the construction of great irrigation works, which the people who settled in the valley of the Rio Grande of that time painfully paid for. It neglected, however, to realize that nature intended this region to be a desert and it made no provision to protect these people from the relentless forces of nature which pressed in on them from every side. The winds covered up with sand what the waters failed to wash away. A permanent civilization in these river valleys of the Southwest must be founded upon control of the desert, just as methodically as we control the torrential rivers. The sooner this fact is realized, the sooner will our lawmakers have achieved a permanently successful reclamation policy.

CUTANEOUS SENSATION[1]

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THIS is really a very elementary problem with which you all have had first-hand experience. You know the distinctly different qualities of the sensations of warmth and cold aroused by sudden changes in the temperature of the skin, and the very different sensation of touch which is evoked when a thermally indifferent object comes in contact with the skin. If the heat and cold are sufficient to damage the skin, if the object is applied with crushing force or if it is sharp and penetrates the skin a fourth sensation entirely different from all the others is aroused, and this you call pain. What happens in the skin in each instance, and how are the disturbances which are set up there propagated to the brain, and how do they then make themselves felt in consciousness?

In spite of the primitive nature of this problem it has not by any means been solved. I shall leave out of account entirely the most difficult part; how when these propagated disturbances reach the brain they give rise to conscious sensation, which appears to be something of an entirely different order than neural activity. I can not understand how such a thing as a sensation of warmth makes its appearance as a result or as a concomitant of the activity of certain nerve cells in my brain. I can only admit the fact and leave to the future, perhaps the far distant future, the problem presented by the relation of brain and mind.

But the first part of the problem can be solved. It should be possible to determine which of the several different types of sense organs situated in the skin are sensitive to warmth, cold and touch, respectively, and which respond only to those painful stimuli which carry a threat of injury. It should be possible also to determine how the disturbances, when once set up in the sense organs, are propagated to the spinal cord and brain. It is to some relatively new information on this subject that I wish to direct your attention to-night.

When mechanical, thermal and chemical stimuli of sufficient intensity are applied to the skin they evoke sensations of pain, and it was formerly thought that excessive stimulation of any cutaneous receptor was painful. But this view was quite generally abandoned when it was found that there were separate warm, cold, pain and touch spots in the skin. For more than forty years it has been known that the skin is not uniformly sensitive. This can easily be demonstrated by marking off with a rubber stamp one square centimeter on the front of the forearm and subdividing this into square millimeters. If this area is then explored for touch by taking a not too stiff hair and pressing the end of it against the center of each of these millimeter squares in succession it will be found that touch is felt in only about one out of five of the squares. That is to say, there are about twenty points in each square centimeter on the front of the forearm which are acutely sensitive to touch. It is quite generally believed that these points are the only ones that are sensitive to touch, in spite of the fact that if a stiff hair is used the contact can be felt in every square millimeter. This can be explained as due to the pitting produced by the stiff hair causing a deformation of the skin which extends to and stimulates a true touch spot.

By appropriate means it is possible to identify points which are acutely and specifically sensitive for cold, others for warmth, and still others for pain. Not every psychologist will admit the absolute specificity and fixed identity of these sensory spots, but all will admit their existence. And, entirely apart from any of the implications of the punctiform theory, the number of these touch, pain, warmth and cold spots in a given square centimeter of skin may be taken as the best available index of the receptivity of that particular region in terms of each of the four varieties of cutaneous sensation.

One of the chief stumbling blocks in the way of the punctiform theory has been the failure to establish a definite relation between these spots and the sense organs in the skin. Yet if the theory is true such a relation must surely exist. For the sake of

[1] Lecture before the Northwestern University chapter of Sigma Xi, on December 9, 1932.

simplicity I shall assume for the moment that each sensory spot contains a sense organ specifically sensitive to one of the four types of stimuli. Later on I shall present a brief summary of such evidence as is available.

When a sense organ is activated by an appropriate stimulus the state of excitation is propagated to the central nervous system along the nerve fiber of which that organ is the peripheral terminus. The nerve fibers, which are so small that they can be seen only with a microscope, are grouped together like the wires in a telephone cable to form nerves. We may next inquire, what is the nature of the excitation which is propagated along the nerve fibers and which when it reaches the brain manifests itself in consciousness as a sensation?

