ON THE

NECESSARY CONDITIONS OF SENSATIONS,

AS ILLUSTRATED BY

THE SENSE OF HEARING.

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THE human mind is conscious of its own existence, and also of the existence without and beyond it, and correlative to it, of a world of matter. The two great facts, mind and matter, are universally recognised, notwithstanding the laborious attempts of different schools of metaphysicians to deny the logical existence of either one or the other. Though we do not know, and may never know, the true nature of either mind or matter, we assume their existence, because we can appreciate certain of their properties either through the medium of the senses or by intellectual processes. If this be granted, we have next to inquire how the mind acquires knowledge of the properties of matter, or of physical phenomena of any kind. Can we separate what is apparently a complicated process into its constituent parts? What are the anatomical and physiological conditions necessary for bringing the subject mind into relation with the object world? These conditions are:—

1. A sense-organ for the reception of movements of matter, and for the communication of these movements to a nerve.

2. A nerve-centre, or brain, which is the seat of consciousness; and,

3. A nerve, endowed with a special sensibility peculiar to the sense, for conveying influences from the sense-organ to the brain.

It will be found we have these three elements in each sense. With regard to the nerve-centre or brain, there may be a still farther subdivision; the influence is not transmitted directly to the cerebral hemispheres, the seat of consciousness, but is first received by a subsidiary ganglion, from which it is passed onwards to the hemispheres. For example, as the necessary conditions of the sense of vision in the higher animals, we find (1) a sense-organ, the retina, for receiving certain movements, the undulations of the ether which constitute a ray of light; (2) a nerve, the optic, for receiving impressions from the retina (probably by the rays of light being reflected by the rods and cones of Müller[1]), generating an influence, and conducting it to the brain; (3) special ganglia, the corpora quadrigemina or optic lobes, by which the primitive influences are received without consciousness, and from thence transmitted to (4) the cerebral hemispheres, where the mind becomes conscious of the influence, and we experience a sensation. With the exact and precise functions of each of these parts we are unacquainted, but there can be no question that all are necessary to give a sensation of light, produced by rays emanating from any luminous body. Remove any one of the four, and the sense of vision, with regard to external things, is destroyed. On the other hand, disordered vision always follows disease of one or more of these. Disease of the optic centres, the corpora quadrigemina, will produce spectra, which, by experience, being projected by the mind into the external world, have all the semblance of reality, and are as real to the individual as if they were really external luminous or reflecting objects producing by ordinary optical laws an image on the retina.

The same method of physiological analysis may be applied to the other senses. No one who has watched the progress of modern histology can have failed to perceive the rapid advances made in the discovery and description of sense-organs. The retina, the organ of Corti, the peculiar organs of smell in the pituitary membrane, the special organs of taste in the tongue, the tactile corpuscles, touch bodies, and Paccinian corpuscles, the end-plates in muscle, the peculiar nervous plexuses on muscle figured by Beale—have now been described with great care and minuteness, and are all to be regarded as sense-organs for the communication of delicate movements of matter to the extremities of nerves. We do not yet know the subsidiary encephalic ganglia for each sense. The olfactory bulbs, which are not nerves, but part of the brain, are the portions devoted to smell, the corpora quadrigemina to sight, and the cerebellum to the muscular sense; but we have not yet any accurate data by which to locate the centres for hearing, taste, and touch. From analogy, it is highly probable that certain portions of the ganglia are devoted to these senses, and the discovery may yet be made by anatomical research and physiological experiment.

My more immediate object in this communication is to show the relation between the movements of matter, the sense-organ, and the character of our sensations. We all know there is such a relation, but it is difficult to state precisely what it is. This can only be done by stating what occurs, or, in other words, by analyzing the sensation with the help of the knowledge we derive from physics and physiology. The analysis and classification of the physical phenomena related to our sensations has been attempted by many psychologists, more especially by Mill, Spencer, Bain, and

[1] Goodsir, Anatomical Memoirs, vol. ii. p. 270.

Taine; but this subject has not, so far as I am aware, received due consideration from physiologists. Instead of discussing at present all the senses, I shall take the sense of hearing as an example, and endeavour to show what really occurs when we hear a sound, or series of sounds.

When air is driven through an organ-pipe of a certain size, we experience a sensation we term a musical sound. The term sound, unfortunately, is applied in the language of daily life, both to the sensation itself and to the cause of the sensation, the vibrations of the air. The sensation belongs to us, and to it we should restrict the term sound; the cause pertains to the air, and consists of vibrations or movements of matter. If the vibrations were produced in a world in which there was no organized ear to listen, there would be no sound. The kinds of sounds are very numerous. They may be high or low. They may have greater or less intensity. They may have different tones or qualities by which the experienced ear can tell the instrument producing them. They may be musical or unmusical. Many sounds, however, cannot be classified with others, so we put each into a separate place, affixing as a label the name and conditions of the object producing it. Thus, we speak of the sound of the rustling of silk, the crumpling of a sheet of paper, the beat of a hammer, etc., etc. That the physical cause of all sounds is a vibration or movement of the air, was known even to Pythagoras and Aristotle. It has also been clearly shown that there is a relation between the number and character of these vibrations and the sensation we experience. For example, if we sound a deep organ-pipe, giving thirty-two distinct successive vibrations per second, we are conscious not only of a deep musical sound, but we can separate the sound into its constituent parts. We can experience distinctly a series of impulses against the membrane of the drum. This experiment is more satisfactory if we convey the sound directly into the ear by a flexible stethoscope. Thus we have two sensations: one, that of a musical sound produced by a regular series of vibrations of the air, and, at the same time, another produced by an individual impulse. But we may advance still farther. If we listen very carefully, we can detect still more elementary sensations. We now observe that each impulse possesses a crescendo and diminuendo character, that is, a swelling and dying away, an undulation. The intensity of the sound varies. At one time it is greater than at another. When we sound a higher note on another organ-pipe, we again have the single sensation of a musical sound, and the more elementary sensations have disappeared, that is, we have become unconscious of them. But though they have ceased to exist as distinct sensations, there are still impulses on the drum corresponding in character to, though less in degree than, those just described as perceived in the lower note. Sir William Hamilton[1] and Taine say they exist as sensations, but as

[1] Hamilton, Lectures, i. 349–351. "To hear the sound of the sea from the shore, we must necessarily hear the parts which make up the whole, that is

I accept the definition of sensation given by Professor Bennett—"Sensation is the *consciousness* of an impression"—I prefer the view that the elementary sensations produced by a note of low pitch disappear in a higher note as sensations, but the physical phenomena, the impulses or impressions, remain. Experience shows that we are not conscious of these rapid impulses, and also that in proportion to the increase of the length of the wave the sound becomes less acute. This will be understood better by examining the accompanying figures, which show diagrammatically the movements of the air in three musical notes of different pitch. Let Fig. 1 represent the distinct pulses of the air produced by a very deep organ-pipe. The maximum of condensation of each undulation is marked *a*, and the minimum *b*. Fig. 2 represents in the same manner a more acute note, in which it will be observed

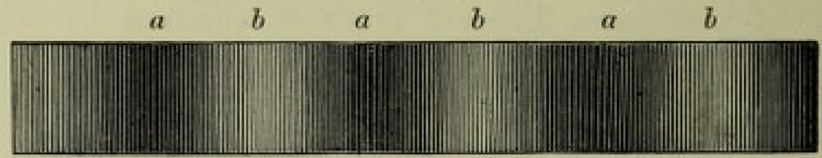

Fig. 1.

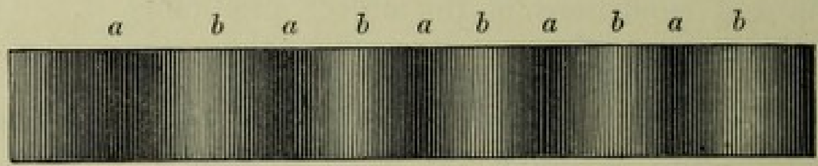

Fig. 2.

