Recent Research in Vibro-Tactile Sensitivity

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By the word, vibro-tactile, I refer to the organs involved in sensations that accompany the application of mechanical vibrations to the skin. The exact nature of this form of sensitivity is still in question, but we have evidence that both superficial and deep sensitivity are involved. Hence our term, vibro-tactile.

Professor Gault and his associates at Northwestern University have been interested in this form of sensitivity during more than a decade. By way of introduction, let me mention the reason for this great interest in the vibro-tactile field. It is a very practical one, namely, the enlargement of the uses of the vibro-tactile senses in relation to the education of the deaf. For those deafened individuals (and there are many of them) who do not have sufficient residual hearing to be helped by an earphone, some other approach must be substituted. The vibro-tactile senses, since they are the phylogenetic ancestor of hearing, appear to be the logical ones. Repeated experiments appear to demonstrate the practicability of this approach.

Probably all of you have touched the cone of your radio loudspeaker and have felt the vibration of the incoming speech or music. Although these vibrations are quite meaningless as felt by the finger-tip, when they are conducted to the ear they are readily distinguished and understood. In other words, the ear is sufficiently keen to respond to the subtle differences among them. The finger-tip is not so. Here then is the real problem: to develop techniques for accentuating these subtle differences so as to make them detectable by the finger-tip. This is a difficult task and already much time has been devoted to this end. The result of this effort has been the development of the Gault-Teletactor or "Phonotactor" as Dr. Gault now prefers to call it, an instrument by which one can feel speech or music. It consists of a microphone, special amplifier and vibrator upon which one places the fingers to feel the vibrations that correspond to the speaker's voice.

Five years ago, the Illinois State School of Deaf installed the Gault-Phonotactor for the use of a first grade class. Two years later, on their own initiative, they extended its use to fourteen classes. Each pupil has a vibrator on his desk which is connected to the teacher's microphone. As she speaks the pupils both read her lips and feel her words. Experiments show that the pupil's comprehension of speech is increased on the average 20 per cent because of these vibro-tactile cues.

I well remember a few years ago observing a teacher at work with the phonotactor. It was the first day of school, and a five year old lad was being introduced to the instrument. He appeared normal in every respect, but he had never heard a sound, and, therefore, did not know that such a thing as sound existed. The child's hand was placed upon the vibrator while the teacher spoke into the microphone. As he felt these vibrations in his fingers he appeared greatly interested in the new experience. Soon he noticed that he felt these vibrations only when the teacher held the microphone to her lips and made certain movements with her vocal apparatus. To us, hearing folk, the teacher was speaking, but to this deaf youngster, she was merely making queer movements with her lips and jaw which, in some mysterious way, caused this tingling in his fingers. Later the child placed the microphone to his own lips and tried to imitate his teacher, and in so doing he made probably the greatest discovery of his life. He discovered his voice. He found that when he exercised the vocal organs something happened—something which he and others could become aware of. Here then started the long process of teaching the child to make the delicate and accurate movements of the vocal musculature necessary to produce speech. In all this process the Gault-Phonotactor played a very useful part.

Although we are interested at the present time in developing the instrument for use as an adjunct to lip-reading and as a means of developing speech, we hope to extend the applications very greatly after we have mastered some of the difficult technical problems.

I think you will readily see that many educational and psychological problems arise from this work. They are being worked out in the State School for the Deaf, in our ow nprivate school, and in the psychological laboratory; but since they are not pertinent to this report we shall pass on. Probably our greatest emphasis at present is on the engineering and physical problems involved. We are confronted with the task of developing apparatus to compensate for what the finger lacks in sensitivity and in discriminating capacity. Here are many fascinating problems but they will not interest you. The fourth main division of our research projects centers around physiological and neurological problems. In the following pages I shall review our research on these items.

THE NATURE OF THE VIBRO-TACTILE SENSES

At least a dozen different experimenters have contributed evidence toward the isolation of specific end-organs involved in this form of sensitivity, but it is all quite incomplete and contradictory. Even the question of the relative role of deep and superficial sensitivity is still uncertain. Most of these studies [1–11] have been clinical observations of the independent loss or impairment of the two forms of sensitivity, and are interpreted as evidence of the existence of independent receptors responsible for vibratory sensitivity.

From the experimental approach, evidence pointing to the same conclusion is available. Bing, for example, by anaesthetizing various areas of the skin with cocaine, demonstrated that vibratory sensitivity is not markedly decreased, although other forms of sensitivity are destroyed. Katz found that the same thing holds after violent rubbing of the skin; namely, tactual sensitivity is impaired much more than vibratory sensitivity. We have found the same thing in our own laboratory, namely, the anaesthetizing the area being stimulated does not markedly decrease sensitivity although tactile sensitivity is entirely absent[12]. However, we doubt the significance of this experiment as an indication of the supreme importance of the deep sensitivity, since it is quite probable that in this case vibrations applied to the anaesthetized area of the skin were conducted through the anaesthetized skin to a normal area. The probability of this explanation has been demonstrated by showing that vibrations applied to the skin can be detected two feet away from the point of application.

Katz[13] argues that since the amplitude of vibration necessary to produce a sensation is far less than the movement required to give rise to tactual sensation, something other than touch must be involved. We discredit this form of reasoning since it would seem quite possible to account for the observed fact by the summation of rapid subliminal tactile impressions into a vibratory sensation. As further evidence of a differentiation he reports different reaction time and latent periods for tactile and vibratory senses.

A difference in the effect of fatigue has been reported. Katz found very little fatigue due to vibratory stimuli whereas touch fatigues quite rapidly. Kampie[14], however, reports different findings. In our laboratory we have carefully investigated the effect of vibratory stimuli versus pressure stimuli on vibratory sensitivity. The results show quite marked differences. Two minutes exposure to a vibratory stimulus decreases considerably one's vibratory sensitivity but two minutes exposure to a purely pressure stimulus shows no fatiguing effect on vibratory sensitivity.

Attempts have been made to correlate vibro-tactile sensitivity with cutaneous spots as mapped out by the traditional psychological experiments. One experimenter found some correlation with point spots from which he concluded that naked nerve endings picked up these vibratory stimuli. This finding, we have been repeatedly unable to verify, and we doubt very much whether correlation with any specific form of sensory experience will ever be established.

The following findings from our laboratory indicate the importance of deep sensitivity in vibro-tactile stimulation, although they by no means indicate that vibro-tactile sensitivity is to be identified solely with deep sensitivity.

(a) The tongue, which is presumedly quite sensitive to touch is not very sensitive to vibratory stimuli. This is verified by Katz but refuted by Pollock, who says the tongue is quite sensitive to vibratory stimuli. This discrepancy in findings can be accounted for, we believe, by the different conditions under which the two results were obtained. Pollock used a much lighter vibraton than ours. Since our vibrator was large and massive, the damping effect of normal variations in pressure was negligible. It is quite possible that different end-organs are involved in the two situations. Furthermore, a different criterion of "more or less sensitive" was used. Our criterion of sensitivity is the threshold intensity, whereas Pollock's criterion is the observer's estimate on the intensity—psychologically a very different thing. We believe that those two facts, difference in apparatus and criterion, will adequately account for the different findings.

(b) The finger nail, which we would expect to find relatively more sensitive to vibratory stimuli than to tactual, is quite sensitive to the Phonotactor. The inference is that the vibratory sense and not touch is responsible for the greater sensitivity of the nail.

(c) Sensitivity is not markedly decreased by the wearing of a kid glove. The opposite is obviously true for the sense of touch.

(d) The back of the finger which contains many times fewer touch spots than the palmar surface is no less sensitive to vibrations. This lack of correlation between sensitivity and the distribution of touch spots suggests the predominant role of the vibratory sense.

(e) The sensitivity is not greatly changed by the use of a point instead of the diaphragm stimulating several square centimeters.

(f) The sole of the foot is less sensitive than the palm of the hand. Since previous experimenters have found the lower extremities less sensitive than the upper extremities to vibratory stimuli, we would expect this result if vibratory stimuli played a dominant role.

VIBRO-TACTILE SENSITIVITY

Although we do not know at present the specific end-organs responsible for the vibratory sensation, or the manner in which they function, we do have very definite data on the sensitivity and discriminatory capacity of these receptors. In our research on extending the uses of this type of sensitivity for the deaf, these data have a great practical value.

One of the first questions to be asked is the frequency range in the vibro-tactile sphere. Several attempts to measure this have been made in various laboratories, and each experimenter has reported a different upper limit. One of the first experimenters[15] reports 528 c.p.s. as the upper limit. Later experimenters[16, 17, 18] placed the upper limit at successively higher values ranging to 2700 c.p.s. We have evidence that all of these upper limits are artifacts, i. e., they are due to the functioning of the specific apparatus employed instead of true upper limits. By using a vibrator especially designed for the higher frequencies, and a high-gain amplifier, we[19] have had observers respond to vibrations as high as 8000 c.p.s. We do not consider this figure as necessarily the upper threshold, but merely the limit to which our apparatus could function with the required amplitude.

Since the frequency range has in the past been determined by the intensity of the stimulation, we turn now to the study of intensity thresholds. Our measure of intensity is so many decibels above an arbitrary level, which in this case is the approximate threshold of the normal ear. Intensity thresholds have been determined for eight different frequency levels, and are given in Table I.

TABLE I.—THE SENSITIVITY OF THE FINGER-TIPS TO VIBRATORY STIMULI

Frequency	Sensitivity of finger-tip in decibels below our arbitrary level
64	41
128	53
256	69
512	89
1024	102
2048	115
4096	105
8192	91

The above thresholds were all determined for the finger-tip. Vibrotactile thresholds for other areas of the body are given in Table II.

TABLE II.—THE SENSITIVITY OF VARIOUS AREAS OF THE BODY TO VIBRATORY STIMULI IN DECIBELS BELOW THE SENSITIVITY OF THE NORMAL EAR

Area of body	Frequency		
	64	256	1024
1. Left index finger	40	67	95
2. Right index finger	44	75	104
3. Right index finger (wearing kid glove)	48	78	108
4. Right index finger (using sharp point instead of large conical diaphragm)	44	75	105
5. Back of the right index finger	45	74	105
6. Nail of the right index finger	43	70	92
7. Tip of tongue	59	90	118
8. Sole of foot	56	77	114
9. Palm of right hand	54	66	101
10. