be made as near unity as desired by translation of the point-cloud distribution with respect to (away from) the origin; r remains invariant to such transformations (*4*). Increasing scale gives the impression of such movement and hence the erroneous conception of improved association (correlation).

This explanation raises several other pertinent questions, some of which may be answerable from data already available from this or related studies. The first is whether significant differences are to be noted between the responses of more sophisticated subjects and those less so, such as beginning statistics students, to whom the role of the mean would be expected to be less obvious. (The existence of this comment suggests not.) Another question is whether complete absence of axes (that is, having point-clouds on otherwise bare panels) or translation of axis origin to the center of gravity of the point clouds or otherwise (without rotation) would change the perceptions and hence the subjects' responses significantly. Such translation without rotation of course maintains the same value of r. Conversely, would different judgments of linear association accompany axis rotation that changes the value of r?

Thus, although the procedures described by Cleveland *et al.* for uncovering perceptual strategies in judging association are clear for the case of centered data, they may not apply when other forms of presentation are used.

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References and Notes

1. W. S. Cleveland, P. Diaconis, R. McGill, *Science* **216**, 1138 (1982).
2. "Degree of association" on a scale of 0 to 100 was the terminology used in the instructions to subjects in two of the three studies. The scatterplot families were in fact separated uniformly by 0.1 from 0.1 to 0.8 in the measure $w(r) = 1 - \sqrt{1 - r^2}$, where r is the correlation coefficient (with $w(r)$ cases of 0.0 and 0.05 thrown in for good measure). In the third experiment, choices of the more highly correlated scatterplot of pairs were requested.
3. Models where the magnitudes of the individual points with respect to the origin are intended do exist. These correspond to regression through the origin by specification or weighting. [G. W. Snedecor and W. G. Cochran, *Statistical Methods* (Iowa State Univ. Press, Ames, ed. 6, 1967), pp. 166–170; M. E. Turner, *Biometrics* **16**, 483 (1960); S. Ehrenson, *J. Org. Chem.* **44**, 1793 (1979)].
4. J. C. Arnold and I. J. Good, *J. Stat. Comp. Simulation* **14**, 69 (1981).
5. This work was carried out at Brookhaven National Laboratory under contract with the Department of Energy and supported by its Office of Basic Energy Sciences.

15 June 1982; revised 9 August 1982

If, as Ehrenson suggests, a subject unconsciously adds the lower left corner of the frame, then it might be that the upper right corner is added as well. We could test all of this with experiments the same as our previous ones, but with the major axis of all point clouds equal to something other than 45°. A competitor to the hypothesis of an unconscious addition of corners is a second hypothesis that the total amount of white space between the frame and the cloud is the important factor. This second hypothesis would predict a similar result in the new experiments as in the old; the first would predict no effect or a lessened effect of a change of point-cloud size.

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Radiation Angle and Heat Transferred to a Bird

In a study of thermoregulatory effects of avian plumage, Lustick *et al.* (*1*) draw two unsubstantiated conclusions: (i) "as the angle of incidence increases, the reflection coefficient goes up no matter what the color" of the feathers, and (ii) "as the bird increases the angle of incidence to direct solar radiation through postural changes . . . color becomes less important," or more specifically that "a dark bird by postural adjustment (increasing the angle of incidence) can effectively become white with regard to solar radiation."

A major difficulty is that analysis omitted the principal variable affected by increased incidence angle: the effective area being irradiated. Absorbed radiant power (R) is governed by $R = A\alpha I$, where A is the silhouette area being irradiated, α the absorption coefficient, and I the irradiance (*2*). Lustick *et al.* (*1*) held I constant and apparently assumed that the inferred change in R was due to altered α, whereas the main effect is actually due to change in A. If a square plane x on a side is normal to the radiation axis, its silhouette area is x^2; but if that square be tilted through an angle θ along any axis parallel to one of its sides, its silhouette has the dimensions x and $x\cos\theta$, for a silhouette area of $x^2\cos\theta$ (*3*).

