sensation to another. The shift of interest may be also a shift in conscious space, so that we begin to make a new localization of the sensations after each lapse. It is easy to observe this phenomenon when a large series of sound sources is present and we attempt to observe them all. In general we shift from one sound source to another in a rhythm corresponding to the temporal quanta.

Central inhibition was one of the first forms of inhibition to be discovered, yet little progress has been made in the psychological observation of it. In hearing especially there are examples of central inhibition that have been known for centuries. A familiar example is the miller who awakes when the mill stops. He is able to inhibit all the normal noises made by the mill and his sleep is not disturbed. He wakes up when the routine inhibitions stop because the neural processes produced by the usual stimulation are no longer present.

Projection of a sensation outside the body

The funneling of sensations into a space outside the body is an important feature of neural funneling, for it controls practically all our behavior. For example, reflected light from an external object produces an image on the retina. The sensations exist only within our body, yet we localize the image outside the eye, even when we use only a single eye and look at an object far away. This localization beyond our perceptual system is of great importance for survival because it enables us to appreciate impending danger or objects of great necessity. This externalization is achieved without the slightest recognition of the optic image itself or the stimulations on the retina.

The same conditions hold for hearing. The sensations are produced by the action of stimuli on the basilar membrane of the cochlea. The cochlea is deeply imbedded in bone, but we do not localize auditory sensations there but usually refer them to a source somewhere in the environment. However, as we have seen, this external reference does not seem to be true for hearing with earphones.

This external projection has probably been learned early in life; certainly this is true for hearing and vision. But we have not acquired this kind of external projection for skin sensations, and so we have an opportunity to discover how stimulus projection in space is learned.

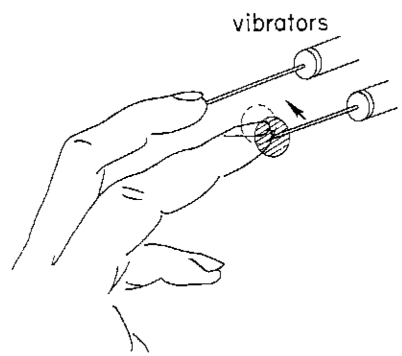


Fig. 176. The localization of a vibratory image in the space between two fingertips.

For this study a pair of vibrators stimulate two fingertips as in Fig. 176. Each vibrator is actuated by the same series of clicks, and their applied currents are varied to give equal magnitudes of sensation on each fingertip when the stimuli are presented separately. Also the setup includes a means of varying the delay time between the clicks of the two series. If a click is delayed for one finger more than 3 or 4 milliseconds, a person feels separate sensations in the two fingertips, as already described. If, however, the time between clicks is reduced to about 1 millisecond the two click series will fuse into one, and the vibratory sensation will be localized in the finger that receives each click the earlier. If the time delay is further decreased the sensation for a trained observer will move into the region between the two fingers, and if then the time relation between the two click series is reversed the click will move to the opposite side. For a person who observes such stimuli for the first time, the click will make a sudden jump from one fingertip to the other on the very first trial. The movement is not continuous from one finger to the other. The jump is abrupt and the observer can localize vibratory sensations only beneath the vibrating tip.

After a few days of observing vibratory phenomena, however, the observer finds that the shifting of sensations on the fingertip, and elsewhere on the skin, loses its abrupt character and goes over into a sort of creeping from one vibrator to the other. Usually after two or three weeks of training the observer can experience a continuous motion of the vibratory sensation from one finger to the other, with a rate of motion corresponding almost linearly to the time difference between the two clicks. This new experience develops more readily when care has been taken that the two vibrators produce stimuli that are identical in magnitude.

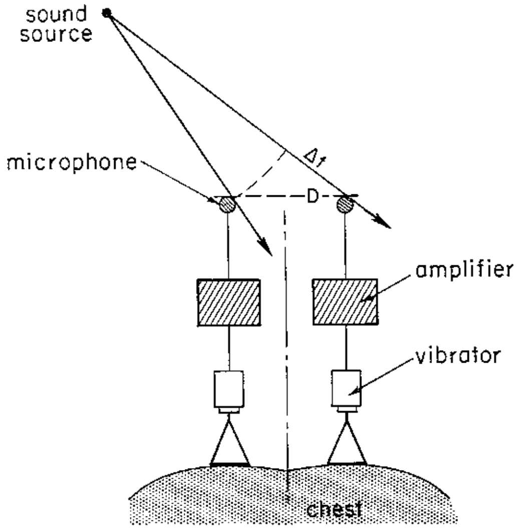
The interesting point in this experiment is that for the condition in which there is no time

delay the vibrations are localized between the two fingers where no skin is present. If the fingers are spread apart the same effect is found, and when the amount of time delay is varied the sensation will move correspondingly in the free space between the fingers.