We know that this wave of excitation, which is called a nerve impulse, travels much too slowly to be an electrical current; and that when such impulses pass over a nerve, there is a slight rise of temperature which can be registered only by the most delicate thermocouple and that they cause the nerve to use minute traces of oxygen, give off equally minute quantities of carbon dioxide, and hydrolyze phosphocreatin.[2] The nerve impulse, therefore, involves chemical changes in the fiber. This is about all that is known concerning the nature of the nerve impulse. But physiologists, making use of a considerable amount of constructive imagination, have pictured it to themselves as follows:

A nerve fiber is surrounded by a plasma membrane which, when in the resting state, is polarized with an excess of positive ions on the outside and of negative ones on the inside. The nerve impulse renders the membrane temporarily permeable and depolarized. Positive ions in front of this permeable portion of the membrane stream backward through it and then forward to neutralize the negative ions on the inner side. This adjacent part of the membrane thus becomes depolarized, and, according to the theory, depolarization for some reason makes it permeable, and the positive ions beyond it can stream backward through it to depolarize in turn the next stretch of the fiber. In this way a wave of electrical and chemical change spreads along the fiber. This is the nerve impulse.

Now it will be obvious that if a wire were run from the active to a resting part of the fiber an electrical current should pass through it from the resting to the active part. This in fact occurs and it has long been known under the name of nerve action current. If one lead of a string galvanometer is attached to the nerve at A and another at B and a volley of nerve impulses is caused to pass down the fibers, when it reaches A there will be a flow of electricity through the galvanometer toward that point, and when it reaches B there will be a flow in the reverse direction toward B. The galvanometer will show a diphasic deflection. By sensitive electrical devices it is possible to record the time, when the impulses pass each of two points, and thus determine the rate of conduction. It is known from data obtained in this way that an impulse travels at different rates in different fibers. The rate may vary from 1 to 100 meters per second in different kinds of fibers.

Naturally the action current is very weak, but recently by the use of vacuum tube amplifiers of the radio type it has been possible to increase its strength very greatly so that the inertialess cathode ray oscillograph can be used as a recording device. By this method Erlanger and Gasser[3] have increased our knowledge of action currents in sensory fibers. We shall have occasion to refer to their work a little later on.

With vacuum tube amplifiers and a capillary electrometer, Adrian,[4] professor of physiology at Cambridge, has been able to record the action currents of individual sensory nerve fibers and for this brilliant work he has been awarded this year's Nobel prize in medicine. He was interested in learning whether he could find any difference in the nerve impulses responsible for the different types of sensation, but could detect none, except that pain impulses traveled at a slower rate than those for touch. The frequency at which the nerve impulses follow each other over a given fiber may vary from 5 to 100 per second, according to the strength of the stimulus, but Adrian has shown that when a tactile end organ is stimulated in such a way that it responds at maximum frequency over a long period of time it does not cause pain. There is nothing characteristic either in duration, frequency or rhythm of the nerve impulses responsible for one type of sensation as against another. There is nothing comparable to the dot-dash system of the Morse telegraphic code.

Since the messages which reach the central nervous system over sensory nerve fibers are all alike, their interpretation as tactile, thermal or painful sensations must depend on the particular centers in the brain which they reach and activate. It is not the type of impulse which is significant but the connections of the fiber over which it passes. The sense organ with which the fiber is associated peripherally

[2] R. W. Gerard, "Nerve Metabolism," *Phys. Rev.*, 12: 469. 1932.

[3] J. Erlanger and H. S. Gasser, "The Action Potential in Fibers of Slow Conduction in the Spinal Roots and Somatic Nerves," *Am. Jour. Physiol.*, 92: 43. 1930.

[4] E. D. Adrian, "The Basis of Sensation," Norton and Company, New York. 1928; "The Messages in Sensory Nerve Fibers and Their Interpretation," *Proc. Roy. Soc. London*, Series B, 109: 1. 1931.

and the center to which it conveys the impulse determine the nature of the resulting sensation.

We return then to a more detailed consideration of the sense organs and sensory nerve fibers.

Several types of sense organs exist in the skin, but certain technical difficulties stand in the way of determining which serve for perception of warmth and which for cold, for touch and for pain. To begin with not every one is willing to cut out a piece of his own skin to make the test. But Dallenbach[5] and his three associates, after they had satisfied themselves of the location and fixed identity of certain warm and cold spots on their arms, had a surgeon excise small squares of skin, each of which included a warm or cold spot, and subjected these to histological examination. They were not able to see in their microscopical sections any special types of sense organs which they could identify as warmth or cold receptors.

Within the last year Bazett[6] has presented evidence which is of importance for the solution of this problem. In one square centimeter of skin he accurately mapped and counted the touch, warmth and cold spots. By means of a thermocouple he estimated the rate of conduction of temperature changes in the tissue and, by comparing the data thus obtained with the time required after application of the stimulus before the sensations of cold or warmth developed, he determined very accurately the depth of the sense organs concerned. The points sensitive to pain were too numerous for accurate enumeration; but 38 touch spots were counted in one square centimeter. In histological preparations of the same region of skin removed during operation on a patient he found the well-known end bulbs of Krause present in 11 out of 100 millimeter squares, while in the subject of his psychological experiments 7 out of 100 such squares had been found sensitive to cold. The depth of the cold receptors, as estimated by comparing the time required for response with the rate of transmission of temperature changes in the skin as determined by the thermocouple, was 100 micra, and the depth of organs of Krause as determined histologically varied from 91 to 103 micra. In 100 square millimeters there was one organ of Ruffini, and in the same area only one warm spot was found. The depth of the warmth receptor was estimated at 300 micra and that of the organ of Ruffini at 285 micra. These results together with those obtained by Strughold and Karbe[7] in their study of the cold spots of the cornea and conjunctiva make it evident that the end bulbs of Krause serve as cold receptors and the end organs of Ruffini as warmth receptors.

Where hairs are present, the nerve endings within their follicles serve as touch receptors.[8] In hairless regions the corpuscles of Meissner and the unencapsulated bulb-like endings described by Bazett probably serve the same purpose. The free nerve endings are quite universally regarded as pain receptors. They are the only endings present within the central parts of the cornea, where pain alone is felt.

The sensory fibers are long threads of protoplasm which arise from cells in the spinal ganglia. The single process of each cell divides into a peripheral branch which runs to the skin and a central branch which enters the spinal cord. Some of these fibers become enclosed in a sheath of fatty material known as myelin and for this reason are called myelinated fibers. Others have no fatty sheath and are known as unmyelinated fibers. The myelinated fibers vary in diameter from 1 to 16 micra, while all the unmyelinated fibers measure less than 1 micron.

The nerves supplying different regions of skin differ greatly in their composition, and this difference is related to the sensory capacities of the regions which they innervate. For instance, it has been found from a study of the nerves of an amputated arm that the median nerve at the wrist, which in proportion to its large size supplies a relatively small area of palmar skin richly endowed with tactile sensibility, contains a very high percentage of myelinated fibers and relatively few unmyelinated fibers. On the other hand, the medial cutaneous nerve of the forearm, which in proportion to its small size supplies a relatively large area of skin which is even more sensitive to painful and thermal stimuli than the palm of the hand but much less sensitive to touch, contains a very large percentage of unmyelinated fibers.[9] Furthermore, the majority of the myelinated fibers in the median nerve are large, while most of those in the medial cutaneous nerve are small. From this we may infer that touch is mediated by large myelinated fibers and pain by the unmyelinated and fine myelinated fibers.

These observations aroused our curiosity, and we decided to investigate nerves supplying still other areas of skin. In order to make a satisfactory comparison of the composition of a nerve with the sensory capacities of the area of skin which it supplies, it became necessary to have some quantitative statement of the sensibility of the different regions of the

5 K. M. Dallenbach, "The Temperature Spots and End Organs," *Am. Jour. Psychol.*, 39: 402. 1927.

6 H. C. Bazett, "Sensation," *Arch. Neurol. and Psychiat.*, 27: 489. 1932.

7 H. Strughold and M. Karbe, "Die Topographie des Kältesinnes auf Cornea und Conjunctiva," *Ztschr. f. Biol.*, 83: 189, 201, 207, 297. 1925.

8 M. v. Frey, "Die Haut als Sinnesfläche," Handbuch der Haut und Geschlechtskrankheiten, Bd. 1, Teil 2, S. 91. 1929.

9 S. W. Ranson, "Cutaneous Sensory Fibers and Sensory Conduction," *Arch. Neurol. and Psychiat.* 26: 1122. 1931.

body in terms of the four varieties of sensation. Fortunately, we were able to find such a statement in recent papers from von Frey's laboratory in Wurzburg.[10] In that laboratory careful counts have been made of the four different types of sensory spots in many regions of the body. From their extensive tables I have extracted a few figures which show how varied are the sensory capacities of the skin in different regions. (Table 1.)