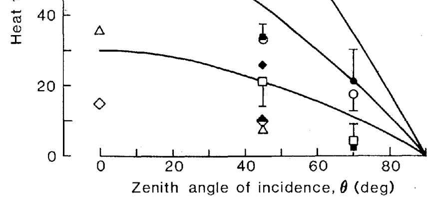

Fig. 1. The expected decrease in heat flow with incidence angle due to decreased area of irradiance is shown by lines calculated with three sample cosine functions having different maximum heat flows at 0° zenith angle. The actual heat flows measured in (*1*) are shown by data points for four experiments with different air temperatures. Error expressions are included where given in (*1*), space on the graph permitting; points not plotted at $\theta = 70°$ are all zero.

There is insufficient information in (*1*) to model heat transfer of the plumage completely (*4*), but one may compare the measured heat flow beneath the feathers with the reduction expected from reduced silhouette areas. Figure 1 shows that the transferred heat does indeed decrease markedly with greater zenith-angle of incidence. However, it does so primarily because of the reduced silhouette area, as indicated by the cosine curves for sample maximum values of 100, 60, and 30 W/m². It might also be true that "as the angle of incidence increases, the reflection coefficient goes up" (*1*), but such an effect would be too small to detect in the data-variability at low angles. Furthermore, there is no evidence that by "increasing the angle of incidence" the bird "can effectively become white" (*5*).

Does the experiment apply to real birds in sunlight? By "postural adjustment" Lustick *et al.* apparently refer to bodily orientation, whereas the principal

0036-8075/82/1126-0919$01.00/0

objective would be to reduce the bird's total silhouette area, rather than the incident angle of radiation on plumage (6). If "postural adjustment" refers to feather-postures [discussed in (1) in relation to conductivity], then the experiment performed in no way mimics the actual situation. Birds do raise and lower feathers during heat stress (7), but such effects entail changes in convective heat loss (8) that were not accounted for by Lustick *et al.* (1) where the angle of the entire plumage patch rather than individual feathers was varied.

In short, the data demonstrate neither a change in reflectivity of feathers nor a relative change in properties of white and gray feathers with incidence angle. The data show only that, as the incidence angle decreases, the heat transferred to beneath the skin decreases approximately according to the expected cosine function of silhouette area regardless of feather color.

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References and Notes

1. S. Lustick, M. Adam, A. Hinko, *Science* **208**, 1052 (1980).
2. D. M. Gates, *Energy Exchange in the Biosphere* (Harper & Row, New York, 1962); W. P. Porter and D. M. Gates, *Ecol. Monogr.* **39**, 245 (1969); and many standard references. The coefficient α is dimensionless; thus, if the unit of I is watts per square meter and that of A is square meters, the units of R will be in watts.
3. The incidence angle is here expressed as the more conventional zenith-angle, found by subtracting 90° from the angles reported in (1).
4. A complete model of actual heat transferred from radiation source to the body beneath the feathers would have to take into account the radiation absorbed as governed by $R = A\alpha I$, the convective heat lost from the feathers (which is a function of the difference in temperature between feathers and surrounding air), the heat stored by the feathers (which depends on their mass and specific heat), and the heat conducted from the periphery through the plumage layer and underlying skin (which depends on the temperature difference between periphery and core, as well as the thermal conductivity of the system).
5. Any consistent decrease in absorption coefficient or thermal conductivity of gray relative to white plumages would be virtually impossible to detect in the variability of data at low angles. Furthermore, the experiment reported in (1) was not sufficiently complete (4) to determine any possible changes in coefficient or conductivity. Assuming constancy of both variables with incidence angle is wholly consistent with the results, given the magnitude of experimental error.
6. The problem is therefore primarily one of the geometry of the bird, and to the extent that a bird is spherical it has limited orientational freedom to adjust its total silhouette area.
7. For example, T. R. Howell, *Univ. Calif. Publ. Zool.* **113**, 1 (1979); R. J. Shallenberger, G. C. Whittow, R. M. Smith, *Condor* **76**, 476 (1974).
8. G. E. Walsberg, G. S. Campbell, J. R. King, *J. Comp. Physiol.* **126**, 211 (1978).
9. I thank G. Causey Whittow for comments on the first manuscript draft.

