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JOHN C. LILLY

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CRITICAL BRAIN SIZE AND LANGUAGE

*JOHN C. LILLY, M.D.**

In the latter part of the last and early part of this century there was some interest in neurological circles about the relation between the size and structure of brains and the degree of "accomplishment" or "intelligence" of the individual concerned [1]. This interest was continued in anthropological comparative research [2, 3]. Some of the results of such investigations are rather unsatisfactory. Measurement of such variables as total brain weight, weights of various parts of the brain, the height of the individual, body weight, various measures of cranial capacity, cephalic indexes, etc. were done in great profusion. The data are unsatisfactory on the behavioral and on the mental side. Donaldson [1] attempted to correlate, as did others, "accomplishment" with a given set of biological dimensions. He showed that accomplishment as measured in that day did correlate in a general statistical sort of a way with total brain size and body height.

Today we are still seeking valid significant nonbiological measures to correlate with the biological data. We are still trying to find some measure of some of the variables subsumed under the words "intelligence," "accomplishment," and similar areas of every-day, clinical, and scientific experience.

The early biological researches culminated in a series of modern studies, exemplified by von Bonin [4], E. W. Count [5], and Tower [6]. As a result of such studies definite correlations were found between brain size and some measure of body size within given orders of similar animals. For example, for the primates there is a definite law relating brain size to

* Director, Communication Research Institute, Miami, Florida. This paper is based on a talk given March 15, 1961, to the Cincinnati Society of Neurology and Psychiatry. Support for this work is from the National Institute of Mental Health and the National Institutes of Neurological Diseases and Blindness; the Coyle Foundation; the Office of Naval Research; Air Force Office of Scientific Research, U.S. Air Force; and from private gifts and contributions to the Communication Research Institute.

body weight: there is in the data a definite uniform trend for the brain size to increase with the body size, weight, and length. In the cetacea a similar relation has been found.

Such regular correlations among the mammalia merely say that as the body (of individuals and of a comparative series of adults of different species) grows larger, the brain grows larger in some regular fashion. Such biological laws say nothing at all about *the performance*—behaviorally, intellectually, mentally, or emotionally—of any of these animals. Such biological laws are self-consistent and inherently make no reference whatsoever to behavioral or to mental variables and their measurement. However, it is of interest to obtain correlations between brain size, brain complexity, body size, and measures of "intelligence" and neurophysiologic and psychologic variables of interest. In order to find appropriate measures, one must eliminate many expectations and presuppositions about what will be found and what will not be found.[1] Let us examine one example—language itself.

Primarily we are interested in human language. Can any correlation be found between brain weight, brain-weight to body-weight ratio (or any of the other biological measurements), and the acquisition of a complex language?

Several lines of evidence suggest the possibility that at least in the mammalia there may be a *critical absolute brain size* below which language, as we know it, is impossible and above which language, as we know it, is possible and even probable [7]. In saying "language as we know it," I am referring not to a literal slavish view of the human languages currently extant; I am referring rather to the ability of these languages to transmit, to store, and to carry from one mind to another mind certain kinds of and degrees of complexity of information. This information can contain data related to the past, the present, and the future and expresses to the mind of the receiver (however imperfectly) the state of mind of the sender, his plans, his actions, his problems. Hypothetically, a nonhuman language may use a logic which is totally strange, an apparent external form which may be bizarre to humans, and contain ways of looking at information which are totally unfamiliar. Thus, when I say "language as we know it," I am referring more to ideational content and to the successful influencing

[1] One might turn the usual view around and ask, "How large a body is needed to maintain a very large brain? What is the minimum size of the self-supporting vehicle for a given size computer?"

of one person by another through the medium of a language than I am to the detailed phonation mechanism and forms of words, sentences, paragraphs, etc.

The lines of reasoning and evidence which suggest this working hypothesis of a critical brain size are as follows: (*a*) modern information and computer theory [8, 9]; (*b*) clinical evidence from the examination of human beings with small brains [10]; (*c*) psychological studies on the development of normal human children acquiring language (see Table 1); (*d*) results of dedicated attempts to teach small-brained primates a human language [13]; (*e*) results of some of our experiments and experiences with the bottlenose dolphin (*Tursiops truncatus*) [7].

