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THE SENSATIONS PRODUCED BY ELECTRICAL STIMULATION OF THE VISUAL CORTEX

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SUMMARY

1. An array of radio receivers, connected to electrodes in contact with the occipital pole of the right cerebral hemisphere, has been implanted into a 52-year-old blind patient. By giving appropriate radio signals, the patient can be caused to experience sensations of light ('phosphenes') in the left half of the visual field.

2. The sensation caused by stimulation through a single electrode is commonly a single very small spot of white light at a constant position in the visual field; but for some electrodes it is two or several such spots, or a small cloud.

3. For weak stimuli the map of the visual field on the cortex agrees roughly with the classical maps of Holmes and others derived from war wounds. With stronger stimuli, additional phosphenes appear; these follow a map that is roughly the classical map inverted about the horizontal meridian.

4. The phosphenes produced by stimulation through electrodes 2·4 mm apart can be easily distinguished. By stimulation through several electrodes simultaneously, the patient can be caused to see predictable simple patterns.

5. The effects of the duration and frequency of stimulating pulses on the threshold have been explored.

6. For cortical phosphenes there is no sharp flicker fusion frequency, and probably no flicker fusion frequency at all.

7. During voluntary eye movements, the phosphenes move with the eyes. During vestibular reflex eye movements they remain fixed in space.

8. Phosphenes ordinarily cease immediately when stimulation ceases, but after strong stimulation they sometimes persist for up to 2 min.

9. Our findings strongly suggest that it will be possible, by improving our prototype, to make a useful prosthesis.

INTRODUCTION

Foerster (1929) and Krause & Schum (1931) were the first to expose the occipital pole of one cerebral hemisphere and investigate the effect of stimulating it electrically. Foerster found that when a point at the extreme occipital pole was stimulated, his patient saw a small spot of light directly in front and motionless. When a point on the medial surface of the left hemisphere just above the calcarine fissure was stimulated, the patient saw a spot of light that moved a little, but was always in the lower right part of the field. Similar stimulation just below the calcarine fissure gave a similar sensation in the upper right part of the field.

Krause & Schum (1931) found that similar localized and well-defined sensations of light could be produced by electrical stimulation of the left occipital pole in a patient who had for over eight years been completely hemianopic from a gunshot wound of the left optic radiation. This showed that the adult visual cortex does not wholly lose its functional capacity after years of deprivation of visual input, as was confirmed by Button & Putnam (1962).

The extensive observations of Penfield on visual sensations produced by electrical stimulation of the cerebral cortex (see Penfield & Rasmussen, 1952; Penfield & Jasper, 1954) relate mainly to regions of cortex outside the striate area. Where they do probably relate to striate cortex they add little to those of Foerster and of Krause & Schum, and even seem somewhat to conflict with them. However, the old German observations are so clear that they encouraged us to investigate whether electrical stimulation of the striate cortex might provide a means of giving useful visual sensations to patients who had lost the use of their eyes.

Preliminary experiments were performed to examine further whether a prosthetic device designed to do this would be likely to be useful, and to test its safety. A prototype prosthesis was then implanted into a patient. The present paper is mainly concerned with the scientific information obtained by studying the performance of this prosthesis.

PRELIMINARY EXPERIMENTS

Transmission of signals across intact skin. Since a prosthesis that is to continue to be useful and safe for years must not involve any permanent breach of the skin, it was first necessary to design improvements on existing methods of transmitting electrical signals across intact skin by means of radio waves. The improvements needed and achieved (Brindley, 1964*a*) were to allow the transmission of a large number of independent signals through a small area of skin, and to make the receivers so efficient that nearly all the power absorbed is delivered to the stimulating electrodes.

Number of channels likely to be needed. The next preliminary requirement was to obtain by simple experiments on normal subjects a rough estimate of the number of channels likely to be needed to give useful function. The estimate obtained (Brindley, 1964*b*) was that fifty channels should, if the corresponding points were favourably placed in the visual field, permit printed or typed letters to be read one at a time, and that 600 channels should make it possible, with the aid of automatic scanning, to achieve a normal reading speed.

Fibrous reaction to an intracranial implant. It seemed probable, by analogy with the behaviour of indwelling tubes inserted for the treatment of hydrocephalus, that any intracranial implant would become walled off from the brain by a continuous sheet of fibrous tissue, and it was necessary to know what effect this would have on the functioning of the implant. Radio receivers and platinum stimulating electrodes, encapsulated in silicone rubber except for the working surfaces of the electrodes, were therefore implanted over the motor cortex of fourteen baboons, and over the occipital cortex of four baboons, and left in place for periods ranging from 3 weeks to 2 years. A fibrous membrane was found covering the inner surface of every implant that was examined 6 weeks or more after insertion. The membrane was always tightly adherent to the implant and separated from the pia and brain by a narrow space continuous with subarachnoid space. It varied in thickness from 0·5 mm (in an animal killed at 6 weeks) to 0·08 mm (in an animal killed at 18 months). The resistivity of the membrane, measured at 100 c/s and 37° C, varied between 390 and 560 Ω.cm. It would thus be expected to have little effect either on the voltage-threshold for stimulation or on the resolving power of the implant, and these were in fact found (in the implants that stimulated the motor cortex) to vary only slightly during periods as long as 2 years.

