either stay with that one or return to the one he had been pressing, whichever he wished. In short, he was forced with each tone signal to "try out" the other device and decide which he preferred to use. In this procedure a rewarding current was made available on one device and zero current on the other. In conjunction with some tone signals the rewarding current would be shifted by the experimenters to the other device; at other times the tone would be given without such a change being made. A sample forced choice record is shown in Fig. 2. This record demonstrates forced choice performance with self-stimulation of the septal area at a current level of 5 ma versus no current. Both spontaneous shifts and forced shifts were followed by rapid return to the initially rewarding lever, and when the tone was associated with shift of reward, the subject's preference shifted accordingly. These data appear to provide sound evidence of the reinforcing or rewarding properties of electrical stimulation at this site. Again, however, when the current was turned off entirely, this subject vacillated back and forth a few times and then continued to press the lever without reinforcement for more than half an hour until stopped. This has been a consistent finding with this patient in all work with him to date.

Table 1 summarizes preliminary findings with respect to rewarding and aversive current levels in various subcortical structures. This material is based on data obtained through use of the three techniques described. The current levels specified should not be taken as firmly established even for this subject. They are intended rather to give a general picture of differential thresholds in the various brain areas. Brady (*13*) has shown that prior stimulation in one area can affect response rate, and presumably reward threshold, in a second area. In our exploratory work we have not adequately controlled for this variable. Also, there has been indication that sites only a few millimeters apart in the same structure may show significantly different thresholds. It would appear, however, that current requirements for both rewarding and aversive effects are generally much higher in the forebrain structures than in the hypothalamic-tegmental area. Current requirements indicated for the head of the caudate raise some question as to whether the rewarding and aversive properties in this case might have resulted from spread of the field of excitation to other structures.

Table 1. Comparative current intensities, in milliamperes, for "reward" and "aversive" ICSS responding with various subcortical placements: subject D.S. (No. B-12).*

Structure	"Rewarding"	"Aversive"
Caudate (head)	8.0	10.0
Septal area	3.5 and up	‡
Amygdala	0.4	0.8
Central median thalamus	1.25	2.5
Mid-hypothalamus	0.2	0.4
Posterior hypothalamus	0.5	0.7
Post. hypothalamus-tegmentum	0.5	0.7
Tegmentum	†	0.2

* Stimulus parameters: unidirectional rectangular pulses of 0.2 msec duration delivered at 100 pulse/sec. Train duration: 0.5 sec. Bipolar stimulation between electrodes 4 mm apart in all areas except caudate nucleus (monopolar) and posterior hypothalamus-tegmentum (electrodes 2 mm apart). † Not tested below 0.2 ma (apparatus limitations). ‡ Stimulation apparently rewarding and nonaversive up to 12.5 ma. Not tested above this level.

The rather consistent finding of an aversive current level in the range of 25 to 100 percent above the reward level in a given brain site does not correlate well with most animal data. Olds (*2, 14*) reports similar "ambivalent" effects in rats, but these have been less widespread in terms of anatomical locus. Further research is needed to determine whether the present finding may be generalized to other human subjects.

In summary, specialized intracranial self-stimulation techniques have produced data suggestive of the presence of subcortical areas in the human brain in which brief electrical stimulation appears to have rewarding or reinforcing properties. Brain areas thus far suggested as possessing such properties are the head of the caudate nucleus, the septal area, the amygdala, the intralaminar nuclei of the thalamus, the mid-hypothalamus, the posterior hypothalamus, and the boundary of the hypothalamus-tegmentum. With our electrode placements and stimulus parameters, relatively small increases in current above the rewarding level typically produced an aversive effect. These findings are based on data obtained from one clearly nonnormal subject. Any firm conclusions must await the collection of additional data (*15, 16*).

M. P. Bishop
S. Thomas Elder
Robert G. Heath
Department of Psychiatry and Neurology, Tulane University School of Medicine, New Orleans, Louisiana

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Radiolarians: Construction of Spherical Skeleton

Abstract. *The skeleton of spherical radiolarians, which consists basically of a network of hexagonally shaped structures, also contains some non-hexagonal structures, since a network made up entirely of hexagons cannot completely cover a spherically shaped organism.*

Among the radiolaria which can be classified as spherical, probably the most perfectly shaped is *Aulonia hexagonia*. This organism has a skeleton which consists of a basically hexagonal network. Several authors have shown that a completely hexagonal [6, 3] net cannot completely cover a sphere. Thompson (*1*) states this as a consequence of Euler's rule for polyhedra, and Weyl (*2*) gives a simple proof. The [6, 3] net is one composed entirely of hexagons, three of which meet at every vertex. Examination of published sketches shows that the skeleton of *A. hexagonia* contains some pentagonal and heptagonal structures in addition to the hexagons.

Wells (*3*) has presented an equation, based on Euler's rule, which gives the conditions which must be met so that nets can cover spheres. For a net with three rayed vertices;

$$3f_3 + 2f_4 + f_5 \pm 0f_6 - f_7 - 2f_8 \ldots = 12$$

where f_n is the number of n-sided faces. This equation shows that a basically hexagonal net can be fitted to a sphere by introducing 12 pentagonal or six tetragonal or four triangular facets into the hexagonal net. In the particular case of *A. hexagonia* the Wells equation can be stated as $f_5 - f_7 = 12$.

Although pentagonal and heptagonal facets can be seen, there must be twelve more pentagons than heptagons. These non-hexagonal facets of the skeleton always seem to occur together. The basic unit appears to be one pentagonal and one heptagonal structure, but the sketch by Haeckel that is generally reproduced (*1, 2, 4*) shows two different groups, two pentagons and one heptagon, and three pentagons with two heptagons, either of which produces a net gain of one pentagonal facet. Presumably, over the whole skeleton there are 12 such groups of facets. It should be possible, in order to avoid the necessity of incorporating penta- and heptagons into the basically hexagonal net, to make a topological correction in some other way.

Hexastylus phaenaxonius is made up of a hexagonal net skeleton which is modified by six spines. It is suggested that these spines affect the disposition of the hexagonal units of the net in such a way as to effect the topological correction. Figure 1 shows how a spine of cruciform shape can contribute to the correction by supplying what is effectively a tetragonal facet, hence six spines.

Although the six spines could provide the net correction, it can be seen that there are non-hexagonal facets in the *H. phaenaxonius* skeleton. If a criterion of stable net formation is that the vertex angles must be as close to 120° as possible it is likely that non-hexagonal facets would be required if the facets have a wide size variation. This size variation has been seen. The most stable three-rayed net is [6, 3] when it is composed of regular, equal

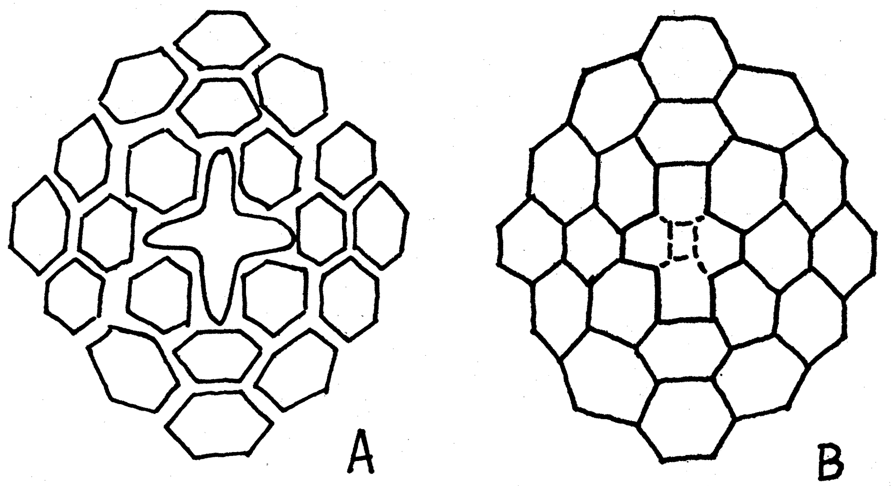

Fig. 1. *A*. Possible arrangement of skeletal network units around a spine in radiolarians. *B*. Equivalent net showing the effect of introducing a tetragonal-shaped facet in the center.

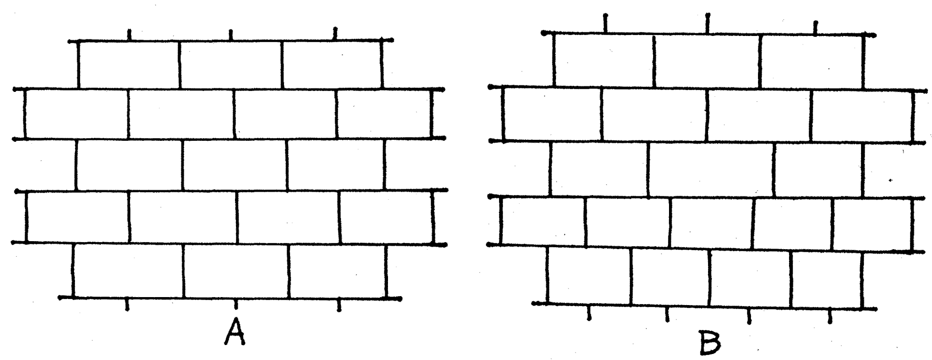

Fig. 2. *A*. Diagrammatic representation of a regular [6, 3] hexagonal net. *B*. Net of equal area with one penta-/heptagonal structure introduced, which adds two more facets without increasing the area.

hexagons. When the facets are not completely regular it appears that the penta- / heptagonal pair can occur with almost equal facility. Figure 2 is an attempt to show diagrammatically that the effect of introducing a penta-/-heptagonal pair into a regular hexagonal network produces a size change in the basic unit. Figure 2*A* represents a portion of a net which is topologically equivalent to [6, 3]. Each unit has effectively six vertices and each vertex is three rayed. Figure 2*B* shows a section of a net which is equal in area to that shown in Fig. 2*A* but which contains two more facets. This illustrates how the introduction of a penta-/-heptagonal pair reduces the size of the facet. This is also illustrated in the skeleton of *Xiphostylus alcedo* which has an equatorial girdle, and the facets bordering this girdle provide the topological correction. Yet, in the mainly hexagonal net skeleton, several penta-/-heptagonal pairs can be seen (*4*). The facets of the net are of unequal size.

The basically hexagonal network of the skeleton of some spherical radiolarians tends to contain penta-/heptagonal pairs because of the inequality of the facet size; the topological correction which allows the net to cover the sphere is made by adjusting the numbers of penta- and hexagons or by introducing features which affect the dispersal of basic net units in the same way as a non-hexagonal facet.

I. J. SMALLEY

Department of Applied Chemistry, Northampton College, London, E.C.1, England

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