which, rats learn to direct their behavior toward the environment. The particular response observed during tail-pinch may be determined by factors similar to those for brain stimulation. With both procedures, oral responsiveness increases in a way that is modified by experience with particular objects in the environment.

The finding that a relatively nonspecific stimulus can induce rats to learn a new habit in order to obtain an appropriate goal object for consummatory behavior has implications not only for interpreting behavior elicited by electrical brain stimulation but also for elucidating the conditions necessary for all learning. Indeed, several theorists have suggested that arousal may be a sufficient condition for learning (*15*). Thus, a general activation of some nonspecific arousal system within the brain would increase an organism's responsiveness to environmental stimuli and facilitate appropriate responses. The relative importance of species-typical response constraints and the role of specific neuronal circuitry are areas for future investigation.

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References and Notes

1. J. F. Marshall, J. S. Richardson, P. Teitelbaum, *J. Comp. Physiol. Psychol.* **87**, 808 (1974); S. M. Antelman and H. Szechtman, *Science* **189**, 731 (1975).
2. S. M. Antelman, H. Szechtman, P. Chin, A. E. Fisher, *Brain Res.* **99**, 319 (1975).
3. N. E. Rowland and S. M. Antelman, *Science* **191**, 310 (1976).
4. E. S. Valenstein, V. C. Cox, J. W. Kakolewski, *ibid.* **159**, 1119 (1968).
5. R. A. Wise, *ibid.* **162**, 377 (1968); *ibid.* **165**, 929 (1969).
6. ———, *Brain Res.* **67**, 187 (1974).
7. W. W. Roberts and H. O. Kiess, *J. Comp. Physiol. Psychol.* **58**, 187 (1964).
8. E. E. Coons, M. Levak, N. E. Miller, *Science* **150**, 1320 (1965).
9. J. Mendelson and S. L. Chorover, *ibid.* **149**, 559 (1965).
10. W. W. Roberts and R. J. Carey, *J. Comp. Physiol. Psychol.* **59**, 317 (1965).
11. Latency decreased monotonically with experience [Jonckheere's tau (τ) = 0.31, $z = 2.40$, $P < .02$, two-tailed]. Gnawing duration increased monotonically with experience ($\tau = 0.34$, $z = 2.64$, $P < .01$, two-tailed) [A. R. Jonckheere, *Br. J. Stat. Psychol.* **7**, 93 (1954)].
12. B. J. Sahakian and T. W. Robbins, in preparation.
13. Binomial tests, two-tailed [S. Siegel, *Nonparametric Statistics for the Behavioral Sciences* (McGraw-Hill, New York, 1956)].
14. E. S. Valenstein, in *Nebraska Symposium on Motivation*, J. K. Cole and T. B. Sonderegger, Eds. (Univ. of Nebraska Press, Lincoln, 1974), p. 251.
15. E. S. Valenstein, V. C. Cox, J. W. Kakolewski, *Psychol. Rev.* **77**, 16 (1970); A. Routtenberg, *ibid.* **75**, 51 (1968); D. E. Berlyne, in *Nebraska Symposium on Motivation*, D. Levine, Ed. (Univ. of Nebraska Press, Lincoln, 1967), p.1.
16. We thank M. J. Morgan, T. W. Robbins, T. J. Roper, and B. J. Sahakian for their helpful comments and suggestions, M. Del Fiacco for helping to test the animals, and Professor O. L. Zangwill for use of the facilities of the Cambridge Psychological Laboratory.