No epileptic attacks were observed in any of these baboons, although no anticonvulsant drugs were given. One was killed before the planned date because of deep ulceration of the scalp over the implant. The rest remained perfectly healthy until the intended (and actual) date for killing them.

Confirmation of the observations of Krause & Schum (1931). In a 47-year-old patient with a meningo-sarcoma that originated in the posterior part of the falx and had invaded both occipital lobes, we stimulated, during an operation for partial removal of the tumour, forty points on the calcarine and neighbouring cortex of each hemisphere. The patient had before and immediately after the operation no visual function beyond the ability to distinguish sudden illumination of a dark room from sudden darkening of a brightly lit one. From the appearance of his occipital lobes we feared that there might be no striate cortex capable of functioning, and indeed we found that at all forty points tested in the left hemisphere and at thirty-eight of the forty tested in the right hemisphere, electrical stimulation had no effect. But at two of the points in the right hemisphere, stimulation consistently caused the patient to report seeing a spot of light in the lower left part of his visual field. We had thus confirmed that stimulation of the calcarine cortex can cause localized visual sensations in a patient who gets no such sensations from his eyes.

THE PROTOTYPE HUMAN PROSTHETIC IMPLANT

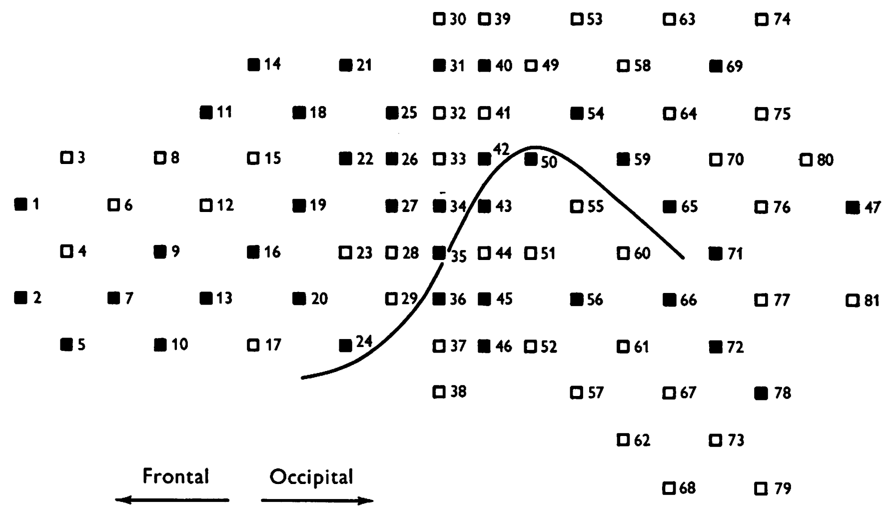
Technical details. The extracranial part of the implant (see Pl. 1 and 2 and Pl. 3, fig. 1) consists of an array of eighty radio receivers, encapsulated in silicone rubber. The circuit of each receiver is that of fig. 1*B* of Brindley (1964*a*), with $C_1 = 75$ pF, $R = 8{\cdot}2$ kΩ, $L = 3{\cdot}7$ or $9{\cdot}1$ μH. Alternate receivers in the rectangular lattice are tuned to 6·0 and 9·5 Mc/s.

The array of radio receivers is joined by a cable to the intracranial part of the implant, which is a cap of silicone rubber, moulded to fit the calcarine and neighbouring cortex of the right hemisphere and bearing eighty platinum electrodes. The working surface of each electrode is a square of side 0·8 mm. Each of the receivers is connected to one of the intracranial electrodes and to a ring of platinum strips on the outer surface of the extracranial part of the implant that serves as the indifferent electrode.

To activate a given receiver, and so stimulate the cortex through its electrode, the transmitting coil of an oscillator tuned to the appropriate frequency is pressed against the scalp immediately over it. Thus the selection of a given receiver is achieved mainly by geometry and only secondarily by tuning. The radio signals are pulsed. A commonly used and satisfactory mode is 100 pulses/sec each of length 200 μsec, but many other patterns have been tried. Various kinds of oscillators have been used, most commonly cross-coupled Hartley oscillators using EEL 80 double pentodes. To be satisfactory, an oscillator should be capable of delivering a mean power of 90 mW and a peak power (in 200 μsec pulses) of 900 mW into a receiver at a distance of 5 mm.

The 0·8 mm platinum electrodes behave *in situ* for 400 μsec or shorter pulses roughly as ohmic resistors of about 3000 Ω. For longer pulses the capacitative behaviour of the metal–electrolyte junction has to be taken into account.

