closely given by the product of escape velocity v_0 and pericentric distance R_0, where

$$v_0 = (2\,G\,M/R_0)^{1/2}$$

Finally,

$$h/H = \frac{(2\,G\,M\,R_0)^{1/2}\,m}{0.4\,M\,R^2\,\omega} \qquad (11)$$

By using values appropriate to Venus (that is, $M = 4.87 \times 10^{27}$ g; $R = 6.06 \times 10^8$ cm; $\omega = 1.46 \times 10^{-4}\ \text{sec}^{-1}$; $R_0 \sim 2R$), we find that for $h/H \geqq 1$, we need

$$m \geqq 1.46 \times 10^{26}\ \text{g} \qquad (12)$$

This value of m is roughly twice the moon's mass and is therefore a plausible value. A larger value would, in fact, produce a retrograde spin for the planet.

The moon is fated to crash into the planet's surface and will presumably disappear. Yet a "smile of the Cheshire cat" may remain. The whole capture process occupies a time span of the order of 100 years, during which all the kinetic energy of rotation of the planet Venus is dissipated, mainly by internal tidal friction. The average energy dissipated per gram is

$$\tfrac{1}{2}\,C\,\omega^2/M = 0.2\,R^2\,\omega^2 \qquad (13)$$

Numerically this works out to be $(10^9/P^2)$ erg/g, where P is the initial spin period measured in (24-hour) days. For example, an initial 6-hour period would correspond to 1.6×10^{10} erg/g, sufficient to melt most silicate rocks.

Should events have taken place in this manner, then capture of a moon may have provided the trigger for the internal melting of Venus, for the formation of a core, and for the copious production of an atmosphere through volcanic emissions (*12*).

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8. The tidal bulges are modeled as leading the Earth-moon line by an angle δ, which in turn is related to the effective tidal Q by $\tan 2\delta = Q^{-1}$. See, for instance, W. M. Kaula, *An Introduction to Planetary Physics* (Wiley, New York, 1968), p. 201.
9. The actual Q should be reasonably independent of frequency (see 7). But the tidal phase angle δ should depend on a "frequency" defined as $(\omega - n)$ [see S. F. Singer, *Geophys. J. Roy. Astron. Soc.* **15**, 205 (1968)]. This work has been extended to three dimensions (that is, nonequatorial orbits) and to nonlinear dependence of δ on ω, but with essentially unchanged results [see S. F. Singer, *J. Geophys. Res.*, in press; *Trans. Amer. Geophys. Union* **51**, 637 (1970)].
10. A further argument is provided by the work of P. Goldreich and S. J. Peale [*Astron. J.* **75**, 273 (1970)]. They conclude that solar gravitational tidal interaction would produce a prograde spin, even if Venus had started with a large retrograde spin. In their view, atmospheric torques due to thermal tides or frictional dissipation at the core-mantle boundary—if large enough—could produce the observed obliquity.
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6 August 1970

Celestial Rotation: Its Importance in the Development of Migratory Orientation

Abstract. *Three groups of indigo buntings were hand-raised in various conditions of visual isolation from celestial cues. When they had been prevented from viewing the night sky prior to the autumn migration season, birds tested under planetarium skies were unable to select the normal migration direction. By contrast, when they had been exposed as juveniles to a normal, rotating, planetarium sky, individuals displayed typical southerly directional preferences. The third group was exposed to an incorrect planetarium sky in which the stars rotated about a fictitious axis. When tested during the autumn, these birds took up the "correct" migration direction relative to the new axis of rotation. These results fail to support the hypothesis of a "genetic star map." They suggest, instead, a maturation process in which stellar cues come to be associated with a directional reference system provided by the axis of celestial rotation.*

The ontogenetic development of animal orientation abilities has received very little study. Early workers were impressed by the fact that the young of many species of birds migrate alone, setting out on a course they have never traveled before without the benefit of experienced companions. This suggested that directional tendencies must develop without any prior migratory experience and therefore must be entirely genetically predetermined (*1*).

Field studies, however, point to a dichotomy of navigation capabilities between young and adult birds. When birds of several species were captured and displaced from their normal autumnal migration routes, the adults corrected for this displacement and returned to the normal winter quarters but immatures (birds on their first autumnal migration) did not (*2*). Prior migratory experience improved orientation performance.

I arrived at a somewhat similar conclusion from studies of the migratory orientation of caged indigo buntings; the consistency and accuracy of the orientation exhibited by adults was greater than that of young, hand-raised birds. (*3*). Furthermore, young birds prevented from viewing celestial cues during their premigratory development showed weaker orientation tendencies than those exposed to the natural surroundings, including the day-night sky. I speculated that the maturation process was a complex one, which involved the coupling of stellar information with some secondary set of reference cues.