TABLE 1

Region	Number of spots per sq. cm. sensitive to			
	Pain	Touch	Cold	Warmth
Apex of nose	44	100	13	
Chest	196	29	9	0.3
Front of thigh	192	13	5	0.4
Front of forearm	203	23	6	0.4
Palmar surface of finger tips	60	100+	0.7	1.0
Back of fingers	100	9	8	1.7

Touch surfaces, such as the tips of the fingers and the tip of the nose, are relatively poor in pain spots and extremely rich in touch spots. The reverse is true of most of the remaining body surface. On the front of the thigh there are in each square centimeter of skin 192 pain spots and 13 touch spots, and on the front of the forearm 203 pain spots and 23 touch spots per square centimeter. On the touch surfaces there are from 44 to 60 pain spots per square centimeter as compared to from 100 to 200 in the same area on other regions of the body. Furthermore, on the touch surfaces there are about 100 touch spots as compared with 9, 23, 13 and 29 in other regions. Except in the territory around the mouth, warm and cold spots are comparatively few. If we may assume that the number of nerve fibers mediating each of the four varieties of sensation is proportional to the number of spots, we may say at once that the number of fibers mediating temperature sensations constitute an insignificant part of the total fiber content of sensory nerves, and that if pain and touch fibers differ histologically, it should be possible to see a striking difference between the nerves supplying a tactile surface like the palmar surface of the hand and fingers and those supplying regions like the front of the forearm. Such differences can readily be seen. The median nerve at the wrist, which supplies the palmar surface of the hands and fingers with high tactile and low pain sensibility, is composed chiefly of large myelinated fibers. The medial cutaneous nerve of the forearm, which supplies a region of low tactile sensibility very rich in pain spots, contains great numbers of fine myelinated and unmyelinated fibers. The inference seems clear that the large fibers mediate touch and small ones pain.

A detailed investigation of the cutaneous nerves, in which Dr. Droegemueller and Mrs. Davenport are participating and which is being aided by a grant from the American Medical Association, is now under way and has disclosed some interesting facts. To economize effort we have restricted the analysis to a single bundle or fascicle of fibers in each nerve. A fascicle in the medial cutaneous nerve of the forearm was found to contain 2,903 unmyelinated fibers, 563 myelinated fibers under 5 μ in diameter, 78 between 5 and 8 μ, and 273 more than 8 μ in diameter (Table 2). It is interesting to compare these data

TABLE 2

SENSORY SPOTS ON THE FRONT OF THE FOREARM AND NERVE FIBERS IN THE MEDIAL CUTANEOUS NERVE OF THE FOREARM

	Sensory spots in 1 sq. cm.	Per cent. of total spots	Fibers: Myelinated	Fibers: Unmyelinated	Fibers: Per cent. of total fibers
Pain	203	87.3	(1–5 μ) 563	2903	90.8
Temp.	6.4	2.8	(5.1–8 μ) 78		2.04
Touch	23	9.9	(8.1–16 μ) 273		7.15

with the distribution of sensory spots in the region supplied by the nerve. There are 203 pain spots, 6 or 7 temperature spots and 23 touch spots in one square centimeter of the skin on the front of the forearm. Of the total number of spots about 87 per cent. are sensitive to pain, about 3 per cent to temperature and 10 per cent to touch. Of the total number of fibers, 90 per cent., including myelinated and unmyelinated, are under 5 μ in diameter, 2 per cent. have a diameter between 5 and 8 μ, and 7 per cent. between 8 and 16 μ. The agreement between the percentages of the different types of spots and of these three groups of fibers is very close and seems to indicate that pain may be mediated by the small fibers, touch by the large ones, and temperature sensations by those of intermediate size. It is only by including the un-

[10] H. Strughold, "Die Dichte der Schmerzpunkte auf der menschlichen Haut," *Ztschr. f. Biol.*, 80: 367. 1923. H. Rein, "Ueber die Topographie der Warmempfindung," *Ztschr. f. Biol.*, 82: 513. 1925. H. Strughold und R. Portz, "Die Dichte der Kältepunkte auf der menschlichen Haut," *Ztschr. f. Biol.*, 91: 563. 1931.