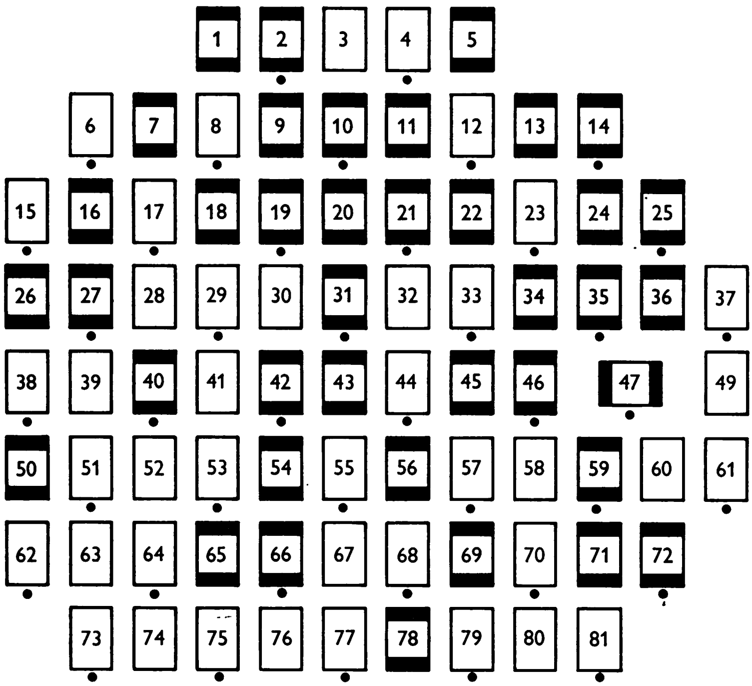
Clinical details. Our patient, aged 52 yr, who had been myopic from childhood, developed bilateral glaucoma in 1962. Vision failed progressively and then in 1967 after a right retinal detachment she was left blind, despite several corrective operations. When examined in June, 1967 the patient could only recognize a flash of light in a narrow strip of the temporal field of the right eye, and hand movements in a small part of the peripheral lower temporal field of the left eye. Neither of these surviving regions of field came closer than 15° to the fovea and neither was of practical use to the patient.



Text-fig. 1. The arrangement of cortical electrodes. Each is connected to the receiver that has the same number in Text-fig. 2. The thirty-nine electrodes that have given phosphenes are shown as filled squares. Of these thirty-nine, five ceased after some months to give phosphenes. It will be seen that the numbering of the electrodes is regular except for the displacement of 47 and the omission of 48. The heavy line shows the conjectured position of the calcarine fissure in relation to the electrodes.

Surgical technique. The extracranial part of the implant was placed beneath the pericranium and secured by tantalum screws to the skull. The intracranial part was inserted through a trephine opening. It lies mainly between the medial surface of the occipital pole of the right cerebral hemisphere and the falx cerebri, and rests in part on the tentorium. Its exact position can be well judged from Pl. 1 and 2.

General results of stimulation. These were demonstrated to the Physiological Society in November 1967, and the abstract of this demonstration has been published (Brindley & Lewin, 1968). When a train of short pulses of radio waves is delivered to one of the eighty receivers, the phosphene that the patient sees is typically a very small spot of white light, described as 'like a star in the sky', or 'the size of a grain of sago at arm's length'. This is the commonest kind of phosphene, and all phosphenes that are within 10° of the point of regard are of this kind. Phosphenes that lie further from the point of regard are sometimes elongated, the length being from $1\frac{1}{2}$ to 4 times the width. The long axis may be vertical, horizontal or oblique. The commonest description of such elongated phosphenes is 'like a grain of rice at arm's length'. One exceptionally long one, 21° from the fixation point, is 'like half a matchstick at arm's length'. The most peripheral phosphenes (1, 2, 5, 7 and 10 of Text-fig. 3) are round but not



Text-fig. 2. The arrangement of receivers in the extracranial part of the implant. Those that have given phosphenes are shown with thick ends. Of those that have never given phosphenes, numbers 4, 8, 49, 61, 79 and 81 had failed electrically before the implant was inserted. A dot under a receiver indicates that it is tuned to 9·5 Mc/s. The other receivers are tuned to 6·0 Mc/s.

point-like. They are usually described as clouds. When pressed to assess their size, the patient likens them to peas at arm's length, but says that this is a poor description, as they differ from the more central phosphenes in lacking sharpness rather than in being definitely bigger.

Stimulation through a single cortical electrode does not necessarily produce a single phosphene. There are three electrodes (34, 36 and 50 of Text-fig. 1) for which the phosphene consists of a pair of points about a degree apart, and two (45 and 56 of Text-fig. 1) for which it is a row of three points, each about a degree from the next. Two electrodes (65 and 71 of Text-fig. 1) give clusters of ten or more dim points, distributed over regions of the visual field as much as 15° across.

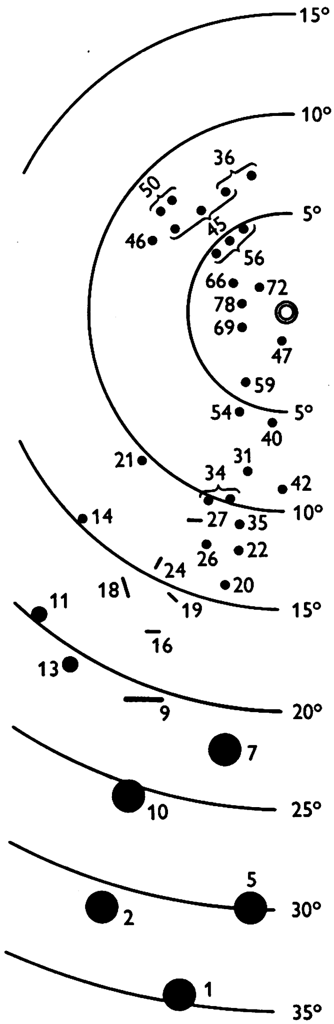
When a phosphene consists of two, three or many points all in the same region, the threshold for each point is the same or nearly so; thus it is not possible to get a single point by merely weakening the stimulus. But there is another kind of double phosphene for which this is possible: for thirteen of the electrodes, weak stimulation gives a point phosphene in one part of the field, and stronger stimulation gives in addition a point phosphene in a very different part. For ten of these the low-threshold phosphene is in the lower part of the field and the high-threshold in the upper, for three the reverse.

The sensations produced by stimulation are always of light, not darkness. They do not fade during continued stimulation, and when stimulation ceases, the sensation generally ceases abruptly. After strong stimulation, the sensation of light sometimes persists, as will be described later.

The map of the visual field on the cortex. It is well known from the observations of Holmes (1918), Teuber, Battersby & Bender (1960) and others, mainly on war wounds, that lesions of the striate cortex at the posterior pole of the hemisphere cause central or paracentral field defects, and that the more anterior a lesion of the medial surface of the occipital lobe is, the more peripheral is the field defect. High-lying lesions of the medial surface of the occipital lobe produce defects in the lower part of a lower quadrant, and low-lying lesions produce defects in the upper part of an upper quadrant of the field. Defects of the directly lateral parts of the visual field (near the 3 o'clock and 9 o'clock meridians) are not produced by any lesions of the medial surface of the occipital lobe, and the parts of the cortex concerned with these parts of the field have therefore long been believed to lie buried in the calcarine fissure.

The phosphenes produced by electrical stimulation in our patient were mapped by two techniques. The first used a hemispherical bowl ('bowl perimeter'; see Pl. 3, fig. 2) of 59 cm radius. The patient was asked to grasp a small knob projecting from a point on its inner surface with her right hand, look at the grasping fingers, and point to the phosphene with her left hand. The second technique was simply to present pairs of stimuli sequentially, and ask here to describe the spatial relations between the corresponding phosphenes. The two techniques supplement one another; the second is better for determining the fine details of the relations between phosphenes, but the first is needed to discover the scale of the map thus constructed.

The map of low-threshold phosphenes (i.e. disregarding the supplementary ones that come in with strong stimulation) is shown in Text-fig. 3. It is roughly concordant with the classical map derived from war wounds if one assumes that the position of the calcarine fissure is that shown as a heavy line. The mapping is not very regular; for example the phosphenes produced by stimulation through electrodes 18, 24 and 27 lie in this order



Text-fig. 3. The positions of phosphenes in the visual field, excluding high-threshold phosphenes. The symbols used indicate very roughly the size and shape of the phosphenes. Four phosphenes that are not shown in the figure are as follows. Electrode 25 gave a single point phosphene not far from that of electrode 26; it failed before it had been properly plotted. Electrode 43 gave, and still gives, a single point phosphene that coincides with the middle one of the three given by electrode 45. Electrodes 65 and 71 give large cloud-like phosphenes containing many faint points, wholly below the horizontal meridian and ranging between 3° and 15° from the point of regard.

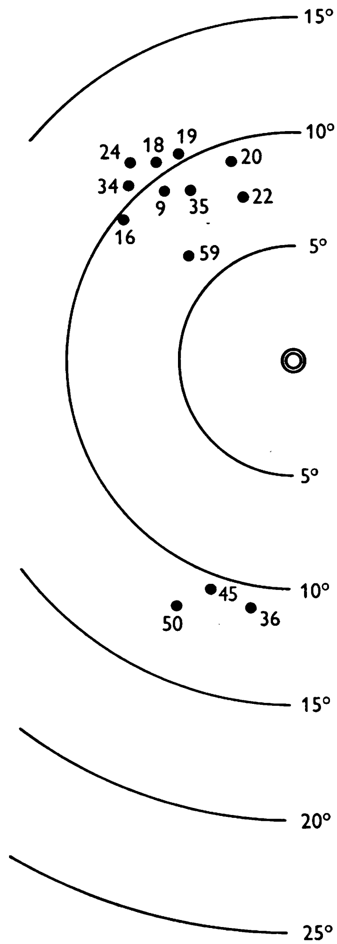
on a straight line (great circle) in the visual field; but on the cortex 24 is very far from the line joining 18 to 27.

As would be expected from the classical map, no phosphene lies in the directly lateral part of the field. The only phosphenes between the 8 and 10 o'clock meridians are two that lie less than 2° from the point of regard.