The following experiments were designed to test more precisely the ability of hand-reared birds to use celestial cues and to determine the possible importance of celestial rotation in providing an axis of reference for direction determination.

Twenty-six nestling indigo buntings between the ages of 4 and 10 days were removed from their nests and hand-raised in the laboratory, where their visual experience with celestial cues was carefully controlled. I housed the birds in 2 by 2 by 2 foot (65 by

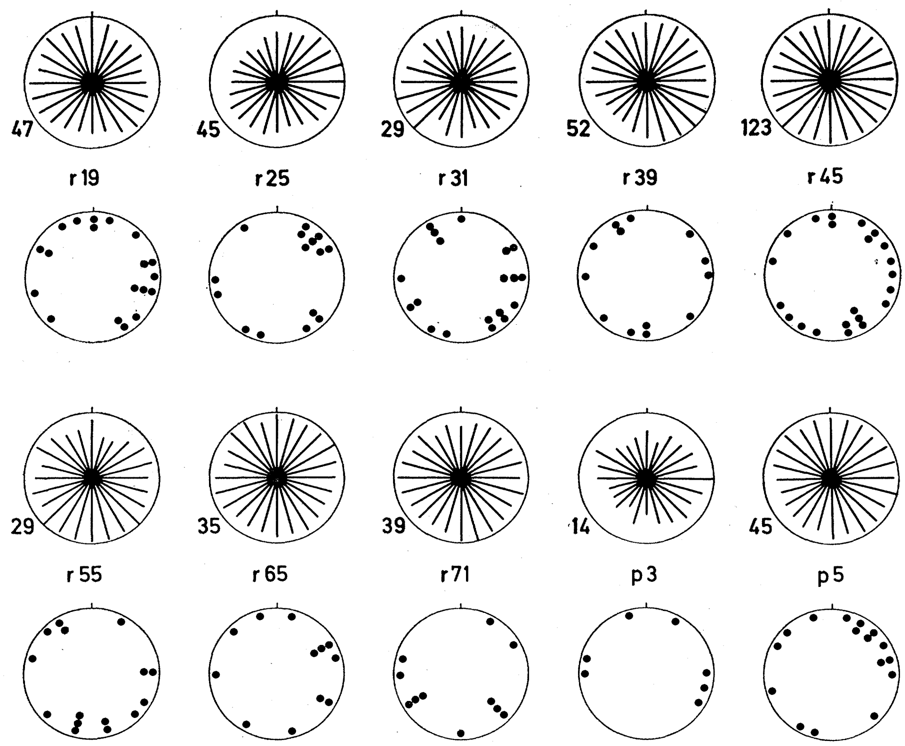


Fig. 1. Orientation of young indigo buntings prevented from viewing celestial cues during their early development. The birds were tested under a stationary, autumnal planetarium sky set for 42°N. (Top) Vector diagram summaries plotted such that the radius equals the greatest number of units of activity in any one 15-degree sector. The number that this represents is written at the lower left of each diagram. (Bottom) Distributions of mean directions for all experiments. In all figures, arrow points attached to circles indicate mean directions of orientation when the distributions shown depart significantly from random ($P \lesssim .05$).

65 by 65 cm) cages in an 8 by 8 foot (2.4 by 2.4 m) room equipped with a hung ceiling made of translucent plastic. The birds thus were prevented from ever viewing a point source of light during their development. Both fluorescent and incandescent lights were present above the artificial ceiling, and the day length was controlled by an astronomical time clock to simulate the day length outdoors.

The birds were hand-fed at frequent intervals until approximately 25 days of age (15 days postfledging), when they became self-sufficient. I then placed them in one of three experimental groups. The first, group A, never left the 8 by 8 foot living quarters until I tested their orientational tendencies during the autumn migration season. These birds were never allowed to view either the sun or the night sky.

The birds of group B also were prevented from viewing the sun. However, these individuals were taken into the Cornell research planetarium and exposed to the normal night sky during the months of August and September (*4*). The artificial sky was set to duplicate the sky outdoors and was changed appropriately to simulate the seasonal changes of hour-angle positions that occur between August and the migration season. The Spitz star projector was modified to rotate at a speed of one revolution per 24 hours, thus duplicating the normal pattern of celestial rotation. The young buntings continued to live in the room described above, but three times a week they were removed to the planetarium at 9:00 p.m. and returned to their normal cages between 4:30 and 5:00 a.m. (EDT).