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Threshold Model of Feeding Territoriality and Test with a Hawaiian Honeycreeper

Abstract. *A model is proposed predicting that in nectarivorous birds territorial behavior will occur above a lower threshold of nectar productivity in a foraging area and disappear above an upper threshold. These thresholds are determined by the daily costs of living of territorial and of nonterritorial individuals and by the pressure of competing birds for the resource. Decline of efficiency of territorial exclusiveness is predicted as productivity increases from the lower to the upper threshold. Hawaiian honeycreepers (*Vestiaria coccinea*) supported the model.*

The study of territoriality—herein defined as the maintenance of an area "within which the resident controls or restricts use of one or more environmental resources" (*1*)—has been characterized by a lack of tests of theoretical predictions (*2*). In this study we have applied a model to the energetic economics of feeding (nonbreeding) territoriality in a nectar-eating passerine bird, endemic to the Hawaiian Islands. The model predicts the conditions that determine the presence or absence of feeding territoriality in this species.

Ecologists (*2, 3*) have suggested some of the factors that should determine whether feeding territoriality in birds, involving costly defense and chasing, is economically feasible. Assuming that energy is potentially limiting, only under certain circumstances will the benefit of territoriality exceed the cost and will the establishment of a territory be favored. Conversely, if energy is not limiting, territorial behavior confers no energetic advantage and should cease to exist. Various studies (*4*) of flower-feeding hummingbirds suggested the overriding importance of high energy content of the resource (floral nectar) in territorial establishment. Likewise the number of inflorescences available seems (*5*) to determine territoriality in an African sunbird, as territories always included approximately the same number of flowers. Such environmental parameters as dispersion of food sources and number of competitors have little effect on the estimated energetic cost of territorial behavior in a Hawaiian honeycreeper (*6*). However, our present study shows that the number of inflorescences and the intruder pressure together determine the energetic yield of the territory to its owner, and therefore can be used to predict accurately the presence or absence of territoriality even though these parameters have little effect on territorial cost. Although one pioneering study (*5*) has quantitatively predicted and partially documented changes in territorial behavior based on economics, to our knowledge a thoroughly quantified test of this idea has yet to be accomplished.

Under conditions of potential food limitation, an animal should be able to raise the level of food availability in its foraging area by preventing other individuals from using its food supply. This prevention involves cost, including energy spent advertising or chasing (or both). If the added cost of living territorially equals or exceeds the resultant increase in energy availability, territorial behavior should not occur. The minimum energetic productivity (calories produced on a territory over 24 hours) required to favor territorial behavior should be predictable on the basis of (i) energetic yield to a nonterritorial individual, (ii) increase in yield to a territorial individual, and (iii) added cost of being territorial. This can be expressed in the following terms

$$E + T < aP + bP$$

That is, in order for territoriality to occur, E (basic cost of living) plus T (added cost of being territorial) must be less than the yield to the individual if nonterritorial (fraction a of productivity P) plus the extra yield gained by the individual if territorial (fraction b of productivity P). The value of the term bP will depend on the efficiency e of the territorial owner at restricting use of P, and therefore bP can be expressed as:

$$e\,(1 - a)\,P$$

where e is the fraction of intruders excluded by the owner.

As P becomes large, e can become gradually smaller, and the total energy costs of the territory owner will still be met. Eventually P may reach a value that satisfies the energy requirements of the owner, even given zero efficiency at excluding intruders. At very high values of P, then, territoriality should not occur. As P decreases below such high levels, an upper threshold for territoriality should be reached when

$$aP < E$$

That is, the yield to the nonterritorial individual must be less than basic energy requirements if territoriality is to occur.

Combining the conditions for territoriality, one expects to see the behavior when

$$\frac{E + T}{a + e(1 - a)} < P < \frac{E}{a}$$

The model's predictions are illustrated in Fig. 1. If e varies, as suggested above, the model predicts a more complex relation between productivity and behavior (seen in the lower parts of Fig. 1, A and B). Intensely territorial means high e, moderate means lower e, and nonterritorial means $e = 0$.

The assumptions on which this model is based are as follows. Nectar is the defended resource; increase in e requires an increase in T; the function of feeding (nonbreeding) territoriality is to increase the availability of food; territoriality occurs when food is potentially limiting; counterselection pressures, such as risks of injury or predation, act *against* feeding territoriality; the birds do not need extra calories for growth (*6, 7*) or reproduction (*7, 8*) at this time of year; and nectar is approximately 100 percent assimilable (*9*).

We applied this model to the iiwi, a species of Hawaiian honeycreeper, *Vestiaria coccinea* (Aves: Drepanididae) that is specialized to take nectar as an energy source (*6, 7, 10–12*) and, in summer months, feeds primarily on the red-flowered tree *Metrosideros collina* (Myrtaceae). We studied the behavior and territorial characteristics of *V. coccinea* in the summers of 1974 and 1975 by selecting three nonterritorial and seven territorial individuals. Our observations were made at elevations between 1380 and 1850 m on the southwestern slopes of the volcano Mauna Loa. The study sites and subjects have been described (*6, 11, 13, 14*). By precise time budget measurements and estimation of associated energetics (*6, 11*) for eight of these ten birds we estimated that the cost of basic living (nonterritorial cost, E) in this species averages 13.4 kcal per 24 hours and that the cost of being territorial is a mean of 2.3 kcal per 24 hours above basic living cost.

The benefit variables to be measured for the model were nectar productivity and the percentage yield of nectar to nonterritorial individuals. Productivity was determined according to described methods (*12–14*). The rate of nectar flow in trees on three iiwi territories was surprisingly consistent (mean = 0.259 ± 0.010 kcal per 24 hours per inflorescence; three trees and 18 inflorescences) and was assumed to be constant for all foraging areas. Individual feeding areas were mapped, and the number of inflorescences (hereafter called flowers) in each foraging area was counted with binoculars. The nectar taken by other honeycreepers on foraging areas of nonterritorial birds was assumed to be directly related to the number of intrusions and to the nectar production on the foraging area. Intruders remained on foraging areas a mean of 3.5 ± 0.5 minutes (95 percent confidence interval) and visited a mean of 12 ± 4 flowers per minute. The number of intruders on the foraging area of one of the nonterritorial birds was counted, and thief-minutes per day was calculated and multiplied by the nectar production of 12 flowers in kilocalories per minute to give the number of kilocalories lost to thieves per day. This technique somewhat underestimates energy lost to thieves because it does not account either for thieving of accumulated nectar stores by avian intruders or for loss to insects. We found that intruders accounted for 75 percent of the nectar produced on the foraging area of the nonterritorial bird.