The additional point phospenes which, for twelve of the electrodes, appear when the stimulus is strong, are greatly at variance with the classical map. It might be supposed that they are due to spread of current to a fold of buried cortex, but the fact that they are points makes this supposition unlikely. They seem rather to indicate a second map, superimposed on the classical one. When the low-threshold phosphene of any electrode is in the upper part of the field, between the 10 and 12 o'clock meridians, the high-threshold phosphene, if there is one, is always in the lower part of the field, between the 6 and 8 o'clock meridians. If the low-threshold phosphene is in the lower field the high-threshold is in the upper. The map of high-threshold phosphenes (Text-fig. 4) roughly resembles that of low-threshold phosphenes inverted about a horizontal line slightly below that through the point of regard. This resemblance is only rough, and there is no evident pattern in the discrepancies from it.

Resolving power. Adjacent electrodes are generally either 3·4 mm or (in the middle part of the implant) 2·4 mm apart. There are ten pairs of electrodes separated by 2·4 mm where both members of the pair certainly give phosphenes. For each of these pairs, the phosphene produced by stimulation through one electrode is easily distinguishable from that produced by stimulation through the other, for any strengths of stimuli. This constant easy distinguishability applies only to fairly rapid sequential presentation; for example, if the members of a pair are called x and y, the patient can always easily distinguish x followed by x from x followed by y, and either from y followed by x, if the following is at an interval of between $\frac{1}{10}$ sec and 2 sec. When the interval much exceeds 2 sec, the distinction can be made only for a minority of pairs of adjacent electrodes, where the corresponding phosphenes differ in some quality other than position in the visual field.

When stimuli are put through two electrodes simultaneously, the phosphenes characteristic of each are seen together. If the two electrodes are remote from each other on the cortex, this is all that is seen; there is no interaction. Between some pairs even of neighbouring electrodes (2·4 mm apart), there is no detectable interaction. But for other close pairs, interactions of two kinds may be found. First, stimulation through each may cause the phosphene produced by the other to become more diffuse, so that the combined phosphene is a strip of light, though from the separate appearances of its components it would be expected to be two discrete points. This is not a large effect, and occurs only with a minority of close pairs. When it does occur, it is little affected by whether the pulses in the two electrodes are synchronous. The second kind of interaction occurs



Text-fig. 4. The positions of high-threshold phosphenes in the visual field.

between electrodes 26 and 34 or 31 and 34. Each of these produces a low-threshold phosphene in the lower part of the visual field, and 34 also produces a high-threshold phosphene in the upper part of the field. If stimuli a little too weak to produce the high-threshold phosphene are sent through 34, then the addition of synchronous stimuli in 26 or 31 will cause the high-threshold phosphene to appear. Asynchronous stimuli have no such effect.

By stimulating through several electrodes simultaneously, simple patterns can be built up which agree with those expected from the positions of their constituents. The number of electrodes that give good phosphenes is too small and their placing in the visual field too unfavourable to permit the patient to read, even at one letter per glance, but the pattern-discrimination achieved is compatible with the original expectation that if a prosthesis gave $50n$ good resolvable phosphenes conveniently placed in the visual field, it would permit the reading of about n letters per glance.

Effect of pulse duration. At constant frequency and strength of radio pulses, increasing the duration of each pulse makes the phosphene brighter up to about 0·6 msec. Further increase of duration has little effect, but this fact is uninformative, since the effects on the pulses of the capacities of the electrode and its 1 μF blocking capacitors certainly become significant at 1 msec, and are perhaps not quite negligible at as little as 0·2 msec. Table 1 shows an estimate, for electrode 19, of the relation between pulse

TABLE 1. The relation between pulse duration and threshold potential for electrode 19 of Text-figs. 1 and 2, measured at 30 pulses/sec

Duration (μsec)	Threshold (V)	Duration (μsec)	Threshold (V)
1000	8	60	19
600	9	40	25
400	9	30	28
300	10	20	36
200	13	10	56
100	16		

duration and threshold measured at 30 pulses/sec. The potentials given in the Table are measured on a duplicate of one of the receivers of the implant, connected to a dummy load (1·0 μF in series with 3000 Ω) estimated to match an electrode. The duplicate receiver was placed at a distance from the transmitting coil equal to the estimated distance of receiver 19 below the surface of the skin. The primary estimates of electrode properties were derived from measurements on implants in baboons, and the primary estimate of distance below the skin from X-ray photographs. All these estimates could be roughly checked by means of records of the stimulating pulses taken from electrodes on the patient's scalp. From the time constant of a pulse and the time constant of return to the base line after a pulse the resistance and capacity of the electrode can in principle be separately determined, though for various practical reasons the estimates are very rough. From the known non-linearity of the relation between the amplitude of a radio pulse and the output from a receiver activated by it (a non-linearity that depends on properties of the diode of the receiver) the absolute output voltage of a receiver in the patient can be checked with an accuracy of perhaps $\pm 30\%$, the chief uncertainty being due to the small signals picked up by many other receivers in the implant. These small signals are probably always subliminal for the cortex, but they are significant in the scalp records, since in these all of them add linearly.

The strength–duration relation for threshold at 140 pulses/sec differs little from that at 30 pulses/sec, except that all thresholds are about 25% lower.

For supraliminal stimuli, strength and duration are nearly but not exactly interchangeable. If one attempts to determine a strength–duration relation for 'constant' sensation, one obtains a relation nearly like that of Table 1 with all voltages multiplied by a constant factor, but the patient says that when the phosphenes produced by long and by short pulses are exactly matched in brightness, they differ slightly in their spatial appearance, that produced by the shorter pulse being usually a little more diffuse.