Even more dramatic than this experiment is the one in which two vibrators are placed on the thighs, one above each knee. Here the vibrators can stimulate large skin surfaces and produce strong vibratory sensations. By training an observer first to note the localization of the vibration when the knees are together, he can be made to perceive a sensation that moves continuously from one knee to the other. If the observer now spreads the knees apart he will again experience at first a jumping of the sensation from one knee to the other. In time, however, the observer will become convinced that the vibratory sensation can be localized in the free space between the knees, and he will be able to experience a displacement of the sensation in this free space when an appropriate time delay between one stimulus and the other is introduced. This experience is a very peculiar one.

We can go even further in this projection of sensations into free space with the equipment shown in Fig. 177. In this setup are two microphones connected to vibrators that rest on the right and left sides of the chest. When a loudspeaker producing clicks at a rate of about 2 per second is placed on the left as shown, a vibratory sensation will be felt on the left side of the chest. Then if the loudspeaker is moved from left to right the vibratory sensation will

Fig. 177. Equipment for study of the localization of vibration outside the body. Sound from a loudspeaker is picked up by two microphones and converted into vibrations. From *Annals of Otology, Rhinology, and Laryngology* [102].



jump to the right side of the chest. Whenever the sound source is on the extreme right, we feel the vibrations only on the right side of the chest, and when it is on the extreme left we feel them only on the left side of the chest.

If the vibrators are carefully matched, this jumping from one side of the chest to the other occurs precisely in accordance with the position of the sound source. After weeks of practice an observer will no longer experience the jumping of the vibratory sensation from one side to the other, but this sensation will move continuously in accordance with the lateral position of the sound source. He can look at the sound source and compare it with the location of the vibratory sensation to prove the close relationship between them. However, even after days of experience of this kind, the vibratory sensation will continue to move and be felt on the surface of the chest.

Some observers, however, following with the eye the position of the loudspeaker in the room and the close agreement between their angle of view and this position, became able for no obvious reason to locate the vibratory sensation close to the loudspeaker when its distance from the chest was no greater than 2 or 3 feet. It is difficult to say how this distant projection of the vibratory sensation was achieved. In general there was an intermediate stage at which both possibilities were present, when the vibrations could be localized on the skin surface or be projected to the position of the loudspeaker. There is no doubt that the visual observation of the loudspeaker position played a significant role in the learning process. After several months of training it became possible to localize the vibratory sensation, even with the eyes closed, at a position outside the body, though usually this position was closer to the body than to the loudspeaker. No observer believed that he would be able to project the vibratory sensations farther than 3 feet from his skin, even after further training.

This matter of the external projection of vibratory sensations seems to be strange and hard to believe, yet it is well known in many fields. Every well-trained machinist projects his sensations of pressure to the tip of a screwdriver, and it is this projection that enables him to work rapidly and correctly. For most people this projection is so common that they are unaware of its existence. The same type of projection occurs in cutting with a knife, and our adjustments of the blade make use of sensations projected to its edge. Nowadays the palpation of tumors and cysts does not play the same role in medical diagnosis that it did before the extensive use of X-rays, but in earlier times a good practitioner did not feel a tumor as at his fingertips but he projected his vibratory and pressure sensations into the patient. His procedure used a complex interaction between pressure and vibratory sensations in locating a small tumor cyst, and the location could later be verified in surgery.

I found the localization of sensations in free space to be a very important feature of behavior. To study the matter further I wore two hearing aids that were properly damped so that the sounds could be picked up by means of two microphones on the chest and then transmitted to the two ears without change in pressure amplitude. Stereophonic hearing was well established, but a perception of the distance of sound sources was lost. I shall not forget my frustration in trying to cross the street during rush hour traffic while wearing this transmission system. Almost all the cars seemed to jump suddenly into consciousness, and I was unable to put them in order according to their immediacy. I should probably have required weeks of experience to become adjusted to this new type of projection. A small change in the amplification of one side was enough to cancel the whole learned adjustment.