TABLE 1

THRESHOLD QUANTITIES FOR HUMAN ACQUISITION OF SPEECH: AGE AND BRAIN WEIGHT*

Age (Months)	Brain Weight [11] (Grams)	Speech Stages [12] (First Appearances)
2	480	Responds to human voice, cooing, and vocalizes pleasure
4	580	Vocal play. Eagerness and displeasure expressed vocally
6	660	Imitates sounds
9	770	First word
11	850	Imitates syllables and words. Second word
13	930	Vocabulary expands rapidly
17	1,030	Names objects and pictures
21	1,060	Combines words in speech
23	1,070	Uses pronouns, understands prepositions, uses phrases and sentences

* From J. C. Lilly, *Man and Dolphin* [7].

In modern information and computer theory there is a rapidly developing realization that the number of interconnected active elements in a computer determines certain levels and kinds of performance—i.e., if a computer has a number of elements below a certain value, it cannot do certain things. This is illustrated in part by Ashby's analysis [8] and by the performance of the early computers as compared with the modern ones [9].

The talking and writing normal human brain is said to contain 13 billions of interconnected neurons and 65 billions of glial elements. The largest modern computers contain the order of several millions of interconnected (theoretically equivalent) elements. Theoretically, the storage capacity in each case is some power function of the number of elements. To store all the phonation and writing program of a spoken and written language—the reasoning programs, all the literature read, and all the conversations held—probably requires at least the 13 billions of neurons, or their equivalent. For an equivalent performance, a talking-conversing-reasoning-learning artificial computer may need such a large number of elements (or their equivalents) in it.

The critical level for the rapid and quickly expanding acquisition of language in the normal human child lies somewhere between 900 and 1,000 gm. (see Table 1). The acquisition of its first human language by a normal child as it grows is an extremely complex and remarkably fast process. Such correlations between brain size, the age of the child, and the acquisition of various portions of a human language are suggestive.

If one adds to this evidence data derived from dedicated attempts to train humans with very small brains to speak—i.e., on the order of 350 to 650 gm.—there is an immediate apparent difference in the type and in the speed of the performance, as Ireland demonstrated in 1900. A human with a 350 gm. brain can learn a relatively small vocabulary if taught with sufficient dedication over a sufficient number of months and years under the proper circumstances. Possibly the rate of learning might be somewhat increased by more modern methods [14, 15].

Similarly, there has been at least one dedicated attempt to teach a primate of about 350 gm. brain size, the chimpanzee, to speak English. This work by the Hayes with Viki led to Viki's saying "mamma," "pappa," "cup," and "up" after two years of work [13].

As is well known, the cetacea (whales) have large brains and hence are of interest for exploratory studies. Of all of the whales available for study, only *Tursiops truncatus* (the bottlenose dolphin) is available in sufficient quantity at the present time for protracted serious work. In the beginning, our studies on this species were strictly neurological—the problems that we were interested in were the finding and mapping of the motor cortex, the sensory projection areas, and the motivational systems [16, 17]. It was during the course of these studies in a routine examination of these animals for a possible vocalization capability that we discovered their totally unexpected ability to make noises which resembled the human speech and laughter which occurred in the laboratory [7, 17]. It was this finding in 1957 which led to more intensive investigations along these lines.

On the biological side, *Tursiops truncatus* has a complex brain mass comparable to and even larger than that of the human. His absolute brain size is larger than the human: his brain weight divided by body-weight ratio is less than that of the human; and his brain-weight to body-length ratio is also less than that of the human. I question the possible significance of these "biologic" ratios without other sorts of data.

(Somehow or other, some humans have made such ratios into a "status symbol" placing *Homo sapiens* at the top of the hierarchy of all the mam-