Effect of frequency. There is no sharp flicker fusion frequency for cortical phosphenes, and probably no flicker fusion frequency at all. When questioned, the patient always reports seeing flicker in every phosphene, even when the number of pulses per second is several hundred or several thousand. This can hardly be due to low-frequency modulation of the signal in the transmitter, for none was detectable in the output of a duplicate receiver rigidly connected to the transmitting coil. The patient is sure that the frequency of flicker is neither that of the pulse nor twice that of the pulse; it is substantially faster. This probably excludes a vascular origin. It is very unlikely that mechanical vibration of the transmitting coil can have been concerned, as the coil was pressed against the scalp by springs attached to a heavy (430 g) hat, and no tremor of the head, hat or coil was visible. The flicker is similar for electrodes whose phosphenes are points, clusters of points, rice grains at arm's length, or small clouds. One may perhaps doubt whether a blind person's use of the word 'flicker' corresponds to a sighted person's, but her description of it as 'a rapid flashing on and off, a little too quick for the flashes to be counted', seems convincing. Even clearer is her statement that there is no difference of kind between the phosphenes seen at 20, 200 and 2000 pulses/sec. The phosphenes produced by 20 pulses/sec is

TABLE 2. The relation between frequency and threshold potential for electrode 19 of Text-figs. 1 and 2, measured with pulses of duration 30 μsec

Frequency (pulses/sec)	Threshold (V)	Frequency (pulses/sec)	Threshold (V)
25	29	400	35
50	27	630	37
100	21	1000	39
160	21	1600	35
250	25	4000	29

described as flickering slightly, but only slightly, more strongly than those produced by the other two frequencies.

Table 2 shows for electrode 19 the relation between frequency and strength for threshold, the pulses being 30 μsec in length. The potentials were measured as in Table 1.

For supraliminal stimuli, strength and frequency, like strength and duration, are nearly but not exactly interchangeable. The changes of strength needed to compensate for the effects of frequency on apparent brightness are rather small in the range 25–4000 pulses/sec. When brightness has been equalized, small differences of spatial distribution or degree of flicker sometimes remain.

Non-visual sensations. Two kinds of non-visual sensation are sometimes produced by bringing transmitting coils up to the implant: tingling in the scalp and deep pain in the head. The tingling in the scalp is evidently due to the current that flows through the extracranial indifferent electrodes. It occurs when any five or more receivers are strongly activated if the pulses in all of them are synchronous. It is a minor nuisance which can be easily avoided by inserting delays between the pulses transmitted to different receivers.

Deep pain is produced only when strong signals are delivered to any one of four receivers: 14, 19, 31 and 40. For receiver 31 the pain is felt in the right side of the head, for the others in the mid line. All these receivers also give visual sensations. For receiver 14 the thresholds for phosphene and pain are about equal. For the other three receivers the threshold for pain is about twice that for producing a phosphene. The deep pain in the head comes on immediately at the beginning of stimulation, and ceases immediately when stimulation ceases. But if by accident it is provoked several times in succession it sometimes leaves behind it a less severe pain in and around the right eye, which fades away during the following 10 min.

It is very probable that the deep pain in the head is due to stimulation of meningeal pain fibres.

Effects of voluntary and reflex eye movements. If while stimuli are being delivered through a cortical electrode the patient moves her eyes to one side or up or down, the phosphene appears to move in the direction of the eye movement. It is difficult to be sure that the magnitude of its apparent movement corresponds to that of the eyes, but it seems likely that it does. Certainly the relation of phosphenes to the point of regard as plotted in the bowl perimeter is the same when the head as well as the eyes face the hand that grasps the fixation knob as it is when the head is turned 30° to the left or right, so that the patient, in order to look towards the fixation knob, has to turn her eyes by 30° in relation to her head.

If while stimuli are being delivered through a cortical electrode the patient's head is rotated passively, she says that the phosphene remains fixed in space, and does not move with the head.

In these two tests, cortical phosphenes behave at least nearly like after-images of retinal origin. We were unsuccessful in our attempts to produce durable and well-resolved after-images in the still functioning parts of our patient's visual field, and therefore could not check directly that cortical phosphenes and retinal after-images behaved alike.

After-effects of stimulation. For stimuli of not more than 1·5 times threshold, the phosphene always ceases instantly when the stimulus ceases. For stronger stimuli it sometimes ceases instantly, but sometimes persists for a time that is usually between half a minute and a minute, and never exceeds 2 min. When a phosphene persists, its final disappearance is preceded by a decrease in the frequency and an increase in the conspicuousness of its flickering.

Persisting phosphenes never expand or change their position in the visual field.

CONCLUSIONS

Two of our findings are wholly unexpected: the high-threshold phosphenes, with their inverted map, and the absence of any flicker fusion frequency. Our other observations agree roughly with what we hoped to find, but had no grounds for expecting with confidence. They suggest that it will be possible to make a useful prosthesis by improving our prototype, and we are working on means of improving it.

