THE RELATIONSHIP OF CUTANEOUS SENSIBILITY TO NEUROHISTOLOGY IN THE HUMAN PINNA

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INTRODUCTION

In a recent investigation, Weddell & Zander (1950) compared and contrasted the histological methods commonly adopted for the display of neural elements in peripheral tissues, using the cornea as their testing ground and controlling their observations by phase-contrast examination of fresh untreated specimens. They found that the appearances produced depended to a significant degree on the precise technique adopted, and that no single method was of universal applicability. However, it was possible, by using the pictures obtained by silver impregnation and by methylene-blue staining to complement one another, to interpret the results in the light of the phase-contrast observations.

It appeared worth while to apply this newly gained experience to the examination of preparations of human skin. The area selected was the auricle of the ear, since in this region relatively large areas of thin skin are available, resting on a minimal base of relatively homogeneous subcutaneous tissue. At the same time, the sensitivity of the auricle to the four commonly recognized modalities of sensation was assessed in terms of the sensitivity of other skin areas.

There is surprisingly little precedent for an attempt to compare the sensory capacities of two areas of skin; the most recent paper is that of Hutchison, Tough & Wyburn (1948). The two control areas for the present investigation were the front of the forearm and the palmar aspect of a finger. The first of these was chosen since it has been the site of election for sensory experiments in the past, and has thus acquired the status of a standard area. The second was taken as representative of a specialized sensory region.

MATERIAL AND METHODS

A. *Sensory testing*

An investigation was made of the responses of a number of healthy men to stimulation of the cranial surface of the auricle by a variety of agents; no subject had previous experience of experiments involving sensory testing. In essentials the methods used were merely a refinement of the usual clinical methods. Since, however, there is evidence (Sinclair & Hinshaw, 1951*a*) that testing methods are an important factor in the results of sensory experiments of this kind, full details are given.

Comparisons between auricle and forearm

A testing area of 1 sq. cm. was marked out on the flattest available region by means of a square rubber stamp ruled in millimetres, care being taken to avoid

any large veins. An exactly similar control area was established on the front of the right forearm 12 cm. above the proximal crease of the wrist.

In ten subjects each area was stimulated ten times at random by a vertically applied no. 2 nylon thread 2·5 cm. in length (Sinclair & Hinshaw, 1951*b*): the subject was asked to shut his eyes and to respond every time he felt himself touched. The numbers of responses in the two areas were then compared. In the same ten subjects four or five pricks were then applied to each area with a long round-bodied needle (Sinclair & Hinshaw, 1951*b*): the pricks were of a severity just short of drawing blood. The subject was then asked if he could detect any difference between the experiences produced in the two areas.

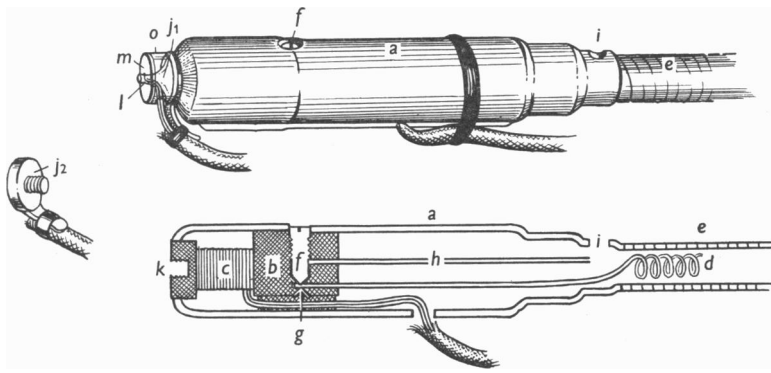

Fig. 1. ***Temperature probe.*** **The vulcanite holder *a* contains a copper block *b* which can be heated by the coil *c* or cooled by allowing carbon dioxide under pressure to expand inside it. The gas is brought from the cylinder along the coiled stainless steel tube *d* which is enclosed in flexible gas piping *e* to allow the instrument mobility. The terminal part of the tube is straight and is let into the block *b*, where it is pierced at right angles by a small hole closed by the adjustable bevelled screw *f*. When this screw is partly withdrawn the gas rapidly expands at the point *g* and escapes past the screw to the waste pipe *h*, which leads it to the vent *i*. Copper tips of various shapes (j_1, j_2) can be screwed into the socket *k* and so heated or cooled. Each terminal bears a fine thermocouple *l* as close as possible to its tip. The small terminal j_1 which has a tip 1·5 mm. in diameter, is shielded by a perforated mica disc *m* which allows the tip to protrude 1 mm. beyond it and is secured to the base of the terminal by cellotape *o*; this mica reduces radiation to the skin from the base-plate. The large terminal j_2 (12·5 mm. in diameter) needs no shielding, since its whole surface is employed.**

Temperature stimuli were applied to each area by means of a special probe which could be heated electrically or cooled by allowing carbon dioxide to expand through a small orifice in its interior (Fig. 1). This probe was fitted with a series of detachable copper tips, each carrying a thermocouple which recorded the temperature of the tip correct to within half a degree Centigrade. Ten subjects were used for the warm comparisons, and ten for the cold comparisons.

