One more example of how advances in one field of science may lead to advances in other, distantly related fields is the recent use of superconducting instruments in the study of the visual system. At the heart of these instruments is the superconducting quantum interference device (SQUID), which is exquisitely sensitive to weak magnetic fields. These devices do not depend upon Faraday induction and even respond to DC fields. In the case of the visual system, fields of interest arise from the flow of current in active neural tissue. Such magnetic fields are only about a billionth of the earth’s steady field. Indeed, these fields are weaker even than the fields associated with electrical equipment in the laboratory and also those that would be produced by moving magnetic material in the vicinity of the subject. Clearly, these stray fields limit one’s ability to detect neuromagnetic fields. To vitiate this limitation, one may enclose a patient or subject together with the SQUID sensing equipment in a magnetically shielded room. Recordings of transient visually evoked fields were recently made in such enclosures, and they differ in several respects from the classic evoked potentials. Also, over a range of high luminances the amplitude of the VEF changes monotonically with stimulus luminance. However, as in other studies, the simultaneously recorded VEP saturates at high luminances, where it does not exhibit a change in amplitude with luminance. Apart from these as yet unreplicated findings, there is little else to report about the transient VEF. Perhaps it is worth noting here that we have just succeeded in detecting the transient VEF in our laboratory and are now in a position to replicate the findings reported above. In any event, to date virtually all other studies of the VEF are concerned with the steady-state response.

At this time, all published studies of the steady-state VEF have originated in the Neuromagnetism Laboratory operated jointly by the Physics and Psychology Departments of New York University. These studies were conducted in a normal laboratory environment and not in a shielded enclosure. This technological development makes it possible to bring the SQUID into the clinic. Work without shielding requires the use of a specially designed detection coil known as a second derivative gradiometer. This detection coil responds to local fields and rejects uniform fields and fields with uniform spatial gradients. The gradiometer and SQUID are housed together in a fiberglass Dewar flask, where they are immersed in liquid helium.
The gradiometer is coupled magnetically to the SQUID, which is otherwise isolated from its immediate environment by a small superconducting shield. Thus the SQUID responds to current flowing in the gradiometer but cannot sense fields generated by relatively distant sources. A device of this type was successfully employed in detecting localized magnetic fields over the occipital region of the head when a pattern of bars was periodically flashed on and off.4

Subsequent studies using contrast reversal gratings and a SQUID system have led to many interesting findings. Among these was the report that the latency of the VEF to gratings increases with their spatial frequency.5,6 A similar result was obtained in transient VEP studies.7-8 There is a high correlation between the response latency and simple reaction time to flashed gratings. However, in the case of the VEF, the latency effect is detected over one active region of the cortex. Responses to the same stimuli detected at a nearby region do not exhibit the same latency effect.

The ability to detect separately the activity of functionally and anatomically distinct populations of cells may be an important advantage of the VEF.9 Comparable VEP experiments have not yet provided the same degree of discrimination. Thus the VEF detected on the midline between 2 and 6 cm above the inion exhibits the latency effect. However, another region between 7 and 10 cm above the inion reveals the activity of a different population that does not respond in step with the first population. Unlike the VEP, which is quite strong over the frontal regions of the head, the VEF is absent at points higher than about 10 cm above the inion.

Another recent finding is that it is possible to measure separately the response latencies of the neuromagnetic fields arising from the two hemispheres of the brain.10 Moreover, there are strong individual differences in the latencies with which the two hemispheres respond to stimulation by contrast reversal gratings. In some individuals the two hemispheres respond with the same latency. In others one hemisphere responds faster than the other. In the case of one subject, one of his hemispheres responded 100 msec more slowly than the other. The faster hemisphere responded to a 5 cy/deg grating with a "normal" latency of about 110 msec.

The extrafoveal retina contributes strongly to the neuromagnetic response. This was proved in as yet unpublished experiments in which the central 2 degrees of the visual field was exposed to a steady and spatially uniform light. This central region was surrounded by an annulus containing a counterphase grating. The outer diameter of the annular region was 6 degrees. The measured response was about half the amplitude of the response produced by stimulation of the entire 6-degree field of view by the counterphase grating. Stimulation of central region by the grating with the annulus filled by a uniform and steady field of light produced a weak response. The remarkable aspect of these results is that the phase of the response produced by stimulation of the fovea differed from the phase of the response produced by stimulation of the annulus by nearly \( \pi \) radians. The vector sum of the independently produced central and extrafoveal responses has a smaller amplitude than that produced by stimulation of the extrafoveal region alone. The empirical effect of stimulating both the central 2 degrees and the annulus simultaneously, however, was a response whose amplitude was twice that of stimulation of the annular region alone. The phase of this response was nearly the same as the phase of the response to stimulation of the annulus. This is indicative of a strong nonlinear interaction between the effects of stimulation of the foveal and extrafoveal regions.

Data obtained thus far are consistent with a model in which the fields from area 17 are produced by two horizontally oriented, equivalent current dipoles in each hemisphere acting as near-mirror images of each other. The fields produced by these dipoles leave the head above the inion and re-enter the base of the brain via a path well below the inion. Observations confirm the existence of this return path.
Detecting the magnetic field is tantamount to directly sensing the tangential flow of primary current within the cortex. Predictions from models indicate that this phenomenon is not dependent upon the presence of accompanying volume currents spreading symmetrically throughout the interior of the skull. Moreover, the neuromagnetic field is unaffected by the weak currents in the dermis that are due to the volume currents and make possible the detection of the VEP. The invulnerability to volume currents and the sensitivity to the stronger currents in active neural tissue may provide some advantages in resolving functionally and anatomically separate populations of cells. This method is truly monopolar, and therefore some of the ambiguity inherent in the essentially bipolar method of potential recording is absent.

It should be noted that superconducting devices are now widely employed in other areas of the biomedical sciences. A recent review of these applications of superconducting devices was entitled Biomagnetism, to indicate that it deals with all magnetic fields arising from within the organism. Neuromagnetism is but a subspecialty of this new area of work. Thus many laboratories are now investigating the magnetic field of the adult as well as fetal heart. Other laboratories are using various magnetic sensing devices to study the lung and the fields associated with various contaminants it may contain. Still others are studying fields associated with the storage of compounds of iron in various organs of the body as a result of dietary or disease factors. This is an international endeavor. There are about seven active laboratories in the United States, one in Canada, two in Finland, and one in France. Two laboratories are getting underway in Italy, and an elaborate effort is being initiated in West Berlin. Interest has been exhibited by several groups in the Soviet Union. At the present time, in the United States only one laboratory is centering its work on sensory systems with an emphasis on vision and related psychological processes. Another has begun detailed studies of auditory evoked fields, and one is investigating DC magnetic phenomena of the head. It is too early to be certain as to the fruitfulness of all this work. We look forward to the future in the hope that important insights of value to the vision research community will be realized.

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