24 February 1981; revised 30 September 1981

I agree with Hailman (1) that the reduction in surface area as the angle of incidence increases plays a major role in reducing the radiative heat load. In fact, Lustick *et al.* (2) earlier concluded "Orientation toward the sun and postural adjustments to vary the angle of incidence of solar radiation can minimize radiative heat gain by . . . reducing the exposed surface area . . . (silhouette is minimal)." This does not exclude that increasing the angle of incidence might increase the reflection coefficient. According to Monteith (3), when the angle of incidence exceeds 45°, the reflection coefficient increases for water and other natural surfaces over the solar spectrum 0.4 to 3.0 μm. Much of this reflection is between 0.7 and 3.0 μm where color is of little importance. Under our experimental conditions (radiation source directly overhead) increasing the angle of incidence also decreased the surface area as Hailman pointed out. When increasing the angle of incidence from 90° to 160° at an air temperature of 20°C and a radiation level of 697 W/m^2 (0.4 to 1.4 μm) the net heat flow through both white and gray plumages decreased more than could be explained by surface area change alone. Although we did not distinguish (4) between the reductions in heat flow due to changes in surface area and changes in reflection coefficient, our data (4) suggests that both are occurring (surface area is reduced by 66 percent when the angle of incidence is increased from 90° to 160° while heat flow decreased approximately 100 percent). In fact, the thermal gradient is in the opposite direction, being slightly greater in the white plumage. I agree that we did not prove that as the angle of incidence increases the reflection coefficient goes up.

I believe that the data (2, 4) show that a dark-colored plumage acquires a greater radiative heat load than a light-colored plumage under the experimental conditions of (i) no forced convection and (ii) feathers forming a smooth surface [not erected (5)]. This finding is consistent with those of Walsberg *et al.* (6). In light-colored erected feathers or fur, if the angle of incidence is such that the solar radiation penetrates, it will be reradiated inward and reflection could decrease (3). This was not the case in our experiment.

Although we (2, 4) have not definitely shown that the reflectance coefficient changes with increased angle of incidence above 45°, I feel that our major conclusions are still valid. As was stated (4), "In considering the importance of color to radiative heat load, the bird's ability to decrease absorptivity by postural adjustments must be included, as well as stress induced by heat or cold. During heat stress, a dark bird by postural adjustment (increasing the angle of incidence) can effectively become white with regard to solar radiation. A cold-stressed bird would require a large surface area at 90° to the radiation source, and under these conditions a darker color would have the greatest benefit. Thus by postural adjustments birds can decrease the effects of dark coloration under heat stress and increase its effect when cold stressed." The intended meaning was that by postural adjustments (the animal facing the sun with long axis parallel to the sun's rays and tilting the body to increase angle of incidence) the difference in the radiative heat load between dark and light plumage decreases, as the data indicate. Thus, the decreased differences (1, 2) are due mainly to a reduction in exposed surface area. Yet a change in the reflectance coefficient cannot be ruled out as contributing to a part of the decreased difference. Riemerschmid and Elder (7) have shown that the reflectance of cattle coats laid flat on the ground is greater with oblique insolation than with the sun normal to the coat. Hutchinson *et al.* (8) also present data to suggest that reflectance (gloss) may increase with increased angle of incidence.

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References and Notes

1. J. P. Hailman, *Science* **218**, 919 (1982).
2. S. Lustick, B. Battersby, M. Kelty, *ibid.* **200**, 81 (1978).
3. J. L. Monteith, *Principles of Environmental Physics* (American Elsevier, New York, 1973).
4. S. Lustick, M. Adam, A. Hinko, *Science* **208**, 1052 (1980).
5. Heat transfer through the gray plumage normal to the radiation source (0.4 to 1.4 μm) was four times that of the white plumage even though free convection was greater from the darker plumage because of its higher surface temperature. Only half this difference could be accounted for by our empirical determinations of the insulating qualities of the different colored plumages which should take into account thermal conductivity and heat storage. In the three tests with no water layer between radiation source and plumage, the excessive thermal radiation would mask the effect of color as pointed out in the text.
6. G. E. Walsberg, G. S. Campbell, J. R. King, *J. Comp. Physiol.* **126**, 211 (1978); G. E. Walsberg, *Auk* **99**, 495 (1982).
7. G. Riemerschmid and J. S. Elder, *Onderstepoort J. Vet. Sci. Anim. Ind.* **20**, 223 (1945).
8. J. C. D. Hutchinson, T. E. Allen, F. B. Spence, *Comp. Biochem. Physiol.* **52A**, 343 (1975).

5 August 1982