In the first test 100 stimuli were given to the marked area, using a tip 1·5 mm. in diameter at a temperature of 45° C. This tip projected 1 mm. beyond a mica disc 12·5 mm. in diameter (Fig. 1) which served to prevent stimulation of the skin by radiation from the hot metal block. The stimuli were delivered in groups of ten, using the columns on the ruled area as a guide. The odd-numbered columns were covered first, then the even-numbered ones, with an interval of 1 min. between each

column. Each stimulus remained in contact with the skin for 2 sec., and the time taken to complete one column was between 40 and 50 sec. The instrument was allowed to rest by its own weight on the forearm, but in the ear it was necessary to hold out the auricle at an angle to the side of the head and apply the stimulus at as constant a pressure as possible with the other hand.

The subject was aware that the stimulus was warm, but was also told that he might not experience anything beyond the feeling of the pressure of the instrument; he was asked to report immediately any sensation of warmth. The time available for each judgement was deliberately made short in view of the inexperience of the subjects; they were not asked to make any introspective evaluations.

After a rest of some 5 min. the control area was covered in exactly the same way and the numbers of responses in the two areas were subsequently compared. In order to neutralize any possible 'learning effect' the control area was taken first in five subjects and the experimental area first in the other five. Each man was asked if he observed any subjective difference between the sensations he had experienced in the two areas.

After a further rest of 5 min., a new area of skin in both ear and forearm was selected and an attempt was made to establish the threshold for the sensation of warmth, using this time a probe tip with a diameter of 12·5 mm. The threshold was approached from both directions in steps of 1° C., and the tip was allowed to remain in contact with the skin for a period of 10 sec. if no immediate response was obtained. As few stimuli as possible were applied in order to avoid the effect of fatigue, though it was found that with a stimulus of this size fatigue to a constant temperature did not occur until much later than the time taken by the threshold experiments. The threshold was taken as the mean of the reading above which every stimulus was reported as warm and the reading below which every stimulus was reported as neutral.

The cold comparisons in the remaining ten subjects were made in an exactly similar manner, the number of cold responses per 100 stimuli being obtained with the small tip of the instrument cooled to 15° C., and the threshold to cold being determined in the same way as the threshold to warm.

Comparisons between auricle and finger

Another thirty comparisons were made between the auricle and a control area sited on the front of the proximal phalanx of the right ring finger. The subjects used were for the most part those who took part in the forearm comparisons, and the only procedural difference was that in the touch comparisons a no. 1 nylon thread was used, since it was found that no. 2 thread gave 100% responses from both testing areas.

'Cold spots'

In five subjects a number of areas especially sensitive to cold stimuli were located by a metal tip 1 mm. in diameter at a temperature of 15° C. When the same point on the skin had given rise to three successive and unequivocal responses of cold it was marked with a spot of indian ink carried into the skin on the point of a fine needle. The histology of these areas was studied after biopsy.

B. *Histology*

Pieces of skin from the region of the concha and antihelix of the cranial aspect of nineteen human ears were impregnated with silver by the method described by Weddell & Zander (1950) for the cornea. Minor *ad hoc* modifications were occasionally made to ensure that the axis cylinders of the nerve fibres in the skin were outlined selectively. Each piece of skin was between 1 and 2 sq.cm. in area, and in many of the ears several such pieces were studied; the total area of skin available was thus over 30 sq.cm. Three of the pieces contained marked spots which had previously been found to be sensitive to cold. In addition, three specimens of skin from the lateral aspect of the auricle and three portions of auricular cartilage were examined by the same technique. All material was taken so as to avoid the regions of the intrinsic muscles of the auricle.

Control sections were taken from the palmar aspect of an amputated human ring finger to act as a check on the silver impregnation technique.