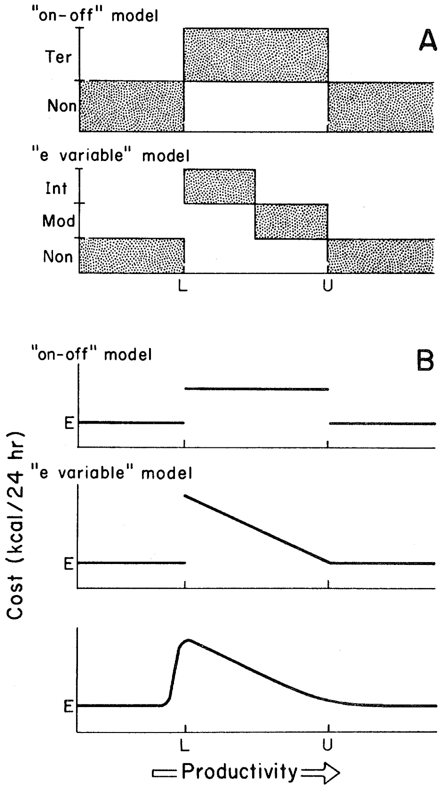

Fig. 1. (A) Behavior categories model. (Top) Model predicts on and off behavior of territoriality as a function of the productivity P of a bird's foraging area; *Ter*, territorial behavior present; *Non*, territorial behavior absent; L, the lower threshold for territoriality which is equal to $(E + T)/[a + e(1 - a)]$; U, the upper threshold which equals E/a. Behaviors fall into two categories only, "territorial" or "nonterritorial." For *V. coccinea*, L is predicted to be 15.7 kcal per 24 hours or 60 flowers; U is 53.6 kcal per 24 hours or 207 flowers. (Bottom) The model predicts that, if the effort invested in territorial exclusiveness decreases as P increases from L to U, birds will be more effective at excluding intruders just above the lower threshold (that is, intensely territorial) than near the upper threshold (moderately territorial); three categories of behavior are therefore indicated on the ordinate. (B) Cost model. (Top) Model predicts that the cost of living will be higher during territorial behavior ($L < P < U$) than during nonterritorial behavior ($P < L$, $P > U$). (Middle) Model predicts that the cost of living will increase suddenly at the lower threshold and decline to the nonterritorial level at the upper threshold. (Bottom) Variation on prediction above, allowing for variability of behavior at the lower threshold.

Two intensely territorial individuals were able to exclude 92 and 100 percent of the intruders on their territories, but we observed other territorial individuals to be less efficient.

We now have all the values required for application of the model to *V. coccinea*: $E = 13.4$ kcal per 24 hours; $T = 2.3$ kcal per 24 hours; $a = 0.25$; and $e_{\max} = 1.0$, e variable.

The realistic form of the cost model that *V. coccinea* should follow is shown in the lower part of Fig. 1B. We measured e in only two of the eight individuals for which we had cost values, and decided that we could apply another measure of intensity and effectiveness of territoriality, the intensity of advertisement, which we had already measured for another study (*6*). Because of the large proportion of time devoted to advertisement and because it is an action involving flight, advertisement is the main cost of territoriality in *V. coccinea*, being a mean of 18 percent of the cost of territorial living, while chasing was only 1 percent (*6*). Assuming that more effort invested in advertising results in more effective territoriality, then this effort should be an indirect measure of e. This was the measure we used in categorizing the five territorial individuals—analyzed previously (*6*) for territorial living cost—into intensely or moderately territorial: The advertisement costs of two of the five individuals were at or above 18 percent of living costs, and those of the other three were all 14 percent or less.

Iiwis were not territorial at either low or high flower abundances, but they were territorial at intermediate flower abundances (Fig. 2). In 1975, flower densities were two to eight times higher than in 1974 and none of the several *Vestiaria* seen was territorial; thus, the effect was more dramatic than is suggested by our sample of two birds ($P = 250$ and 500) for which we obtained cost measurements. The results therefore generally support the model's predictions of presence or absence of territorial behavior.

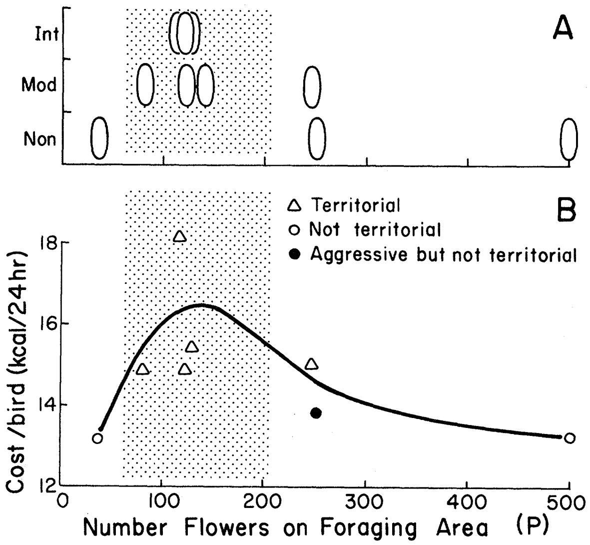

Fig. 2. Shaded area indicates the *P* values in number of flowers on foraging area at which foraging *V. coccinea* should exhibit territoriality according to the models in Fig. 1. (A) Behaviors falling into three categories (see Fig. 1A) of ten *V. coccinea*. (B) Living costs estimated by time-energy budget techniques for eight *V. coccinea*, as a function of the number of flowers on their foraging areas. Curve is fit by eye; the peak is the mean *x* and *y* values for three individuals, with *P* between 115 and 128 flowers.

The main discrepancy was one 1974 individual that was territorial at a *P* value above the upper threshold. That year the flowering of *Metrosideros* was poor and patchy, with occasional heavily flowering trees. This bird occupied such a tree; its territoriality may have been a response to the general paucity and unpredictability of the nectar resource that year. Even in 1974 individuals with foraging areas below the lower threshold were rare because they quickly abandon such an area. Our one individual supplemented its diet by foraging extensively for insects. Nine of ten individuals (Fig. 2A) supported the model's prediction of territorial behavior, an agreement significant at the .02 level (binomial probability of nine agreements out of ten possible).

The intensity of territorial behavior (Fig. 2A) supported the predictions (Fig. 1A) fairly well. However, the birds may have responded to intruder pressure by varying advertisement intensity. Less advertisement is required to be highly effective when intruder pressure is low. Thus, energy invested in advertisement is not a good measure of *e* because of variable intruder pressure, and *e* should be measured directly as percentage of intruders that are effectively excluded. We have these values for two of the birds in Fig. 2B and for the two birds for which we did not measure cost. These four values suggested a negative relationship with *P* ($r = -.44$), but more data are necessary to establish this with certainty.

That more energy is put into territoriality toward the lower threshold than at the upper threshold is supported by the fact that the shape of the cost curve (Fig. 2B) agreed well with the model's prediction (Fig. 1B). Ambivalent behavior occurred at both lower and upper thresholds. The individual with 80 flowers had a large territory and was sequentially visiting the trees on its area; it was not advertising intensely, the primary form of territorial defense (*6*). However, intruder pressure was low at this site; and *e*, had it been measured, would have been high. At the upper threshold, one of the birds was not territorial, since it excluded none of the many intruders on its foraging area. However, it occasionally would fly aggressively toward an intruder and supplant the intruder at its flower, but subsequently would ignore it.

In order for feeding territoriality to be a viable strategy, the behavior must make the resource involved more available than it would be without the behavior. From our data it seems that the resource must be considerably more productive (80 to 120 flowers) than predicted (60 flowers) in order for full territoriality to occur. That the minimum number of flowers required for establishment and maintenance of territories by *V. coccinea* is relatively constant and higher than the predicted threshold is supported by other observations (*15*). In one study site that had about five resident *V. coccinea*, two territories had 140 and 121 flowers; we returned 9 days later and found that the territory that had 121 flowers now had only 83, and the bird had abandoned it. Thus, we believe that a minimum of about 120 flowers is a necessary requirement for the establishment of a territory, double the predicted value for the lower threshold. The predicted value is insensitive to changes in *T*: assigning *T* the maximal value measured in any individual [4.8 kcal per 24 hours (*6*)] merely increases the lower threshold to 70 flowers. This suggests that the birds are defending an excess of about 16 kcal per 24 hours. A small part of this excess is harvested by insects (*14*). Also, some of the excess may be an artifact of underestimating *a*; however, observations of unexploited nectar on one of the territories suggested that a majority of excess is real. We feel that the energy surpluses are essential hedges against periods of energy demand. Our measurements were conducted during days of mild weather; lower temperatures and rain occur frequently at these elevations, causing both lower nectar production rates (*14*) and higher homeothermic metabolism. In addition, the richness of the territory, unless territory dimensions change over time, will vary with onset, peak, and decline of flowering. Others (*2, 3*) have suggested that a guaranteed food supply over a length of time may be a "goal" of territoriality. We agree that feeding territoriality may function to increase the predictability of a food source as well as to increase its availability.