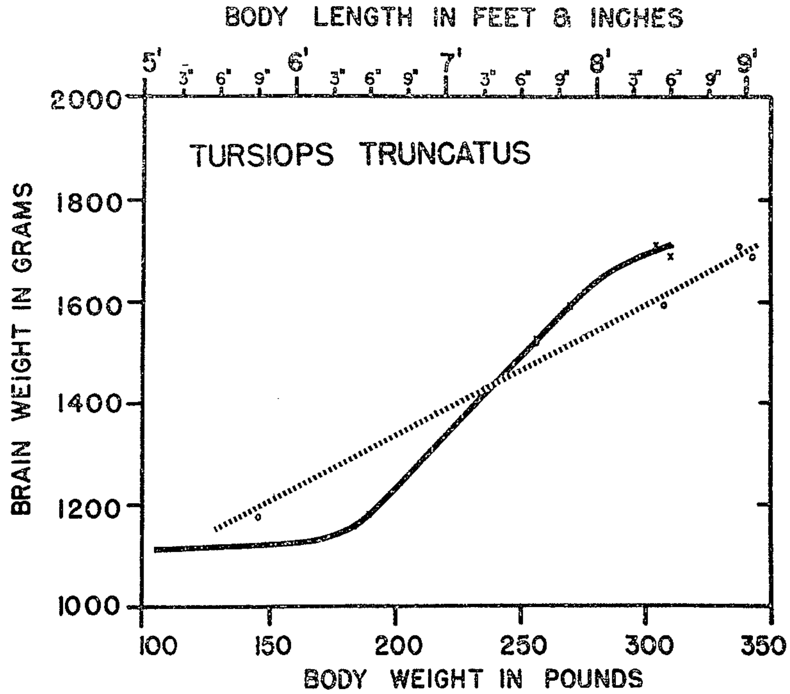

FIG. 1.—The bottlenose dolphin's brain weight is given on the left hand edge of the figure. The body weight versus the brain weight is the dotted curve. The solid curve is the body length versus the brain weight. It should be noted that the critical value of mammalian brain weight (900–1,000 gm.), which is the subject of this article, is below all values in this figure; all brains of bottlenose dolphins measured to date are above the critical threshold value.

mals. I do not necessarily agree or disagree with such a view, but I suggest that we should examine the value of such assumptions carefully.)

Figure 1 shows the absolute values of the brain weight, body length, and body weight of *Tursiops*. One can see that the brain weight increases more or less linearly with body weight over the range in which we have obtained data. *Tursiops* continues to grow beyond the 8 feet 6 inches length shown here, but we have not yet obtained the brain from the large (up to 12 feet) specimens. Recently we found suggestive evidence that this animal, either at birth or soon thereafter, has the critical brain weight mentioned above of 900 to 1,000 gm., a six-month-old, 5-foot, specimen's brain weighed 1,150 gm. This brain weight is reached by the average human at about 34 months [11], well after the acquired language is becoming complex. Presumably, then, soon after birth the bottlenose dolphin should possess a very high capacity for acquiring a complex language.

To return to the brain-weight to body-weight ratio and the brain-weight to body-length ratio and their considerations, as has been pointed out many times by others, if the brain-weight to body-weight ratio were an important variable to correlate with intelligence or accomplishment or language functions, some of the smaller primates would be in a better position than man. The brain-weight to body-length ratio was chosen for the very large whales because of the impracticality of measuring body weight and because it is thought that length is a more important variable for a mammal swimming at or near neutral buoyancy than is weight or mass. Man comes out with a high value for both of these ratios. However, one must consider in far greater detail central nervous system factors in nervous systems of different sizes and their probable relations to behavior before these ratios can have much meaning in the correlations.

In a study on the unanesthetized *Macaca mulatta* (*M. rhesus*) brain, we have shown that the whole cerebral cortex has fairly direct efferent paths to the periphery, i.e., all of the cerebral cortex can be considered "motor" [18]. If one then considers the "motor strip" in each of a series of primates, one can show that the chimpanzee, the gorilla, and the human each has approximately this same size of motor cerebral cortex; i.e., once the motor aspect of cerebral cortical function (phylogenetically) reached a certain critical size in the small primates, there was no need for it to become any larger in the larger-bodied primates. In other words, a small, handed animal had developed the critical size of motor cerebral cortex necessary for the complete control of all the musculature of the basic primate body. Therefore, in the larger-muscled, larger-boned primate bodies the motor cortex did not increase any further. However, the total brain did increase in size.

Many investigators are looking for the functions of all the rest of the cerebral cortex in the large primates and in man [19–21]. We know that the primary afferent projection areas have increased somewhat from

Macaca to man but that the rest of the cortex is where the main expansion is taking place. These are the areas within which pathological lesions cause aphasias and all of the neurological matters of such keen interest in the human. In other words, as the human brain expanded, a language function capability developed, and the physiology of the human cerebral cortex becomes, at least partially, that of working out the physiology of human language.