Lastly, two specimens of skin from the cranial aspect of the auricle were stained by methylene blue in the living subject, after the location and marking of an area especially sensitive to cold. The dye was made up to a concentration of 0·02 % in physiological saline; it was injected intradermally, and the skin was removed 25 min. after injection. The dye was fixed and the skin prepared for microscopic examination with due regard to the various precautions listed by Weddell & Zander (1950).

OBSERVATIONS

A. *Sensory testing*

Comparison of auricle with forearm

(1) *Touch.* Every stimulus on every ear was appreciated, but only 68 % of the stimuli on the forearm were felt; the difference is statistically significant ($p < 0{\cdot}01$).

(2) *Pinprick.* Six subjects thought the ear pricks 'more painful' or 'sharper' than those in the forearm; two could detect no difference, and two thought the pricks were sharper in the forearm·

(3) *Cold.* The mean number of responses per 100 stimuli in the ear was 21·1; in the forearm it was 29·2. This difference was not, however, statistically significant. The mean threshold for cold in the ear was 27·8° C.; in the forearm it was 27·4° C.; these figures do not differ significantly.

Four out of ten subjects remarked a qualitative difference between the ear responses and the forearm ones, especially when the large stimulator tip was used; one of them expressed it by saying that the sensation in the ear was 'rather stinging cold, like a snowball', while the forearm sensation was not so definite. Three subjects considered the subjective judgements required were easier to make in the ear; two thought the forearm experiments easier and the remaining five had no preference.

(4) *Warm.* The mean number of responses per 100 stimuli in both the ear and the forearm was exactly the same, 8·9. The mean threshold for warm in the ear was 36·9° C., while in the forearm it was 35·2° C.; the difference was not of statistical significance. No subject could detect any qualitative difference between the two areas, but two thought the task of making a judgement was easier in the ear and one thought the reverse.

Comparison of auricle with finger

(1) *Touch.* In spite of the fact that a lighter thread was used, every stimulus applied to every ear was appreciated, whereas only 49 % of the stimuli on the finger were felt; the difference in favour of the ear was statistically significant ($p < 0{\cdot}01$).

(2) *Pinprick.* Four subjects considered the finger pricks were 'sharper' than those in the auricle; five could detect no difference and one thought the pricks were sharper in the auricle.

(3) *Cold.* The mean number of responses per 100 stimuli in the ear was 17·8; in the finger it was 21·1. This difference was not statistically significant. The mean threshold for cold in the auricle was 29·4° C.; in the finger it was 29·5° C.

Three out of ten subjects experienced a qualititative difference between auricle and finger, the ear sensations being more 'stinging'. The same three subjects also considered the subjective judgements were easier to make in the ear; the remaining seven had no preference.

(4) *Warm.* The mean number of responses per 100 stimuli was 8·1 in the ear and 6·0 in the finger; the mean threshold for warm in the ear was 38·3° C., while in the finger it was 39·5° C. In neither case is the difference of statistical significance.

Two subjects considered that in the ear the warm sensation rose more quickly to its maximum intensity than in the finger; the remaining eight could detect no qualitative difference. No subject had any preference in respect of the ease of making judgements.

Effect of chronological testing order

There was no evidence from the figures in any of the series of temperature experiments of any tendency towards either a 'learning' or a 'fatigue' effect in the testing area which was examined second.

B. *Histology*

(1) *Skin from the auricle*

The skin was smooth and thin, with many fine hairs. In the dermis, nerve fibres of various diameters were grouped into bundles of all sizes and formed a complicated cutaneous nerve plexus in every way similar to that in the dorsum of the ear of the rabbit (Weddell, 1941), except that, owing to the greater thickness of the human skin, it was more difficult to focus so many nerve bundles at a time.

Individual fibres terminated in one of two ways. Either they formed a complicated basket-like network around hair follicles (Fig. 2), or they ended freely after branching repeatedly. These free endings covered a wide area in the more superficial layers of the dermis and the deeper layers of the epidermis. The fibres from which they arose were either finely myelinated or non-myelinated, and were usually smooth in outline. In contrast, their successive branches, which were only clearly displayed in the methylene blue specimens (Weddell & Zander, 1950), were beaded (Fig. 3).

No 'organized endings'* were seen in any of the specimens examined. Occasionally something resembling one was noticed, but every such object could be shown to be an artefact, whose true nature could be made out by focusing up and down or by

* In this paper the term 'organized ending' refers to any closely knit and well-localized nerve termination (other than a simple terminal bead), whether or not it is surrounded by a connective-tissue capsule.

examining serial sections. In this way it was found that most of these artefacts were due to tearing of a fibre or fibre bundle in which the Schwann or surrounding connective-tissue elements were partially impregnated. Most of them occurred close to the plane of separation of the skin from the cartilage, and it is highly probable that their presence here was connected with the local damage inevitable at this point when the skin was stripped off (Weddell & Zander, 1950).