The resolving power of the cortex for electrical stimuli is especially satisfactory; it seems likely that the number of electrodes could be increased to at least 200 per hemisphere and all the phosphenes remain resolvable.

Our findings strongly suggest that it will be possible, by improving our prototype, to make a prosthesis that will permit blind patients not only to avoid obstacles when walking, but to read print or handwriting, perhaps at speeds comparable with those habitual among sighted people.

We thank the Medical Research Council for financial support, Professor P. M. Daniel for examining the brains of baboons used in preliminary experiments, and especially our patient for her careful and accurate observations during over 100 hr of testing.

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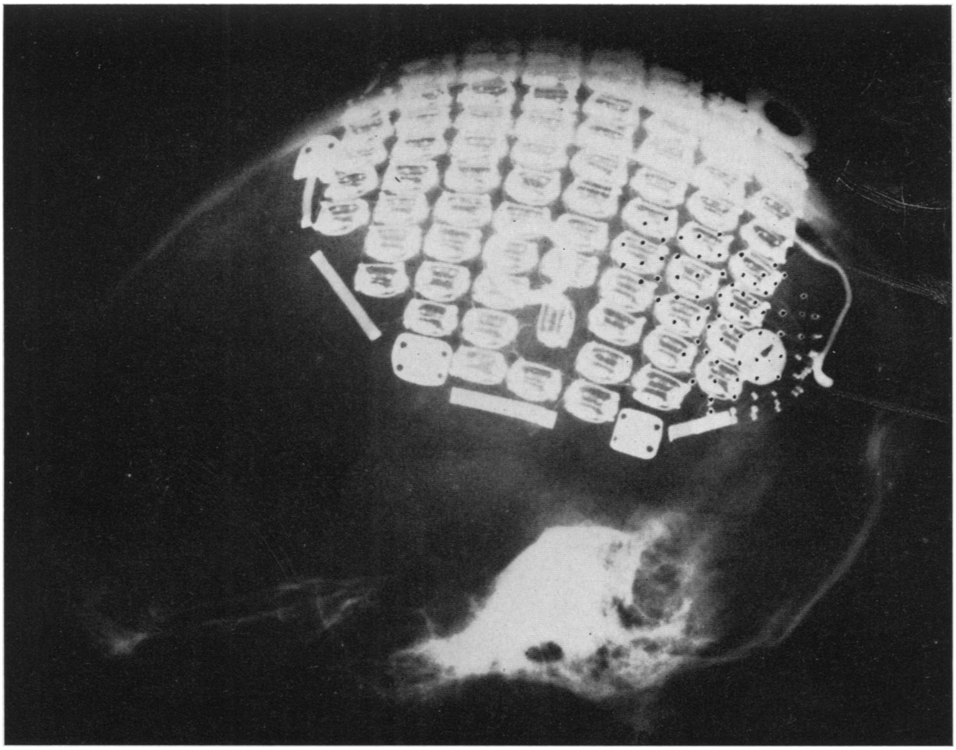

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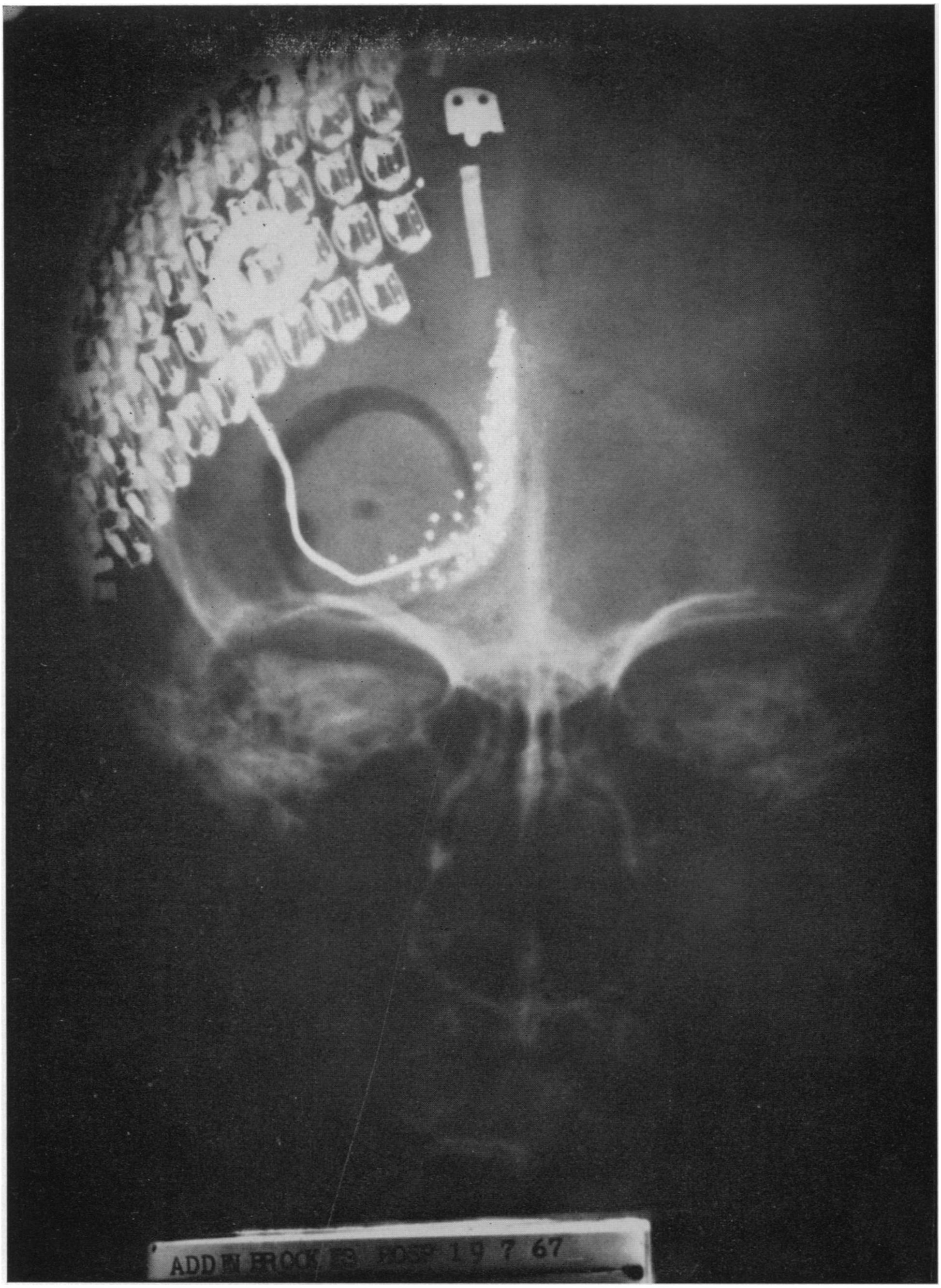

