To which this reply was sent:

The American Association of Anatomists assembled at Toronto is gratified to receive Your Lordship's stimulating message. We would assure Your Excellency that Canadian and other American anatomists form what we call a syncytium.

THE SECRETARY

The Hon. and Rev. Henry John Cody, president of the University of Toronto, led the after-dinner speaking with a most cordial address of welcome, in which he described briefly the organization and character of the University of Toronto, with its 8,000 students. President Cody also called attention to the number of Canadian medical scientists, and particularly to the anatomists trained in Canada who have influenced anatomical work in the United States, mentioning especially Professors Osler and McCrae, Addison, Barker, Bensley, Chambers, Cowdry, Harvey, Macklin and McMurrich.

Dr. J. P. McMurrich, professor emeritus of anatomy in the University of Toronto, sketched biographically two pioneer contributors to anatomy in Canada: Michel Sarrazin (1659–1735), who first described the comparative anatomy of Canadian mammals in communications to the Académie Royale in Paris, and James Douglas (1800–1886), a prominent early teacher of human anatomy and the 'grand old man' of Quebec.

The president of the association, Professor F. T. Lewis, of Harvard University, then delivered the annual presidential address entitled "The Fundamentals of Cell Shape."[1] In advance of publication, he was permitted to announce the finding of Dr. J. W. Marvin, of Columbia University, that compressed lead shot of one size have an average of 14 facets—not 12—so that an accepted distinction between solid and liquid bodies in this respect disappears. With solids, such as a mass of peas, a primary contact with 12 neighbors may be expected, but upon expansion to fill completely all interstices, an average of 14 facets will be established, as indeed might be expected from *a priori* considerations. The lecturer indulged the hope that sometime there may be a symposium, with lively discussion, on the neglected problems of cell shape and statics, "for there are indications" which he seemed to see "of a ripple of interest in that direction."

The final day included five morning programs, valuable throughout. Special mention may be made of the superb moving pictures of capillaries in the frog, reacting to the external stimulus of a needle point by the thickening of individual endothelial cells and the local adhesion of a pair of passing red corpuscles (Zweifach and Chambers, New York University).

Four afternoon papers of greater length preceded adjournment. Professor Boyden, of the University of Minnesota, primarily interested in Talmudic anatomy as a commentary on gall-bladder anomalies, explained the nature of this lore in a comprehensive historical survey. Professor Kappers, of the Institute for Brain Research, Amsterdam, showed in detail the comparative anatomy of the hypothalamic autonomic centers, and Professor Ranson dealt with their functional significance. Finally Professor Bensley presented his penetrating micro-chemical studies of mitochondria, dealing with the distribution of lipids in protoplasm and their relation to its constitution.

Professor Grant, of the University of Toronto, and his associates on the local committee, in cooperation with Professor Corner, of the University of Rochester, the able and experienced secretary of the association, had anticipated every need of such a convention. The first Canadian session of the Anatomists was rewardingly alert.

CORRESPONDENT

[1] For summary, see SCIENCE, April 2, 1937, Supplement, p. 10.

SPECIAL ARTICLES

CORTICAL REPRESENTATION OF TACTILE SENSIBILITY AS INDICATED BY CORTICAL POTENTIALS[1]

THE observations reported below were obtained in the course of experiments directed toward a functional analysis of the somesthetic area of the cerebral cortex. It was thought that a study of the slow components of potentials which may be picked up by widely separated electrodes and which presumably result from the summed activity of cortical elements might be of value. First in cats and later in monkeys, it was found that the application of discrete tactile stimuli to a given cutaneous area produces in the cortex of the anesthetized animal well-localized surface positive waves. The potentials are of such magnitude, show such regularity over periods of time and are so decisive in all their characteristics that we have been able to employ them in mapping a cortical representation of the tactile sensibility of the body surface.

The most essential requirements for observing and recording these potentials are: (1) anesthesia of sufficient depth to reduce the Berger waves to minimal frequency and size;[2] (2) the use of mechanically dis-

[1] From the Department of Physiology, Johns Hopkins University School of Medicine.

[2] It has previously been shown that surface positive activity occurs in the deeply anesthetized cat's cortex

crete stimuli which are brief in duraton, low in frequency and near the human threshold in intensity; (3) properly spaced thread electrodes. A cathode ray oscillograph is used for observing and recording the responses.