Similarly, we might expect that the smaller cetacea long ago developed the critical "motor brain" size for the control of their body in their aquatic environment. Similarly, only a relatively small portion of the huge cerebral cortex of the larger forms would be needed for adequate control of the larger body musculature. Such minimum size motor cortex should be adequate for the smallest, 100-pound (*Phocaena*), and for even the very largest, 60-ton, bodies (*Physeter*) found in this sequence of mammals. Thus, part of our task is locating and mapping the motor cortex in the cetacea and locating and mapping the primary afferent areas and any other functions which we know are related to the neurology of language and other functions in the human. This is part of the biological side of our problems.

We have made some progress in this area and have found that *Tursiops* does have a relatively small fraction of the cerebral cortex given over to primary motor functions and that this motor cortex has extremely well differentiated movements represented within it, especially for the crossed monocular and dual binocular eye movements. Similarly, we have shown that there are vast areas of the cerebral cortex of *Tursiops* which are as nonmotoric as comparable large areas in the human. We as yet do not know what functions these areas serve and do not have sufficient data on their possible functions to test for the analogues of human speech. The primary projection areas for the various peripheral receptors are currently being explored, including visual and acoustic.

In view of the state of the evidence, it is still a problem whether or not *Tursiops* (and possibly other cetaceans) have an extremely large acoustic cerebral cortex. We know now that they do have a sonar—i.e., an echolocation, recognition, ranging, and navigation—system which is far better than any that man has yet invented [22].

On the achievement, intelligence, performance, and language side of the investigation as opposed to the biological side, we have been exploring two areas of research: (1) the possibility of a natural language among *Tursiops*, and (2) their ability to learn a human language [7, 17].

On a purely formal basis we have shown [7, 16, 17, 23] that *Tursiops* have an extremely complex phonation ability and can do the following: (*a*) emit whistles in formal alternating "polite" exchanges between two individuals; (*b*) emit clicks (which vary in their frequency components from one click to the next) in polite formal exchanges between two animals; (*c*) emit squawks, barks, wails, etc. in similar exchanges; (*d*) emit supersonic clicks for echo-ranging and recognition; (*e*) emit "humanoid" sounds which are similar to those of human speech, and some of which are recognizable mimicry of human words and phrases; (*f*) perform two of the above simultaneously—i.e., emit clicks and whistles, emit whistles and wails, emit "humanoid" sounds and whistles, etc.; (*g*) during specific distressful situations and their correction by the group, animals can influence one another's behavior by sonic exchanges [7, 17].

Some of the most interesting information is connected with their ability to make sounds which resemble those emitted by humans during speaking. We have been investigating this area intensively over the last several months and have confirmed our previous findings of 1957–58. We have found that if one of these animals is placed in close contact with humans who talk to him every day, eventually he will begin to raise his blowhole up out of water and make "humanoid" noises in air. (Their normal mode of discourse is underwater.) We find (without the use of electrical stimulation of the brain by means of electrodes) that we can obtain mimicry of several human words ("more," "up," "speak," "squirt," "ok," "yes," etc.).

Studies are being made to see what elements of human English speech they are able to reproduce. I wish to emphasize here that these are primitive copies of our speech which occur at such high frequency and over such short periods of time that the untrained listener has difficulty when first hearing these sounds. (Some increased clarity—for training listeners—is often obtained by slowing down the recordings on tape for playback by a factor of 2 or 4.) After several hours of such exposure, however, the human observers can learn to speed up their perception and begin to detect the resemblances and primitive copies of words in these dolphin emissions. Objective studies of these emissions by sonic spectrographic presentation and by trained listeners are in progress [23].

In closing, I wish to emphasize that in this sort of work one can neither zoölogize nor anthropomorphize and obtain significant results. I think that we all know what we mean by anthropomorphizing. Here I am dealing with it in the limited extent of seeing oneself in another animal or seeing one's own species in another species. This must be assiduously avoided when working with animals such as the dolphins. However, this does not mean that one should abandon empathy or the use of conscious attempts to place oneself in the position of the other animal. There is a vast difference, on the one side, between slavish unconscious identification and projection of oneself into the other animal and, on the other side, the use of empathy, sympathy, and the application of disciplined and informed imagination to that animal's position in the scheme of things in nature.

