own reproductive effort.

PATRICK J. WEATHERHEAD
DREW J. HOYSAK

Department of Biology,
Carleton University,
Ottawa, Ontario K1S 5B6,
Canada

VON SCHANTZ *ET AL.* REPLY—Weatherhead and Hoysak are correct that the significant correlation between male spur length and female reproductive success disappears when females hatching no chicks are removed. But we are not convinced that their reanalysis is relevant. First, we find no basis for their challenge of our interpretation that "the genetic superiority of long-spurred males is directly responsible for the increased reproductive success of females mating with them". Data on the survival rates of chicks in relation to their paternity would have been necessary to reach such a conclusion, but were not available. Rather, we stated explicitly (p.168 of ref. 1) that "We do not know to what extent male genetic quality affects the number of hatched chicks and offspring survival", which is clearly divergent from the interpretation Weatherhead and Hoysak force upon us.

Of the 15 females hatching no chicks (Fig. 1*b* in ref. 1), only three suffered from nest predation. A removal of the effect of nest predation, as Weatherhead and Hoysak suggest, does therefore not affect the correlation substantially (r=0.337, P<0.02, N=42) so that it is not correct to conclude that predation was the most important cause of variation in female reproductive success.

The remaining "unsuccessful" females either did not attempt nesting (N=9) or abandoned their intact nests (N=3). The spur length was significantly shorter among the mates of the nine non-nesting females than among the mates of females that attempted nesting at least once (t=2.51, P<0.02, N=45). Indeed, these data support Burley's hypothesis[6] that mates of attractive individuals invest more in reproduction. But it remains a controversial question whether the relationship between female reproductive success and mate spur length arises from females' "differential allocation", assuming inheritance of attractiveness[6], the "good genes", assuming inheritance of genotypic quality[7–10], or in some other way. Accordingly, we hesitated to speculate prematurely on the causes of our observations.

The two main alternatives are, in any case, by no means mutually exclusive; if maternal effort affects female reproductive success, as may well be the case, the two hypotheses are difficult to separate. Although we are well aware of Burley's hypothesis and fully accept Weatherhead and Hoysak's point, it is in our opinion crucial that our data are not relevant either to the refutation or the promotion of either of the two overlapping hypotheses. In the case of the pheasants we have studied, both processes lead to the same effect, that is sexual selection for a viability-based male trait[1].

TORBJÖRN VON SCHANTZ
GÖRGEN GÖRANSSON
GUNILLA ANDERSSON
MATS GRAHN
HÅKAN WITTZELL*

Departments of Animal Ecology and Theoretical Ecology,*
Ecology Building,
University of Lund,
S-223 62 Lund, Sweden

1. von Schantz, T. *et al. Nature* **337**, 166–169 (1989).
2. Kirkpatrick, M. *Nature* **337**, 116–117 (1989).
3. Pomiankowski, A. *Nature* **337**, 696 (1989).
4. Ricklefs, R.E. *Smithsonian Contrib. Zool.* **9**, 1–48 (1969).
5. Johnsgard, P. *The Pheasants of the World* (Oxford University Press, 1986).
6. Burley, N. *Am. Nat.* **132**, 611–628 (1988).
7. Zahavi, A. *J. theor. Biol.* **67**, 603–605 (1977).
8. Hamilton, W.D. & Zuk, M. *Science* **218**, 384–387 (1982).
9. Kodric-Brown, A. & Brown, J.H. *Am. Nat.* **124**, 309–323 (1984).
10. Andersson, M. *Evolution* **40**, 804–816 (1986).

Synthetic tips

SIR—Capabilities in scanning tunnelling and atomic force microscopy (STM and AFM) depend on probe-tip properties, but tip properties are at present poorly controlled; suitable tips have poor reproducibility at the atomic level. Techniques for precise control of the mechanical and chemical nature of tip structures would be of evident value. We therefore propose a 'molecular tip' made of a protein-like molecule which has been designed to bind to a crystal-corner STM/AFM tip, and which could potentially be tailored, manufactured and reproducible.

Advances in protein engineering[1] and synthesis of novel molecular receptors[2] demonstrate a growing capability for designing large molecules, including those that bind to other molecular structures. We note that crystal corners can have atomically regular equilibrium structures with radii in the nanometer range[3], a size compatible with such binding. If a combination of tip and bound tip-capping molecule could be developed, this could open a wide range of experimental possibilities.

Given a suitable tip-capping molecule, techniques for molecular design and synthesis could be exploited to refashion the working surface opposite the tip-binding surface. Diverse properties should be achievable. In particular, while STM technology has enabled chemical modification of single molecules[4], greater specificity is a significant goal[5]. One approach would exploit positional control of interchangeable reactive moieties on scanning probe microscope tips to favour chemical reactions at specific sites on product molecules bound to a substrate.

Consider an AFM tip capped by a protein (-like) molecule with a working surface incorporating a binding site for a ligand, which in turn bears a reactive moiety. AFMs with tips characterized by a small (~ 1 N/m) vertical spring constant[6] and a large ($\geq 10^3$ N m^{-1}) transverse spring constant (T. Albrecht, personal communication) can be positioned with atomic precision in a liquid medium[6]. Since the spring constants for deforming multi-nanometer scale globular proteins and for bending single bonds are both >10 N m^{-1}, there seems no obstacle to positioning bound reactive moieties with a transverse spring constant $\geq$ N m^{-1}.

Ligands of similar structure can bear differing reactive moieties; these may be interchanged (given suitable binding-site properties) by adjusting ligand solution concentrations. A 10^{-4} M concentration would yield high tip occupancy given a dissociation constant $\leq 10^{-5}$ M, and interchange on a 0.1 s time scale given rate constants $\geq 10^5$ M^{-1} s^{-1} for association and $\geq$10 s^{-1} for dissociation. For protein-ligand interactions, rate constants $\geq 10^8$ M^{-1} s^{-1} and $\geq$100 s^{-1} are compatible[7].

Positioning of reactive moieties by proteins can yield high effective concentrations, >10^2 M even for mobile surface-residue thiol groups[7]. With a bound-ligand effective concentration at the tip $\geq 10^2$ M and a $\leq 10^{-4}$ M concentration in solution, an AFM-based mechanism could create a positionable, site-specific concentration enhancement $\geq 10^6$. At 300 K, a thermally excited structure with a 1 N m^{-1} spring constant will be characterized by a gaussian positional uncertainty with sigma <0.065 nm; the ratio of effective concentration enhancement between a target site and a site 0.25 nm distant will then be >10^3. Thus, strong and adjustable positional control of effective concentrations (and hence of reaction rates) on an atomic distance scale appears physically possible in a class of systems that may be practically realizable.

K. ERIC DREXLER

Department of Computer Science,
Stanford University,
Stanford, California 94305,
USA

JOHN S. FOSTER

IBM Research Division,
Almaden Research Center,
San Jose,
California 95120,
USA

1. DeGrado, W.F., Wasserman, Z.R. & Lear, J.D. *Science* **243**, 622–628 (1989).
2. Lehn, J-M. *Angew. Chem. Int. Ed. Engl.* **27**, 89–112 (1988).
3. Fink, H.W. *IBM J. Res. Dev.* **30**, 460–465 (1986).
4. Foster, J.S., Frommer, J.E. & Arnett, P.C. *Nature* **331**, 324–326 (1988).
5. Drexler, K.E. *Proc. natn. Acad. Sci. U.S.A.* **78**, 5275–5278 (1981).
6. Drake, B. *et al. Science* **243**, 1586–1589 (1989).
7. Creighton, T.E. *Proteins* 1–515 (Freeman, New York, 1984).