Stimulation is most effectively applied to hair-covered areas by a small camel's hair brush; to bare regions by a von Frey hair. These objects are mounted on a light lever of laminated wood which is rigidly attached to the moving armature of an electromagnetic device. The coils of the magnet are energized by a pulse 2 msec. in duration. This produces a regular, quick, to-and-fro movement which, at the end of the lever, amounts to a displacement of approximately 0.5 mm. The electrical pulse generator is a thyratron vacuum tube device possessing widely adjustable parameters and triggered by an independent circuit which also controls the x-axis unit of the cathode ray tube. Thus the pulse which activates the stimulator occurs at a given and adjustable point on the x-axis line. This part of the procedure makes it possible, provided the C.N.S. behaves with sufficient uniformity, to carry out observations with a facility comparable to that enjoyed in studies of the axon potentials of isolated nerve trunks. Experiments on 14 monkeys and 10 cats have shown this to be the case. Even when such disturbances as Berger waves interfere with the regularity and simplicity of the record, the above procedure usually enables one rapidly to determine the presence or absence of a correlated response.

The animals are anesthetized with pentobarbital sodium, chloralosan or dial. The skull is removed so as to expose the greater portion of the surfaces of one or both cortices, dural flaps are turned away and a Cellophane tracing made of such landmarks as sulci and prominent pial vessels. The head of the animal is then immobilized in a Horsley-Clarke instrument constructed to carry two electrodes. This arrangement permits rapid and precise placing of the leads on the pial surface. The electrodes consist of No. 50 cotton thread drawn through sections of steel tubing and kept wet with Ringer's solution. One electrode is placed at a given point on the somesthetic area, the other on an indifferent region, *e.g.*, occipital, temporal or pre-frontal cortex. Many observations have shown us that, provided the two leads are separated by a distance of one cm or more, the position of the "indifferent" electrode has no significant effect on potentials attributable to activity under the "different" electrode. If the animal's blood temperature is maintained at a normal level, frequent wetting of the pial surface with Ringer's is unnecessary and may even cause deterioration. With repeated doses of anesthetic observations may be continued for many hours. During periods of twenty-four hours the potentials obtained in response to tactile stimulation do not progressively undergo significant reduction or changes in character. In the course of most experiments they occasionally disappear for periods of from one to five minutes, but reappear and soon regain their previous size and form.

By using the methods and principles described above we have observed that a well-localized surface positive wave regularly follows each restricted tactile stimulus. Although stimulation of a specific peripheral locus elicits positive potentials detectable over a cortical area of several square millimeters, one or more discrete spots of maximal potential are always found. The site or sites of these can be determined only by exploring the area in steps of a fraction of a millimeter. The size of a cortical area varies with the part of the periphery stimulated. In the monkey, for example, stimulation of a few hairs on the anterior aspect of the lower leg gives rise to a potential change which is restricted to a small area on the contralateral postcentral gyrus. The maximally active spot is about the size of the effective area of the electrode. The potential drops to 25 per cent. of maximum when the "different" lead is moved 0.5 mm medially or rostrally from this point, to 5 to 10 per cent. when the displacement is 1.0 mm in either of these directions. Laterally and caudally the potential decreases somewhat less abruptly. On the other hand, von Frey hair stimulation of the tip of the great toe produces potential changes within a different but larger cortical area. In this case there are two and sometimes three spots of major potential situated 1 to 5 mm from one another. One of these, usually that nearest the central sulcus, shows the shortest latency and the steepest wave front. The others have a definitely longer latency, which appears as a 2 to 5 msec. shift in the entire wave. The fact that in any cortical area the potentials decrease much more precipitously when the electrode is moved in one direction than in another indicates the part played by purely physical spread. In general our experience suggests that within any area potentials greater than 10 per cent. of the maximal are physiologically significant if they occur at distances greater than 1 mm from the maximal point. Electrotonic spread is not so easily estimated, but hardly accounts for the magnitude and behavior of certain of the propagated waves.

The amplitude of a maximal potential may be as great as 1 millivolt, but it usually lies between 100 and 300 microvolts. The rising phase occupies from 3 to 6 msec., the falling phase from 10 to 80 msec.

---

when the sciatic nerve trunk is tetanized by direct electrical stimulation. See A. J. Derbyshire, B. Rempel, A. Forbes and E. F. Lambert, *Am. Jour. Physiol.*, 116: 577, 1936.

Under given conditions these values are quite constant. In the monkey the latencies, in milliseconds, average 15 to 20 for toes, 8 to 11 for fingers and 5 to 9 for face; in the cat the values are, approximately, 11 msec. for hindfoot, 8 for forepaw. The values may fluctuate as much as 20 per cent., but are usually constant within 5 per cent. We usually employ a stimulation frequency of one a second. The response progressively decreases in magnitude as the frequency is increased and it disappears at rates of from 12 to 15 a second. This effect is probably due to the same factors which produce the masking phenomenon described below.

A given cortical spot may yield potentials of approximately equal sizes when a discrete tactile stimulus is applied successively to different points on a restricted peripheral area. Thus brush stimulation of a few hairs within an area on the leg one inch wide and two inches long evokes potentials from a specific spot. Of great interest is the fact that these responses are attenuated or obliterated (masked) if another camel's hair brush is applied with a continuous motion anywhere else within that particular skin area. If the secondary stimulation is applied beyond the boundaries of an area represented at the cortical spot it has no masking effect.

Application of Dusser de Barenne's method of thermocoagulation[3] indicates that at least the outer layers of the cortex are not essentially concerned in the elaboration of these potentials. It is possible that only the terminations of thalamo-cortical neurons are involved, but the magnitude of the potentials, the characteristics of the spreading (*cf.* Adrian[4]) and other aspects of the responses speak against such a conclusion.

A general mapping of the entire Rolandic region and the corresponding area on the medial surface of the hemisphere can be achieved in a single experiment on a monkey by exploring with the stimulator the entire body surface each time the "different" electrode is placed on one of a series of arbitrarily selected cortical spots. Such a procedure consumes many hours, but it gives a good outline of a stable arrangement, the total representation which is revealed by these potentials. It uncovers a more detailed picture than any heretofore presented. Under the conditions of our experiments the representation appears to be confined to areas 3, 1 and 2. Up the postcentral gyrus to the hemispheral rim and then down the medial surface to sulcus cinguli the parts of the contralateral body surface are represented in an orderly sequence which roughly corresponds to that of the motor points on the precentral gyrus. Evidence has been found that in the case of the leg this sequence reflects the metameric origin of the dermatomes. No maximal potentials in response to tactile stimuli are found precentrally. Only the face has shown a definite bilateral representation.

This study, based on receptor stimulation and correlated electrical response, has disclosed a cortical representation of tactile sensibility which is definitely stable. We conclude that whatever functional variations may characterize the total cortical response to a tactile stimulus they are based on a highly stable anatomical substratum which is functionally demonstrable.

WADE H. MARSHALL,
Fellow, National Research Council
CLINTON N. WOOLSEY
PHILIP BARD

[3] J. G. Dusser de Barenne and H. M. Zimmerman, *Arch. Neurol. and Psychiat.*, 33: 122, 1935.

[4] E. D. Adrian, *Jour. Physiol.*, 88: 127, 1936.

QUANTITY ULTRACENTRIFUGATION WITH INTENSE FIELDS

THE air-turbine drive[1] makes it possible to ultracentrifuge[2] large volumes of liquid as well as to carry out the analytical procedures developed by Svedberg[3] and his coworkers. This quantity ultracentrifugation has already been used for several purposes—to concentrate the activity of yellow fever virus[4] and the pneumococcic antibodies[5] in immune horse serum and to crystallize[6] tobacco mosaic virus protein[7] directly from the juice of infected plants. Taken in conjunction with ultracentrifugal analyses it has been employed to isolate the unstable virus proteins responsible for several plant diseases[8] and to obtain in a pure state a similar substance,[9] which carries the virus activity causing infectious papillomatosis in rabbits. It is now being used routinely for the preparation of virus proteins in quantities sufficient for a detailed study of their biological, chemical and physical properties. Such ultracentrifugal preparation of proteins too unstable or present in too small amounts to be ex-

[1] E. Henriot and E. Huguenard, *Compt. rend.*, 180: 1389, 1925; *Jour. phys. radium*, 8: 443, 1927; J. W. Beams, *Rev. Sci. Instr.*, 1: 667, 1930; J. W. Beams and E. G. Pickels, *ibid.*, 6: 299, 1935.

[2] J. Biscoe, E. G. Pickels and R. W. G. Wyckoff, *Jour. Exp. Med.*, 64: 39, 1936; J. H. Bauer and E. G. Pickels, *ibid.*, 64: 503, 1936; R. W. G. Wyckoff and J. B. Lagsdin, *Rev. Sci. Instr.*, 8: 74, 1937.

[3] See T. Svedberg, *Naturwiss.*, 22: 225, 1934, for bibliography.

[4] J. H. Bauer and E. G. Pickels, *op. cit.*

[5] R. W. G. Wyckoff, SCIENCE, 84: 291, 1936.

[6] R. W. G. Wyckoff and R. B. Corey, SCIENCE, 84: 513, 1936.

[7] See W. M. Stanley, *Am. Jour. Botany*, 24: 59, 1937, for bibliography.

[8] W. M. Stanley and R. W. G. Wyckoff, SCIENCE, 85: 181, 1937.

[9] J. W. Beard and R. W. G. Wyckoff, SCIENCE, 85: 201, 1937.