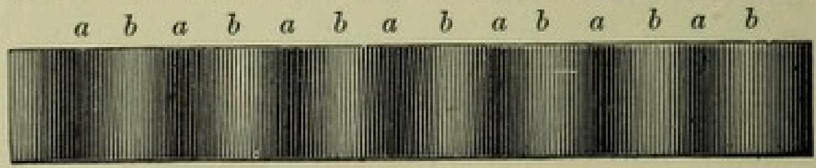

Fig. 3.

that the maxima are nearer each other, and probably could be barely appreciated. In Fig. 3 we have a still more acute note, in which it is impossible to notice the elementary impulses, and in which the maxima are very close together. In each of these three notes the vibrations or waves vary in length, and as we proceed from the deep to the acute the wave-length diminishes. Each impulse is capable itself of producing a sensation did it exist alone, but when a number of such impulses succeed each other with great rapidity, consciousness no longer distinguishes them individually: the whole sound appears one. Now, we see the qualities of high and low, acute and deep, which are really sensations, depend on the shortness of the elementary impulses, and the degree of proximity of their maxima.[1]

to say, the noise of each wave, though each of these little noises only makes itself known to us in the confused assemblage of the whole, and would not be observed if the wave causing it were alone by itself. For we must be affected a little by the movement of this wave, and must have some perception of its sound, however slight; otherwise we should have none of the sound of a hundred thousand such, since a hundred thousand nothings cannot make up anything."

[1] Taine on Intelligence, p. 111.

The vibrations of the air are communicated to the membrana tympani, and from it by a lever-like action of the ossicles to the fluid in the labyrinth. The actual movements of these structures were seen and described in 1870 by Buck,[1] and in 1872 by Burnett, now of Philadelphia, who performed several ingenious experiments in the Physical Institute of Berlin, under the direction of Professor Helmholtz.[2] I have since repeated several of these experiments with the most satisfactory results. It will be found that in proportion to the increase of the number of vibrations of the organ-pipe used for producing the movements, the "excursions" performed by little points of light on the membranes and bones diminish. In Burnett's experiments, the same preparation showed excursions at the point of the long process of the hammer, as follows:—

Vibrations of organ-pipe per second.	Extent of excursions in millimetres.
50	0·080
140	0·064
630	0·008
1160	slight motion.

These experiments show conclusively that the motion of the air is conveyed by the chain of ossicles to the labyrinth.

But musical sounds having the same number of vibrations or pitch may differ in intensity, that is, we are conscious of a somewhat different sensation. This may also be referred to a physical cause. It is well known that the intensity or loudness of a note depends on the extent of movement of the particles of the air; or, in other words, the sensation is correlated to the physical phenomenon of the different degrees of condensation of the wave of air. In each elementary wave there is a maximum and minimum of condensation, and consequently a maximum and minimum of intensity. But here again consciousness fails us. It is only by the application of what is known in physics regarding the changes and conditions of the wave of air that we can understand how the sensation of intensity is built up.

The last quality of a musical note to which I shall allude is that of timbre or colour. It is the sensation we experience on hearing a note of the same pitch and intensity sounded by different instruments. The note C on a violin and on a piano have a different quality. Then vowel *a* pronounced by one human voice, has a different quality than when pronounced by another. For many years this problem was unsolved. Müller conjectured that it was due to the simultaneous action of waves of different velocity, which, conflicting together, produced a wave of a peculiar form. Longet also conjectured that timbre was due to the existence of various waves of different intensity and pitch, which modify the form of the principal wave. The brilliant researches of Helmholtz have now shown

[1] Knapp and Moos, Archives of Ophthalmology and Otology, vol. i., 1870.

[2] Loc. cit., vol. ii., No. 2, 1872.