myelinated with the small myelinated that a sufficient number is obtained to account for the great number of pain spots. It is true that some of these small fibers are of sympathetic origin and are destined for the innervation of the blood vessels, sweat glands and smooth muscles of the hair follicles, but the majority of them are undoubtedly sensory and take origin from cells in the spinal ganglia.[11]

Table 3 shows the distribution of the sensory spots on the front of the thigh and of fibers in a nerve which supplies that area. The agreement is again satisfactory between the percentage of pain spots and small fibers and between the percentage of temperature spots and medium-sized fibers, but we are a little short of the large fibers for touch. A comparison of the distribution of the myelinated fibers of different sizes in these two nerves is instructive. The medial cutaneous nerve of the forearm which supplies skin having twenty-three touch spots per square centimeter has a higher percentage of large fibers than has the lateral cutaneous nerve of the thigh which supplies skin having only thirteen touch spots per square centimeter.

TABLE 3

SENSORY SPOTS ON THE FRONT OF THE THIGH AND NERVE FIBERS IN THE LATERAL CUTANEOUS NERVE OF THE THIGH

			Fibers		
	Sensory spots in 1 sq. cm.	Per cent. of total spots	Myelinated	Unmyelinated	Per cent. of total fibers
Pain	192	91.2	(1–5 μ) 1082	5824	94.17
Temp.	5.4	2.6	(5.1–8 μ) 161		2.19
Touch	13	6.2	(8.1–16 μ) 266		3.62

Gasser and Erlanger,[12] working on nerve action currents amplified by vacuum tubes and recorded by means of a cathode ray oscillograph, have furnished evidence of great importance. When cocaine is applied to a nerve, function is not lost all at once but gradually and in the following order: pain, cold, warmth, touch and motion. Analysis of the action currents shows that with this sort of block the small fibers are first affected, then those of medium size and finally the large fibers. When a pressure block is applied to a nerve, function is lost in the reverse order: motion, touch, cold, warmth and pain; and in this case the cathode ray oscillograph shows that the fibers are thrown out of function in the order of their size, beginning with the largest. The fine fibers and the sense of pain are the last to be affected by pressure and the first to be affected by cocaine. It is impossible to escape the conclusion that pain is mediated by small fibers, temperature sensations by those of intermediate size and touch by the large ones.

The threshold for direct electrical stimulation of small fibers is very much higher than that for large fibers. This is significant, since it has been found that when the electrodes are applied directly to the nerves, weak stimuli which could activate only the large fibers give rise to sensations of touch and that much stronger stimuli which could activate the small fibers are required to produce pain.[13]

Additional evidence pointing in the same direction is available from the phenomenon of sensory dissociation following nerve section in man and from the section of the fine fibers composing the lateral division of the dorsal root of a spinal nerve in the cat,[9] but since time is limited this evidence can not be presented here. Enough has been said to make it evident that progress is being made toward the positive identification of the sensory endings which serve as receptors for each of the varieties of cutaneous sensation and that the new evidence supports the current belief regarding the functions of these end organs. It is also becoming clear that the four varieties of sensations are mediated by different types of fibers—touch by the large myelinated fibers, temperature sensations by those of intermediate size and pain by the fine myelinated and unmyelinated fibers.

OBITUARY

FRANCIS LEROY LANDACRE

DR. FRANCIS LEROY LANDACRE, professor of anatomy and secretary of the College of Medicine of the Ohio State University, died at Columbus, Ohio, on August 23, 1933. His death removes from its faculty of medicine a veteran teacher and one of its most faithful servants and counselors.

Professor Landacre was born near Columbus, Ohio, on February 13, 1867. He attended Ohio Wesleyan and Ohio State Universities, receiving the B.A. degree

[11] S. W. Ranson and H. K. Davenport, "Sensory Unmyelinated Fibers in the Spinal Nerves," *Am. Jour. Anat.*, 48: 331. 1931.

[12] H. S. Gasser and J. Erlanger, "The Rôle of Fiber Size in the Establishment of a Nerve Block by Pressure or Cocaine," *Am. Jour. Physiol.*, 88: 581. 1929.

[13] P. Heinbecker, G. H. Bishop and J. O'Leary, "Fibers in Mixed Nerves and Their Dorsal Roots Responsible for Pain," *Proc. Soc. Exp. Biol. and Med.*, 29: 928. 1932.