The birds of group C were also subjected to planetarium exposure. They were taken on three different nights each week and exposed for a similar length of time to an artificial sky. However, this artificial sky was abnormal in several respects.

Once again I had modified the star projector, this time by constructing a special attachment arm that allowed the celestial sphere to be rotated about any axis of my choosing. For group C, I selected the bright star Betelgeuse as the new "pole star," and the constellation Orion became the dominant pattern in the new "circumpolar" area of the sky.

This new sky setting was selected for several reasons. First, a bright star is located at the pole of the new axis. Second, a very bright constellation is located in the "circumpolar" area. This area has been determined to be of special importance in the celestial orientation process of this species (*5*). Third, the hour-angle position was selected carefully so that the actual northern circumpolar stars (in particular, the constellations Ursa Major and Cassiopea and the star Polaris) were present in this artificial sky. They are located just to the south of the new "celestial equator" and move progressively across the sky from east to west as the night progresses.

The logic behind the experiment is this. If celestial rotation provides a reference axis for migratory orientation, then the birds of group C might adopt this incorrect axis and orient their migratory activity in an inappropriate direction. On the other hand, if young birds possess a genetically predetermined star map as has been proposed by some authors (*6*), then the birds should orient "south" with reference to the normal circumpolar area of the sky. These two "south" directions should be easily distinguishable since they range from 110 to 180 degrees apart in the planetarium settings of group C.

During their exposure to these planetarium skies, the buntings were placed in small, funnel-shaped orientation cages (*7*). In this way they became accustomed to the experimental apparatus that would be used later. The birds from group A were given comparable experience in the orientation cages but always in the isolation room. I did not record behavior during these sessions; thus, the degree of nocturnal activity or attentiveness to the artificial skies prior to the migration season is unknown.

Each individual bird from groups B and C received 22 nights of exposure to the appropriate planetarium sky.

The birds completed the postjuvenal molt and acquired visible subcutaneous fat deposits in late September. This development was taken as a criterion for migratory readiness and experiments were conducted throughout the month of October and into early November. I placed the birds under the same planetarium sky to which they had previously been exposed with the exception that the sky was now held stationary. By preventing direct access to rotational information, I tested whether the birds had integrated information from celestial configurations with the potential reference framework provided by the axis of rotation. The experimental design called for testing the same birds under a rotating sky if no directional preferences appeared under these conditions.

I tested as many as seven buntings simultaneously, placing their funnel cages as close to the centrally located star projector as possible in order to minimize any distortion of the artificial sky. The only change from the "exposure" situation was that the cages now had a freshly inked floor that permitted the accumulation of directional information by the footprint technique (*7*). Each experiment lasted 2 hours, and the hour-angle position of the planetarium sky was set to correspond with the midpoint of the 2-hour period.

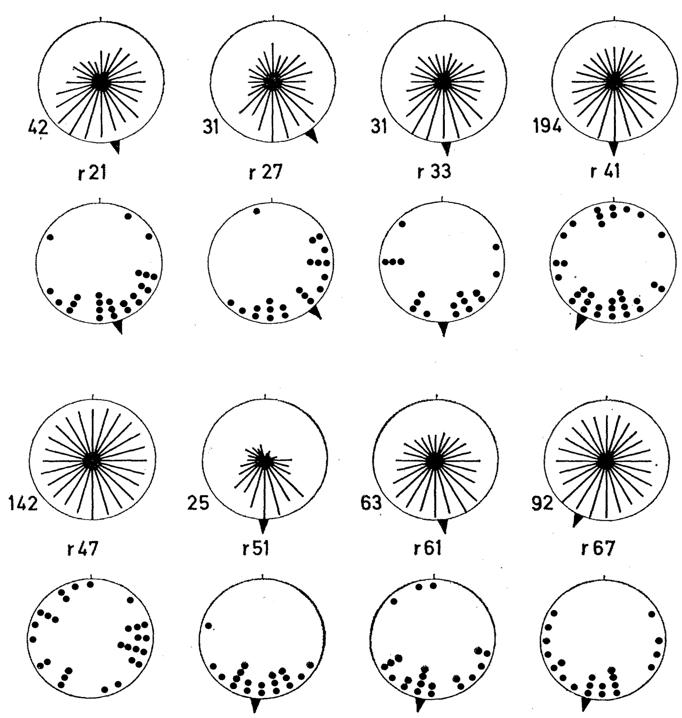
For each data distribution, I tested the null hypothesis of randomness by the "v" modification of the Rayleigh test (*8*), with the expected orientation being southward. Mean direction was calculated by vector analysis (*9*).

The results are shown in Figs. 1 through 3. Of the ten individual buntings of group A, *none* demonstrated a clear-cut directional tendency. This was true whether one analyzed the total activity of each bird or the mean directions taken during replicate tests (Fig. 1). These results argue against the existence of a hereditary star map that the buntings can refer to for navigational information. Rather, they suggest that visual-celestial experience during early ontogeny is important for the normal maturation of stellar orientation abilities.

The results from the buntings of group B support this interpretation. Of the eight birds, seven exhibited a southerly preference in their nocturnal restlessness, the appropriate direction for their first autumnal migration flight (Fig. 2). The data from the eighth bird (r47) do not deviate from random. Although the degree of scatter in the data is large (particularly for r41 and r67) the improvement over the performance of isolate birds (group A) is readily apparent.

Figure 3 shows the findings from group C when directions are plotted relative to the new axis of rotation—that is, with the position of Betelgeuse defining north. All seven birds displayed a "southerly" orientation, which indicated a realignment of directional behavior to correspond with the new axis of rotation (*10*). There was no tendency to move toward true stellar south. Once again, these results are inconsistent with the hypothesis of a predetermined template of star positions.

Taken together, these findings provide strong evidence that early visual experience plays an important role in the development of celestial orientation abilities in indigo buntings. I hypothesize that fledgling buntings respond to the apparent rotational motion of the night sky. The fact that stars located near the celestial axis move through much smaller arcs (have a slower linear velocity) than do those near the celestial equator allows the birds to locate a north-south directional axis. Stars and patterns of stars are of no value for direction finding until their positions are learned relative to some reference location. The axis of rotation appears to function as one such reference system. Once this coupling of stellar and rotational information has occurred, a bird can locate the rotational axis (and, hence, geographic direction) from star patterns alone. This implies that celestial motion per se should become a secondary



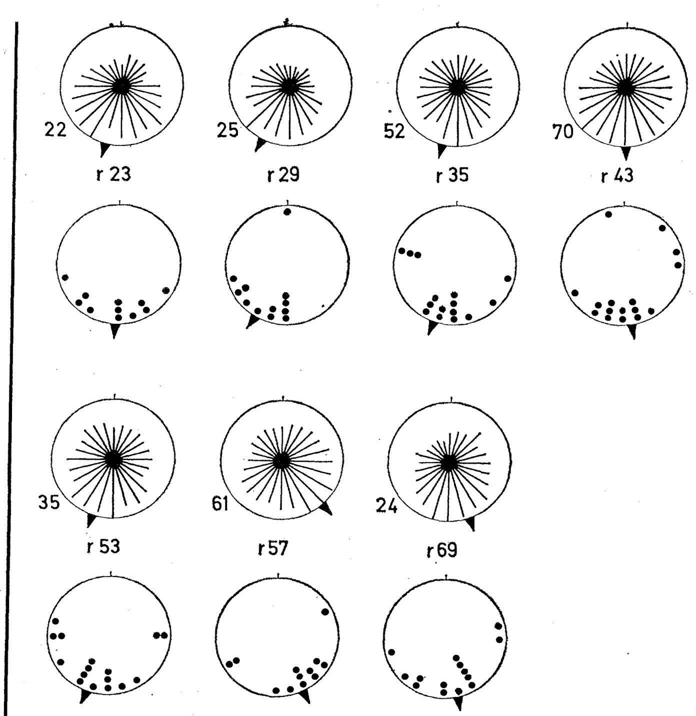


Fig. 2 (left). Orientation of young indigo buntings permitted regular viewings of a normal, rotating, planetarium sky during their early development. Fig. 3 (right). Orientation of young indigo buntings exposed to a planetarium sky that rotated about an incorrect axis during their early development. The data are plotted with the new "pole star" (Betelgeuse, of the constellation Orion) designating "north" or 0 degrees.

or redundant orientational cue for adult birds. The accurate orientation of caged migrants under stationary planetarium skies supports this view (*11*).

This hypothesis does not explain why the young migrant orients southward on its first flight. Rotation seems merely to provide a stable reference axis. The use of this reference to select a southerly heading in preference to any other remains a topic for future investigation.

This study demonstrates the complexity involved in the maturation of one orientational system available to indigo buntings. Undoubtedly, the picture will become more complex as we learn more about additional components of avian guidance systems.

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10. The eighth bird in this group, r49, developed the habit of "somersaulting" in the orientation cage. Since the resulting ink smudges represented an aberrant behavior pattern, they were not included in the quantitative analysis.
11. F. G. Sauer, *Z. Tierpsychol.* **14**, 29 (19… S. T. Emlen, *Auk* **84**, 463 (1967); and results reported in this study. The hypothesis need not imply that buntings directly perceive the slow rate of celestial motion. One can easily locate the axis of rotation by making observations over longer periods of time and comparing the degree of movement of stars located at different points in the celestial sphere.

12. Supported in part by NSF grant GB 13046 X. I thank M. Platt and C. Conley for assistance in rearing and testing the birds; I thank members of Cornell's orientation seminar group for their comments and criticisms; and I thank H. C. Howland and T. Eisner for critical readings of the manuscript.

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Circulating Immunoglobulin M: Increased Concentrations in Endemic and Sporadic Goiter

Abstract. *Increased concentrations of immunoglobulin M have been found in the circulation of approximately half of patients with either endemic or sporadic nontoxic goiter. Blood was obtained from patients in several iodine-deficient goitrous areas; the patients with sporadic goiter resided in or about New York City. Concentrations of immunoglobulins G, A, and D were normal. Blood for control purposes was taken from patients residing in cities near the goiter areas where there was no iodine deficiency, and in New York City. Most of these samples came from hospitalized patients without known thyroid disease and were collected at random. Chi-square values for the difference between the number of goitrous patients with elevated concentrations of immunoglobulin M and those in the control patients were highly significant statistically.*

Endemic goiter remains one of the world's most prevalent diseases. Iodine deficiency is accepted as the precipitating factor, if not the cause, of most endemias (*1*), although a variety of other factors underlying the goitrogenesis have been suggested. Apart from McCarrison (*2*), the concept that infection might be implicated in goitrogenesis has not found much support, except for the demonstration of bacterial pollution in the water of two goitrous areas (*3*). The possibility that an autoimmune process might be operative in endemic goiter has been raised by the observations in two studies that in about half of patients antibody titers to thyroglobulin were increased (*4, 5*) although in a third study this could not be shown (*6*). No particular increase in antibody titers to thyroglobulin has been described in patients with sporadic goiter.

The results of our study reveal that approximately half of patients with either endemic or sporadic goiter had increased concentrations of circulating immunoglobulin M (IgM) whereas only 10 percent or fewer of appropriate controls had increased IgM. There was no corresponding increase in circulating concentrations of immunoglobulin G, A, or D (IgG, IgA, IgD).

Immunoglobulin concentrations were determined by single radial immunodiffusion (*7*). Plates were obtained commercially from Kallestad Laboratories, Inc. The specificity of the antiserums for IgG and IgM, respectively, was checked in two separate trials. No cross-reactions were elicited by IgG placed in the wells of the plate containing antiserum to IgM or by IgM placed in the plate containing antiserum to IgG. Serums for the most part were stored frozen at − 20°C. Serum specimens sent from abroad were preserved by the addition of merthiolate in a 1 : 10,000 concentration except those from Finland and Ecuador. These were lyophilized but not otherwise treated prior to being shipped by air freight.

Serums from areas endemic for goiter were collected as follows: healthy goitrous and nongoitrous patients in the iodine-deficient areas of the Åland Islands, Finland; apparently healthy goitrous subjects from Fourna, Evritania, a mountainous village outside Athens, Greece; and, through the cooperation of Dr. Albrecht Foldenauer, a small series each from healthy goitrous subjects from an endemic area near Munich, Germany. Serums also were obtained from a group of cretins living in two villages in an iodine-deficient area of Ecuador, La Esperanza and Tocachi, through the courtesy of Drs. R. Fierro-Benitez and J. B. Stanbury.

Serums from patients with sporadic nontoxic nodular goiter were kept at −20°C until used (mostly within 1 to

Table 1. Concentrations of IgM in serums of control subjects and of patients from endemic goiter areas.

Location	IgM titers > 180 mg/ml (No.)	IgM titers < 180 mg/ml (No.)
Control subjects		
New York	10	99
Greece (D. Koutras)	4	22
Finland (P. Wahlberg)	2	23
Total	16	144
Goiter patients		
Greece (D. Koutras)	10	10
Finland (P. Wahlberg)	10	6
Germany (A. Foldenauer)	5*	10†
Cretin patients		
Ecuador (R. Fierro-Benitez and J. B. Stanbury)	11	11
Total	25 (+11)	26 (+11)

* Four untreated; one treated. † Six untreated; four treated.