that the quality of a musical sound depends on supplementary tones termed harmonics or overtones, the vibrations of which are two, three, four, five, six, seven, eight, nine, or ten times as rapid as those of the fundamental tone. Some of these harmonics may be heard by an acute ear without any artificial assistance; but most people require to use an instrument called a resonator in order to detect them. A resonator may be either a globular glass flask having a wide mouth, or a globular flask made of brass, or a cone of thin tin. They are of different sizes, and so constructed that the volume of air they contain, when caused to vibrate, will produce a particular tone. When applied to the ear a tone is at once perceived, and this tone depends on the form of the confined mass of air, and the shape and size of the opening. If, however, the tone corresponding to that of the resonator be sounded near it, even feebly, the synchronous vibrations in the resonator are strengthened, and the tone is heard distinctly. Thus a compound musical note, produced by any instrument, may be analyzed, and shown to consist of a fundamental tone, and of certain harmonics or overtones. The fundamental tone is the same for the same note in all instruments, but the addition of certain harmonics or overtones to the fundamental tone gives a certain quality or timbre to the sound. The note C on the treble stave, sounded on a violin, a flute, an organ, or a pianoforte, will have 512 vibrations per second, and, by artificial appliances, may have the same intensity, but the sounds are so different that it is almost impossible for the human ear to confound them. The cause of this difference of quality of sound is the existence of certain harmonics. For instance, in the case of the piano, by the use of appropriate resonators, we can hear distinctly the first six harmonics, the seventh feebly, the eighth more acutely, and the ninth scarcely at all; but when the same note is sounded on the violin, the first six are given very feebly, while the higher ones are distinct. By the aid of a prism, Newton dispersed a ray of white light into its elements, and saw at a glance in a spectrum on a screen, an infinity of different shades of colour, which, however, shade into each imperceptibly, and have a maximum of intensity at certain parts, so that we usually distinguish seven—red, orange, yellow, green, blue, indigo, and violet. We have an analogy in the decomposition of a musical note. We listen, and we experience a peculiar sensation, which, however, is not simple. It is mainly made up of the sensation produced by the vibrations of the fundamental tone; a sensation which can be isolated by many people when their attention is specially directed to it; but this sensation is modified and changed to a certain extent by other influences which attach themselves to it, and which give it a special character. The secondary influences are those produced by the vibrations of the harmonic tones, which differ in various instruments.

I object to calling those secondary influences "sensations," as has been done by Taine[1] and others, because we are not conscious of

[1] Taine, op. cit., p. 112.

them. Consciousness, as a general rule, when a musical note is sounded, "sees the whole, and nothing but the whole." We knew that the note C differed when sounded on various instruments; but, until demonstrated by Helmholtz by the use of resonators, we were unaware of the existence of harmonics. At the same time, it must be remembered that, in certain individuals, a few of the first harmonics can be detected without the use of resonators. These persons, therefore, when they hear a musical note, may really hear more than one sound. They experience a sensation corresponding to the fundamental tone, and they also are able, by concentrated attention, to experience other sensations corresponding to several of the first harmonics. This may help in accounting for the fact that some persons and animals are powerfully influenced by musical notes on certain musical instruments.

Now, it is evident that those influences produced by the vibrations of harmonic tones are transmitted from the internal ear to the nervous centre of hearing, which is situated somewhere in the medulla oblongata beneath the floor of the fourth ventricle, and which is connected, according to Foville, with the flocculus of the cerebellum. But we are not always conscious of these influences. If they are intensified to a certain degree by the use of resonators, the exact amount of increase being unknown, and probably varying in different individuals, we can hear them quite distinctly while we are at the same time trying to listen to the fundamental tone; but, in ordinary circumstances, we are unconscious of them. But while we are unconscious of them, or, in other words, while we have no knowledge of them as distinct sensations, they still have an influence on the sensation produced by the vibrations of the fundamental tone; and it is the character or colour given to this sensation which enables us to know the instrument on which the note is sounded.

I have thus endeavoured to show that our sensations, in the case of hearing, are compounds. They are made up of elements, which we may become conscious of, if motion passes through a certain space and lasts a certain time. But though we are not conscious of this amount of motion or of this time, it still must exist, and produce, in all probability, internal changes in the nerve-centre. Sometimes we are conscious of these changes, sometimes not. These changes may be intensified, and immediately are recognisable by consciousness, as in the case of becoming aware of harmonics by the use of a resonator; but, usually, many of these changes are not recognisable, and yet have an influence on the primary sensation. A similar but not so complete analysis may be effected in the case of the other senses, which will be given at another time; meantime, we cannot but see that the character of our sensations is determined by physical phenomena—chiefly extent and time of movement.

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