Nectar availability above the upper threshold must occur fairly commonly in the honeycreeper-*Metrosideros* community. This is suggested by the fact that feeding territoriality has not been reported in *V. coccinea* in spite of interest (*7, 8, 10, 16*). Our own studies in general spanned three summers, in which only one summer was poor enough in bloom to provide the conditions necessary for observing territoriality [see (*13*)]. This infrequency of territoriality may differ from territorial behavior of hummingbirds (Trochilidae), a notoriously aggressive and territorial nonpasserine group. Sunbirds (Nectariniidae) may behave more like honeycreepers, since they seem to vary in the extent of their aggressive behavior and become nonterritorial when food supplies are very abundant (*5*). Our model provides a means by which degrees of territorial flexibility and their adaptive significances can be studied and compared between different taxonomic groups and in different geographical areas. These comparisons should help in identifying and evaluating selection pressures that act to mold territorial and foraging behavior.

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References and Notes

1. L. L. Wolf, *Condor* **72**, 1 (1970).
2. J. L. Brown and G. H. Orians, *Annu. Rev. Ecol. Syst.* **1**, 239 (1970).
J. L. Brown, *Wilson Bull.* **76**. 160 (1964).
L. L. Wolf, *Auk* **86**, 490 (19 F. G. Stiles and L. L. Wolf, *ibid.* **87**, 467 (1970); F. G. Stiles, *Univ. Calif. Berkeley Publ. Zool.* **97** (1973); F. L. Carpenter, *ibid.* **106** (1976).
5. F. B. Gill and L. L. Wolf, *Ecology* **56**, 333 (1975).
6. F. L. Carpenter and R. E. MacMillen, *Oecologia*, in press.
7. P. H. Baldwin, *Univ. Calif. Berkeley Publ. Zool.* **52** (1953).
8. A. J. Berger, *Hawaiian Birdlife* (Univ. of Hawaii Press, Honolulu, 1973).

→ F. R. Hainsworth, *J. Comp. Physiol.* **88**, 425 (1974).
10. R. C. L. Perkins, *Fauna Hawaiiensis (Introduction)* (Cambridge Univ. Press, Cambridge, 1913).
11. F. L. Carpenter and R. E. MacMillen, *IBP Island Ecosystems IRP Tech. Rep. No. 61* (1975).
12. ______, *ibid., No. 63* (1975).
13. ______, *ibid., No. 33* (1973).
14. F. L. Carpenter, *Ecology*, in press.
15. R. E. MacMillen and F. L. Carpenter, in preparation.
16. R. C. L. Perkins, *Fauna Hawaiiensis (Vertebrata)* (Cambridge Univ. Press, Cambridge, 1903), vol. 1, pp. 365–466; D. Amadon, *Evolution* **1**, 63 (1947); H. T. Spieth, *Am. Nat.* **100**, 470 (1966).
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References

1. T. H. Jukes, R. Holmquist, H. Moise, *Science* **189**, 50 (1975).
2. M. O. Dayhoff, *Atlas of Protein Sequence and Structure* (National Biomedical Research Foundation, Washington, D.C., 1972).
3. J. L. King and T. H. Jukes, *Science* **164**, 788 (1969).
4. C. Gautier, *Ann. Biol.*, in press.
5. R. Grantham, *science* **185**, 862 (1974).
6. A. D. McLachlan, *J. Mol. Biol.* **64**, 417 (1972).

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Average Proteins and the Genetic Code

Jukes, Holmquist, and Moise (*1*) create a new "average protein" which is different from that computed by Dayhoff (*2*), especially in proline and cysteine frequencies. Their sample description does not permit us to understand the reason for the differences. I suspect the sample change explains the contradictory conclusions found by King and Jukes in 1969 (*3*). They then showed serine, leucine, histidine, cysteine, and proline with "near expected frequencies," and this helped them to deduce that proteins reflect the structure of the genetic code. This time the same five amino acids are "significantly lower" than code levels (*1*). Furthermore, no proof is given for their statement that "Clearly, natural selection counteracts the genetic code to neutralize the charge on proteins," although on this and other points allusion is made to a "statistical analysis" and "significant" differences. Jukes *et al.* propose that "evolutionary selection maintains charge neutrality"; this predicts correlation between the amounts of basic and acidic amino acids to maintain neutrality in proteins. I have computed the linear correlation coefficient between frequencies of the two kinds of amino acids in each protein, taking as sample 53 fully determined proteins of length greater than 50 residues (one protein per family) from *Atlas of Protein Sequence and Structure* (*2*). The result, $r = -.07$, disagrees with the proposition of Jukes *et al.*