In the opposite sense it is quite as great a mistake to say that a large-brained animal such as *Tursiops* cannot possibly have any high degree of intelligence, for one reason or another. This dogmatically negative point of view is especially apparent in those people who zoölogize or consider this animal a small-brained one and study only that aspect of its behavior. To some scientists, categorically, *Tursiops* cannot have a complex language of its own nor can it ever learn a human language. The origins of such a categorical attitude appear to come from what A. N. Whitehead described as "the semantic morass stemming from a passionate attachment of some leaders of thought to the cycle of ideas within which they received their own mental stimulus at an impressionable age."

Observers who do and will do productive "language" research on *Tursiops truncatus* are those who use a minimum of preconception about what will be and will *not* be found. The dolphins may learn English (or Russian) or they may not; they may have a complex language of their own or they may not. The evidence suggests these as probably productive areas of research. At the present stage of the science of these animals we do not know for certain. We are keeping our minds open to as many productive possibilities as can be encompassed.

We find our most interested and sympathetic audiences are among those who have had to assume the responsibility of the scientific and clinical examination of human speech, including its acquisition, its preservation, and its restoration, the latter in the therapy of those who have lost it.

I wish to close with a pertinent quotation from D. O. Hebb's Hughlings Jackson Memorial Lecture [19]:

It is clearly implied that scientific investigation proceeds first by the collection of facts and arrives secondly at generalizations from the facts. Speculations and the *a priori* postulate are both ruled out. This is the classical view, deriving from Bacon, but it has been known for some time to be false. No research that breaks new ground will be done in this way; the collection of facts, from which to generalize, demands the guidance of imaginative speculation.

One may add that the imaginative speculation must be disciplined by integrative feedback with the new facts as they are discovered.

REFERENCES

1. H. H. DONALDSON. The growth of the brain. London: Walter Scott Ltd., 1895.
2. E. W. SPITZKA. Trans. Amer. Philos. Soc., **21**:175, 1907.
3. R. J. A. BERRY and L. W. G. BIEHNER. Proc. Roy. Soc. Victoria, **25**, Part II, 1913.
4. G. VON BONIN. J. Gen. Psychol., **16**:379, 1937.
5. E. W. COUNT. Ann. N.Y. Acad. Sci., **46**:993, 1947.
6. D. B. TOWER. J. Comp. Neurol., **101**:19, 1954.
7. J. C. LILLY. Man and dolphin. Garden City: Doubleday & Co., 1961.
8. W. R. ASHBY. Design for a brain, p. 239. New York: J. Wiley, 1952.
9. R. S. LEDLEY. Digital computer and control engineering. New York: McGraw-Hill Book Co., 1960.
10. W. W. IRELAND. Mental affectations of children. London: J. & A. Churchill, 1900.
11. J. M. COPPOLETTA and S. B. WOLBACK. Amer. J. Path., **9**: 55, 1933.
12. D. MCCARTHY. *In:* L. CARMICHAEL (ed.). Manual of child psychology. New York: J. Wiley, 1946.
13. K. HAYES. The ape in our house. New York: Harper Brothers, 1951.
14. O. K. MOORE. Paper presented at the meeting of the Tenth Thomas Alva Edison Foundation Inst., 1959.
15. ———. Proc. of the Third Minnesota Conf. on Gifted Children, University of Minnesota, Oct., 1960.
16. J. C. LILLY and A. M. MILLER. Science, **134**:1873, 1961.
17. J. C. LILLY. Amer. J. Psychiat., **115**:498, 1958.
18. ———. *In:* H. F. HARLOW and C. N. WOOLSEY (eds.). Biological and biochemical basis of behavior, p. 83. Madison: University of Wisconsin Press, 1955.
19. D. O. HEBB. Brain, 82:272, 1959.
20. W. C. HALSTEAD. Brain and intelligence. Chicago: University of Chicago Press, 1947.
21. J. S. SEMMES, S. WEINSTEIN, LILA GHENT, and H. L. TEUBER. Somatosensory changes after penetrating brain wounds in man. Cambridge: Harvard University Press, 1960.
22. W. N. KELLOGG. Porpoises and sonar. Chicago: University of Chicago Press, 1961.
23. J. C. LILLY and A. M. MILLER. Science, **133**:168, 1961.