From these observations I reached the conclusion that the localization of sounds by persons suffering from disorders of hearing is just as important as their hearing of the sounds. If we listen to sounds with only one ear, we usually localize them close to the head. This is especially true for pure tones.

There is no question that localization plays an important role in our perception of internal sounds produced in our own body as distinct from external sounds that are vital for survival. The more we are trained to project external sounds outside the body the easier it becomes to inhibit internal body noise.

Certain fishes are known to detect foreign objects by producing an electric field in the water and observing its changes on their approach to the object. It is surprising how precise this localization is. Lissmann and Machin in 1958 investigated this problem. Figure 178 shows the changes that take place in the electrical field for foreign bodies with different electrical resistances. The fish has an electric field around his body that is modified by his body's presence. A change in the field caused by the approach of a foreign body has to be distinguished from the pattern of his own field. It is likely that in this instance the distortions of the field are projected outside.

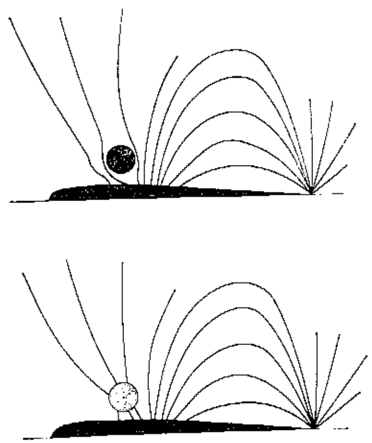


Fig. 178. Patterns of current flow between head and tail of an electric fish, used in the localization of objects with different conductivities. After Lissmann and Machin (*Journal of Experimental Biology*, 1958, 35, 451-486).

Many fishes are able to recognize foreign objects through a distortion of the flow of fluid around their bodies. They can easily identify the approach of the glass wall of an aquarium without bumping into it even when vision is absent. At present I can only admire these achievements, for I have no explanation of them. The most fascinating animal is the porpoise, who leaps after some object held high in the air. The animal must change his visual projection from one appropriate for underwater vision to another for air vision.

Optical illusions and lateral inhibition

Earlier it was shown in the mathematical treatment of the Mach bands that almost the same forms of these bands were produced when the inhibitory unit procedure was applied not just once but three times consecutively. The distribution of the sensory pattern obtained by this repeated manipulation comes so close to the one-step operation that we have no way of telling whether in vision the Mach bands are produced in one step or in several. It is highly probable that several repeated steps are used. This consideration brings up the question whether some of the optical illusions, which are modifications of a stimulus pattern, may not be understood by considering them from the point of view of lateral inhibition. As Fig. 68 shows, in vision the neural unit has a wide inhibitory area, so that the lateral inhibitory effects probably extend to large regions. It is possible, however, that the lateral spread of the neural unit is different at different neural levels.

It was shown by Révész (1934) that optical illusions have their counterparts in skin sensations. Several of his experiments were repeated using cardboard cutouts of various shapes pressed on the skin surface, and comparing the pressure pattern thereby produced with the resulting pattern of sensation on the skin surface. A major difficulty in working with illusions on the skin is that the difference limen for distance discrimination is large, amounting to several centimeters, and often there is not enough room on the skin to produce conveniently the stimulus patterns of a size comparable with those used on the retina in optical illusions. Nevertheless it is possible to produce some illusions on the skin surface.

The most famous optical illusion, known as Müller-Lyer's, consists of two lines of equal length with extensions pointing in opposite directions, as shown in Fig. 179. When cardboard cutouts of these forms were pressed against the side of the thigh or the abdomen, most observers reported that the length of the line with extensions pointing away from the center seemed longer than the line with extensions pointing inward. Several tests were necessary to find the best length of the different sections, which were 1 mm thick. It was found most convenient to give the center line a length of about 14 cm and to make the extensions about 7 cm long. Care had to be taken not to press too hard on the skin surface, for it is mainly the superficial part of the skin and not the deep underlying muscle layer that is affected.

I consider this apparent change in the length of the center line to be produced in some degree by lateral inhibition. If an angular pattern, such as the solid line in *a* of Fig. 180 is pressed