The regions surrounding the marked cold-sensitive spots did not appear to differ in any way from the rest of the specimen; there were certainly no 'organized endings' in relation to them.

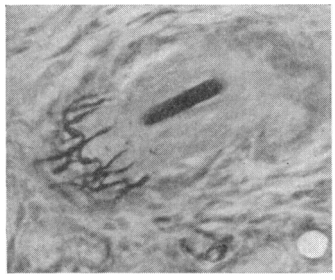

Fig. 2.

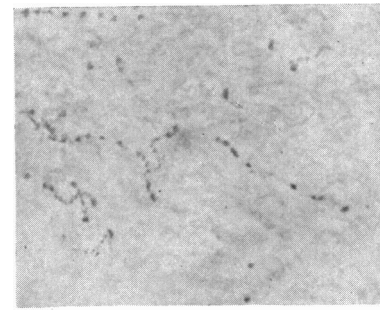

Fig. 3.

Fig. 2. Basket-like network of nerve fibres surrounding a hair follicle in the human auricle. Silver impregnation. (×350.)

Fig. 3. Free beaded nerve terminals in the epidermis of the human auricle. Methylene blue. (×650.)

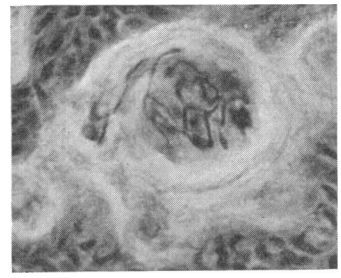

Fig. 4. Complex organized nerve ending from a dermal papilla in the human finger. Silver impregnation. (×650.)

(2) *Cartilage*

No nervous tissue of any kind was seen in the cartilage itself; there were nerve fibres accompanying the blood vessels in the perichondrium, but no organized endings.

(3) *Palmar aspect of the proximal phalanx of the ring finger*

The cutaneous plexus was qualitatively similar to that in the ear; the fibres, however, terminated differently. As in the ear, both myelinated and non-myelinated fibres gave rise to branches which terminated freely. The remaining fibres ended in the dermal papillae in a variety of organized endings (Fig. 4).

DISCUSSION

The human auricle is a region from which most of us have at one time or another experienced the sensations of touch, pain, cold and warm. In this investigation we have attempted to show that its sensitivity to these four classes of sensation is in no way unique, being of the same order as that of the skin on the front of the ring finger and the forearm. Indeed, the only statistically significant difference obtained was that the ear was more sensitive to touch stimuli of the type employed than the finger, and much more so than the forearm. It must be emphasized that no rigorous comparison was made, and in particular that there was no attempt to map temperature spots. The lability of such spots is well known (Dallenbach, 1927), and it would have been unnecessarily tedious to make a comparison on the basis of the number of spots in a given area. The point is not that the ear is more (or less) sensitive than the finger or forearm, but that tactile, painful and thermal stimuli can be appreciated when they are applied to the back of the auricle, and that, though there may be minor differences, there is apparently no gross qualitative peculiarity about the sensations so aroused.

The methods used to compare the sensory capacity of the ear with that of the control areas are only representative of many others which could be used; as psychological experiments they are open to many objections (the subjects were untrained; skin temperatures were not taken; the endurance and fatiguability of the subject were grossly involved; inadequate allowance was made for the relatively long reaction time to temperature; equivocal responses were dismissed; the pressure of the thermal stimulator was inconstant; the large size of the smaller temperature stimulus in relation to the grid permitted many grid squares to be stimulated at least twice: to name but a few). However, all these objections apply with equal force to the control area, and we may safely draw the conclusion that from the clinical and practical point of view touch, pain, warm and cold sensibility are adequately represented in the skin of the auricle.

The neural apparatus available in the auricle to mediate these sensations appears to comprise a series of complex basket formations round the numerous hair bulbs and a more widely dispersed network of fine undifferentiated terminals. No ending of any other kind was found, either in the skin on the side of the auricle tested, in the deeper tissues, or in the skin on the side remote from stimulation, in spite of the examination of over 30 sq.cm. of skin from twenty-one ears. The methods on which this result rests are those which were compared against phase-contrast appearances in the more favourable setting of the cornea (Weddell & Zander, 1950) and found to be mutually complementary. It cannot reasonably be argued that the silver impregnation failed to show up any 'organized endings', since numerous well-impregnated 'organized endings', both capsulated and non-capsulated, were found in the skin from the front of the finger.

We may therefore advance the main thesis of this paper, which is that, in the auricle at least, 'organized endings' are not essential to the perception of touch, pain, cold and warm stimuli. It is fairly certain that another such region exists in the vicinity of the inferior concha of the nose (Harpman, 1951), and such observations as those of Gilbert (1929) render it at least possible that the whole of

the hairy skin constitutes a third. The auricle is, however, a particularly advantageous area in which to investigate the point, since the skin is thin and easily stripped from the underlying cartilage. There is little depth of dermis and subcutaneous tissue, and it is consequently easy to obtain and examine whole preparations including both skin and the entire underlying tissue.

Our findings thus serve to anchor to a more solid histological foundation the view current in psychological literature (Nafe, 1927, 1942; Kantor, 1947; Jenkins, 1951; Morgan, 1951) that 'organized endings' need not necessarily play any special part in sensory perception. This view has arisen out of repeated failure to relate any specific type of end organ to any specific type of sensation by the technique of biopsy of marked spots. This point is considered in more detail in another place (Weddell, Sinclair, Zander & Hagen, 1952), and it will suffice here to add our own failure to those of previous workers.

This is not, of course, to say that in those regions of the body where 'organized endings' do occur, such as the fingers, the lips, the conjunctiva, the genitalia, etc., they play no part in sensory discrimination. Nevertheless, we may conclude that nerve endings of a single morphological type are in certain regions concerned with more than one sensation (cf. Weddell, Sinclair & Feindel, 1948; Zander & Weddell, 1951). It may also be justifiable to infer that the morphology of a nerve terminal is not a factor of primary importance in determining its sensory specificity.

This conclusion runs directly contrary to the theory of cutaneous sensibility currently held by many physiologists and clinical neurologists and generally attributed to von Frey. The history of the development of this theory has been sketched by Boring (1942). It may perhaps be said to have sprung from the original clinical discovery that certain types or 'modalities' of cutaneous sensation could be separated from one another by the action of various diseases or physical agents. To this was added the doctrine of specific nerve energies attributed to Johannes Müller, the sensory investigations of such workers as Nothnagel (1867), and finally the discovery of the punctate representation of sensation in the skin by Blix (1884), Goldscheider (1884) and Donaldson (1885).

On these foundations the hypothesis was gradually erected that for each 'modality' of sensation a specific type of nerve-ending existed having morphological characteristics enabling its functional activity to be predicted. It was assumed that in relation to each punctate sensory 'spot' one or more end-organs of this type lay ready to initiate a train of events culminating in its possessor experiencing the specific sensation they subserved.

We do not at the moment wish to call in question either the validity or the usefulness of the clinical concepts of sensory 'modalities' or punctate sensibility, but merely to maintain, on a histological basis, that the nature of the neural apparatus in the human auricle negatives the universal application of the concept of morphologically specific receptors to the human skin. It might be possible to argue that the principle if not the details of the von Frey theory still hold, and that there are in fact different terminal mechanisms for the various modalities, but that in the auricle our microscopic technique is inadequate to distinguish them morphologically, though functionally they are distinct. This suggestion cannot be scouted, since the auricular innervation is indeed lavish and complex, and one cannot be certain that

it is not composed of several elements. Nevertheless, it is an uncomfortable suggestion to be forced to make, and, since there are objections to the von Frey theory on other grounds (Ruffini, 1905; Nafe, 1927, 1929; Pradines, 1931; Kantor, 1947) it would appear safer to regard the whole structure of the theory—at least in so far as it involves specific peripheral receptors—as suspect.

SUMMARY AND CONCLUSIONS

The skin of the human auricle, when examined by the best available techniques for displaying peripheral neural elements, does not appear to contain any 'organized' nerve endings. There are only two types of peripheral termination: either the fibres end freely between the hairs or they supply a complicated basket-work round each hair bulb. Nevertheless, cutaneous sensibility in the auricle does not appear in any way peculiar, and touch, pain, cold and warm sensibility are adequately represented. A comparison shows that the sensitivity of the skin of the auricle to the four customarily recognized sensory modalities is comparable to that of the skin of the front of the forearm and the front of the ring finger. It therefore appears that the current theory of cutaneous sensation, which demands specific receptors for each modality of sensation, cannot be of universal application to the human body, and thus its standing must be seriously called in question.

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