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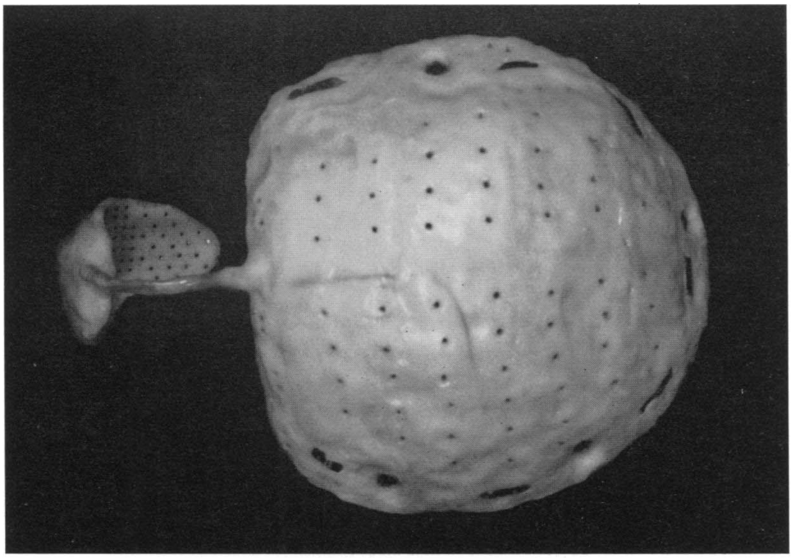

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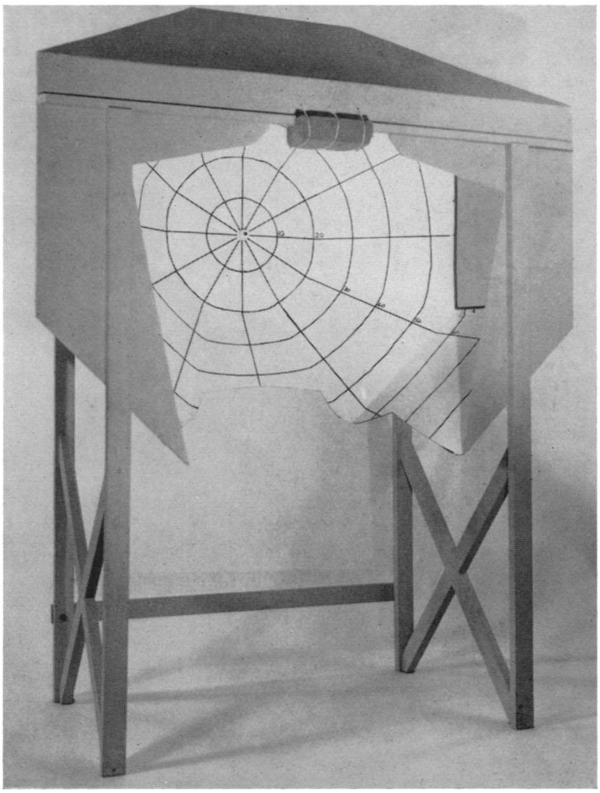

Fig. 2.

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EXPLANATION OF PLATES

PLATE 1

Lateral X-ray photograph of the implant after insertion. The shadows of most of the electrodes are re-touched, and appear in the plate as black dots.

PLATE 2

Antero-posterior X-ray photograph of the implant after insertion.

PLATE 3

Fig. 1. The implant before insertion. Fig. 2. The bowl perimeter.