The biological interpretation given to their "statistical analysis" is questionable. Jukes *et al.* apparently explain all differences between observed and code frequencies for amino acids by selection of side chain properties. They ignore at least two biological possibilities: first, the probability of mutation may not be the same for all codons. Second, there may be selection at another level; for example, on the secondary structure of the messenger RNA, or on differences between the efficiency of the 61 codon-tRNA-enzyme systems. Such differences could be due to the cell concentration of tRNA (transfer RNA) and enzymes and the translation rate of each codon.

That Jukes *et al.* assign an evolutionary role to *some* of the amino acids is unwarranted. In a study of mutations among amino acids, I have found more replacements of lysine to arginine than the converse (*4*), which does not support the "evolutionary intruder" hypothesis (*1*). Also, the idea that arginine entered the code because it had more affinity for ornithine's tRNA than did ornithine itself seems physicochemically unmotivated. And, if alanine's relatively high frequency is due to the fact that its small side chain makes it useful as a "filler" in proteins, why does glycine, whose side chain has a molecular volume only about one-tenth that of alanine (*5*), have a lower frequency than alanine?

Finally, the model proposed for combining "selective and neutral mutations to give a picture of dynamic equilibrium in protein evolution" is obscure. The model becomes clearer by supposing the authors mean, as suggested by their valine-isoleucine example, that the amino acids in the expected range "pool" replace each other without any action of natural selection. But then the differences between amino acid substitution rates (*2, 4, 6*) will reject the hypothesis. Of course, the fact that frequencies of valine and isoleucine are approximately the same in the average protein and in the code is in no way a demonstration that mutations between them should be "neutral."

More data are needed for discriminating between all the influences leading to the present amino acid composition of proteins, particularly between the respective influences of the translation apparatus characteristics and of natural selection.

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Published compilations of amino acid composition are summarized in Table 1. The values found by Reeck and Fisher (*1*), Smith (*2*), and also Dayhoff *et al.* (*3*), substantiate our own findings. Reeck and Fisher and Smith, as well as we (*4*), find lower values for Cys (*5*) and Pro than does Dayhoff. Gautier's statement that we "create a new 'average protein' " is without basis. We did not accept Dayhoff's compilation in its totality because it included short peptides, as well as analyses that were incomplete with respect to Asn, Asp, Gln, and Glu.

King and Jukes (*6*) used the genetic code to calculate expected amino acid frequencies, assuming that each of the four nucleotides was used in proportion to its frequency as inferred from protein data. Jukes *et al.* (*4*) compared observed values with the amino acid frequencies in the genetic code table. The observed values of Ser, Leu, His, Cys, and Pro (Table 1) are lower than the expected values in column (a) of Table 1. When expected amino acid composition is calculated from the nucleotide base ratios inferred from the data in Table 1, the finding of King and Jukes (*6*) is confirmed.

Our statistical analysis is published (*7*) as was an examination of the basic and acidic amino acids in proteins (*8*). Electrical charge neutrality in proteins refers to the fact that some proteins are acidic, others basic, others neutral, and in such proportions as to maintain an organismal *p*H near 7. Correlations between acidic and basic amino acids in *individual* proteins are thus not necessarily expected. This is in accord with Gautier's low correlation coefficient.

Side-chain properties have a profound effect on selection (for example, sickle-cell hemoglobin). No evidence supports Gautier's unreferenced speculation that different codons fix mutations at different rates. The third codon position in partial sequences of hemoglobin messenger RNA (mRNA) sustains five times more fixations than the first two positions (*9*). This speaks against strong selection at the mRNA level. All amino acids have evolutionary roles.

Of the possible 380 directed amino