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A VOICE TONOSCOPE[1]

BY

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The study of motor processes has remained comparatively neglected in experimental psychology. It is not that the motor processes, as compared with the sensory, are less significant, of a baser sort, so much simpler, or fewer in number. It is because the analysis of the one naturally precedes the analysis of the other. The study has been pursued in the natural order in this inceptive stage of the science, but interest now begins to center upon the study of the motor process, not only because the motor process is the outcome of, and the sequel to the sensory process, but also because it is the practical phase of life.

In the psychology of music, the time has now come to begin to turn from the study of the hearing of tones to the study of the singing of tones. But, as we have had need of delicate tone-giving instruments in producing and gauging stimuli for the sensory processes, we now need, in addition, the corresponding means of measuring the results of motor processes. The lack of such instruments is conspicuous. The unaided ear will not serve the purpose. The graphic and photographic apparatus in use are too cumbersome. It is difficult to obtain a simple and at the same time accurate and ready means of measuring the pitch of tones produced by the human voice.

[1] Read before the Section of Anthropology of the American Association for Advancement of Science, Jan. 1, 1902. The name "tonometer" was then used instead of tonoscope, but it is apparent that the latter term is preferable because it distinguishes this instrument more completely from other tone-measuring instruments.

The apparatus that I am to describe is somewhat complicated in construction, but when once built it is easy of manipulation, can be used for rapid work, and can be made sufficiently accurate for all purposes of routine measurements for which it is adapted. It is intended to be used in measuring the pitch of the human voice in singing and speaking; and, since it causes the vibration-frequency, which denotes the pitch of the tone, to be *seen* directly when the tone is sung, this apparatus may pass by the descriptive name of voice tonoscope.

The voice tonoscope is constructed on the principle of the stroboscope; that is, the vibrations of the voice are made visible upon a moving surface by the action of intermittent light. I take pleasure in acknowledging my indebtedness to Professor Scripture, who first employed this method of measurement in an exercise on the reproduction of tones.[1] The apparatus is "built up"; the individual parts, such as the manometric capsule, the vacuum tube, the stroboscopic disk, and the double contact fork, are used in physics, but Scripture was the first to use them in this way for psychological purposes. The special feature of the present apparatus is the stroboscopic screen, shown in Fig. 3, but a brief description of the complete apparatus and of the methods of measuring by means of it will be given.

The following are the essential parts of the apparatus: (1) means of producing a standard tone, (2) a special moving stroboscopic screen, (3) means of projecting the vibrations of the standard tone upon the screen, and (4) means of projecting in a similar manner the vibrations of the tone sung. These parts will be described in the order in which they have been mentioned.

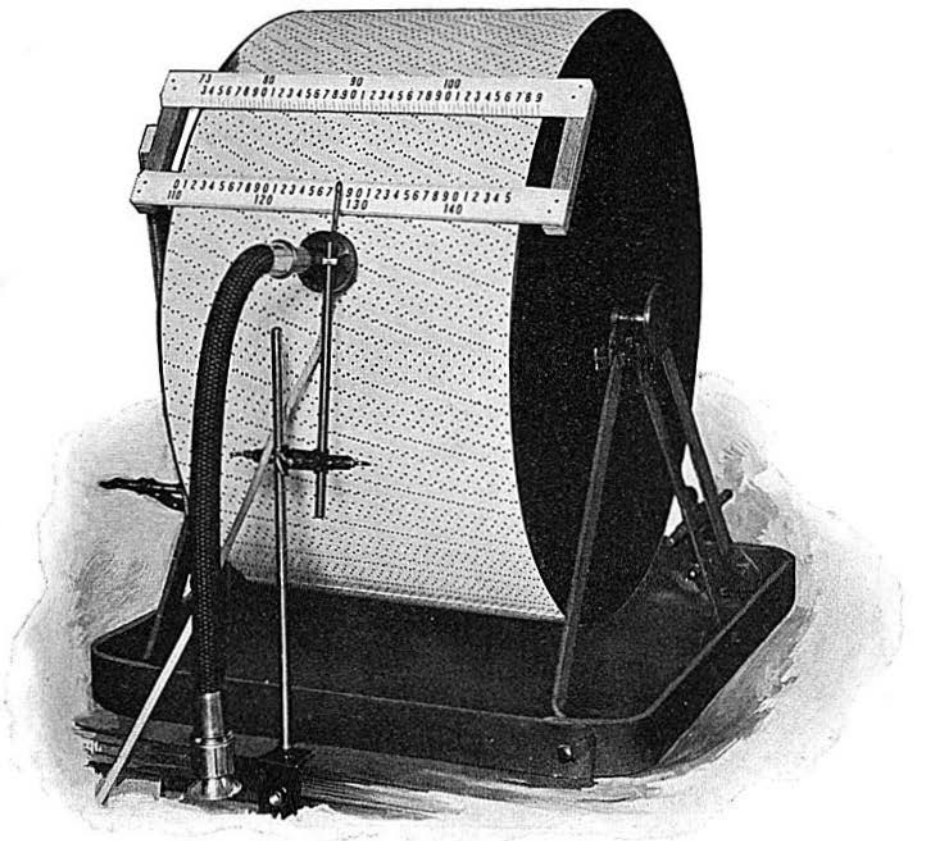
The standard tone, from which the singer takes his key

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[1] SCRIPTURE, *Elementary Course in Psychological Measurements*, Studies from the Yale Psychol. Lab., 1896, IV, 135.

and by which the standard of measurement is determined, is produced by an electric fork in a distant room and is heard through a telephone receiver which is in shunt circuit with the fork. A switch makes it possible for the experimenter to sound the standard tone at required intervals of time; or the observer may himself regulate this roughly by moving the receiver to and from the ear.

The stroboscopic screen is made in the following manner: A metal drum 50 cm. wide and 50 cm. in radius is mounted on ball bearings and revolved by an electric motor. A heavy white paper is stretched around the drum and on this paper seventy-one parallel lines of dots are drawn. The dots are 3 mm. in diameter and equidistant and the lines extend through the complete circumference of the drum. The lines of dots are divided into two series. The first series contains thirty-six lines drawn equidistant and so spaced as to cover the whole screen. Their arrangement and the number of dots in each is shown by the numbers in the upper section of the scale seen in the Figure. The first line has 73 dots and each succeeding line in the series has one more dot than the line immediately preceding. The second series has thirty-five lines and these alternate with those of the first series. This arrangement and the number of dots in each line may be seen by the numbers on the lower section of the scale. As regards the number of dots in each line, the second series forms a direct continuation of the first and the dot-frequencies of the two series together, therefore, extend from seventy-three to one hundred and forty-five by a uniform increment of one dot for each line. The aim in the arrangement of the dots was to secure dot-frequencies which should correspond to the vibration-frequencies of all tones within the range of the human voice. In musical terms, we have here what corresponds to the vibrations of all tones within the octave 73 v. d. to 146 v. d. The stroboscopic effect is such that the dot-frequency for one



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octave will serve quite as well for tones in higher or lower octaves, as will be explained later.

The standard tone is reproduced to vision upon the screen. The accessories for that purpose are not shown in the illustration. On the back side of the drum, there is a scale like the one seen on the front side and occupying a corresponding position. A vacuum tube, 30 cm. long, is fastened at the upper edge of the scale and supplied with a reflector which throws the light on the scale and prevents it from shining over the drum. The terminals of this tube are connected with the secondary terminals of an induction coil. The primary circuit of the coil is completed through a battery and the double contact fork that produces the standard tone. The room is darkened in order to secure the intermittent light effect. Each vibration of the fork breaks the circuit and the resulting spark produces a flash of light in the vacuum tube so that the screen is lighted up once for each vibration of the standard fork. Suppose that the fork is a 100 v. d. fork and the drum is revolving at the rate of one revolution per second. Then, when the dots on the revolving screen pass under the intermittent light, the line which has one hundred dots appears to stand still and is clear and well defined, because the frequency of the dots is the same as the frequency of the lights: every time an image of this line is cast upon the retina the dots appear in the same position. The dots in all other lines appear blurred and moving, assuming more or less the appearance of gray streaks. It is therefore easy to detect the line that is wanted. The purpose of this contrivance for projecting the standard tone is merely to secure the means of regulating the speed of the drum. Thus, in the present case, the speed of the drum is regulated so that the one hundred-dot line stands still continuously. This line then becomes the standard for the visual scale in terms of which the measurements are to be made. Any other tone projected on the same screen in a similar

way will make some other line stand still and the pitch of that tone will be indicated by the number of that line, or a multiple of it; e. g., if the second tone makes the 105-line stand still, it is a tone of 105 v. d., or some multiple of that number, as 210 v. d. or 420 v. d. Which octave it is in can readily be told by the practiced ear but it is also shown by the formation of the dots.

The tone that is sung is projected on the same screen, in a similar manner, although by different means. In this case the intermittence of the light is produced by means of a manometric flame on the side of the drum opposite the vacuum tube. The manometric capsule, with the connected gas tube and the speaking tube, is seen in the Figure. The observer holds the speaking tube before his mouth in the way such tubes are usually held, and sings the tone that is to be determined. The tonal vibrations cause sympathetic vibrations of the little gas flame in the capsule so that the flame rises and recedes once for each vibration of the vocal organs. This gives an intermittent light like the one produced in the vacuum tube on the other side of the drum. When the screen is moving at the standard speed, that line of dots will stand still which has dots to correspond to the frequency of vibration of the tone, and the pitch of the tone is indicated by the number of the line that stands still. The pitch may be seen as soon as it is heard because the visual and the tonal effects are synchronous.

This summary description of the essentials of the apparatus also indicates, in a general way, the mode of procedure in experimenting. It reduces itself to this: the singer takes the key tone from the receiver and sings a tone before the speaking tube; the vibrations are projected on the moving screen and the pitch of the tone is seen on the scale.

Although the apparatus consists of several parts, only the drum with its screen is made for this specific purpose.

The other parts are such as are found in any ordinary physical or psychological laboratory, and need not be described in detail, but some further particulars about the construction and use of the screen are necessary.

The arranging of the lines into two series is important. It is necessary to have all the lines within a certain compass because the necessarily small light will not serve for more than a limited space and the spreading of the record over a large surface would therefore interfere with quick reading. This drum was made as wide as is practicable under the named restrictions. An attempt was made to put the lines in a single series and it was found that then only about thirty lines could be put on the screen and be read satisfactorily. This number of lines would cover only a part of an octave within the desired range of tones. At least seventy lines are needed. By the double series plan it is possible to put seventy-one lines on the space occupied by thirty in the single series plan; and it is easier to read on this screen of seventy-one lines than it was on the original screen of thirty lines covering the same space. The reason for this lies in the fact that by the double series plan no two adjacent lines have nearly the same dot-frequency; consequently the line on each side of the one that stands still appears as a gray streak and forms a sort of frame for the line one is reading. This has two effects: in the first place, the two series may be placed on the same screen without causing any interference; in the second place, the one series of lines makes the other clearer, so that it is possible to put the lines closer together. Having separate scales for the two series is also conducive to clearness. The same device, therefore, makes it possible to save space and add clearness and thus to provide for the desired range of tones.

Let us suppose that the speed of the drum is regulated by the 100 v. d. fork to make one revolution per second. Then, if the tone that is sung lies within the range of the

octave from 36 to 72 v. d., the line that stands still has twice as many dots as there are vibrations in the tone and, in the reading, the number on the scale is simply divided by two; e. g., if the 75-line stands still the tone is 37½ v. d. The ear readily reveals whether or not the tone lies within the low octave and these low tones can be sung only by the male voice. For tones from 73 to 146 v. d., the reading is direct from the scale. This represents the middle range for the baritone. For tones within the octave from 146 to 292 v. d., the line that stands still appears to have twice as many dots as it actually has. That makes it easy to recognize this octave and, in the reading, the number on the scale is doubled: e. g., if the 75-line stands still, the tone is 150 v. d. This octave represents the upper range for the male voice and the middle and part of the lower range for the female voice. From 292 to 584 v. d., there will be four vibrations for each dot in the line that stands still and the numbers on the scale must be multiplied by four. These multiples may be placed in small figures on the scale. The same principle of reading may be extended to higher octaves in so far as it depends upon the screen, but there is a limit set by the degree of sensitiveness of the diaphragm in the manometric capsule.

If a high tone is studied, it is well to run the drum at the rate of two revolutions per second. This can of course be regulated by the 100 v. d. fork. Higher forks may also be used for the sounding of the key-note after they have been tuned with reference to the 100 v. d. fork. The tonoscope may be used in tuning them.

It is only relatively true that a line stands still; it stands still only when there is an absolute agreement between the vibration-frequency and the dot-frequency. If the vibration-frequency is a fraction greater, the dots move gradually downward, and if it is less, they move gradually upward—and the speed of the apparent motion is always in proportion to the difference. Thus, if the tone is 125.5 v. d., no

line stands still, for the 125-line moves downward at the rate of one space per second and the 126-line moves upward at the same rate; but, if the tone is 125.1 v. d. the 125-line moves downward at the rate of only one-tenth of a space per second and the 126-line moves upward at the rate of nine-tenths of a space per second. The practiced observer can therefore readily learn to read in tenths of the scale units.

The accuracy of the reading varies with the accuracy of the singing. The accuracy increases with the steadiness of the voice, and hence with the demand for accurate measurement. The more firmly the pitch is sustained, the easier is the reading. The ordinary singer wavers in the tone that he tries to sustain even for half a second and the experimenter must select the predominating pitch in it.

The drum is heavy and carefully mounted so that it runs at a fairly uniform speed, but if the speed should tend to vary, the experimenter records such variations and a corresponding correction in the readings is made from a table which is exact to one-tenth of a vibration.

The tonoscope is not constructed for any one particular psychological experiment. It is intended to be a general measuring instrument that may be employed in a number of ways. It is simply a quick and accurate means of determining the pitch of tones—not only of the human voice, but also of instruments from which the sound may be projected upon it. In coöperation with a student, Mr. Edward Bechly, I have begun a study of certain facts about the nature of the control of the voice in singing and speaking. The results are not ready for publication but some of the measurements that we have made may be mentioned in order to indicate some purposes for which the tonoscope has been used with excellent success.

1. Sounding a single tone. This measurement presents different aspects according as the tone is taken at random, is heard from a standard, or is heard from a standard and

hummed before being sung. The absolute pitch, the intensity, the mode of vocalization, and the time relations are factors that may be varied in order to determine their effect upon the pitch of the tone.

2. Sustaining a tone. "Sustained" tones vary in pitch according to a general law. The factors that influence this may be determined.

3. Singing tones at certain pitch intervals. The standard tone may be given or it may be taken at random by the voice.

4. Singing musical scales, natural and chromatic, with numerous variations in the conditions.

5. Singing a melody. There is a shocking surprise in store for every singer who tests his ability to sing even the simplest air in true pitch. He finds that his good ear has tolerated great license in the matter of fidelity to pitch. Two-part harmony, or unison singing, may also be measured by recording for one voice on each side of the drum, but this we have not tried.

6. Speaking in a uniform pitch (a pure fiction).

7. The least producible difference in pitch. This is the measurement that is of greatest value for psychology. The least producible difference is to the study of motor processes what the least perceptible difference is to study of sensory processes.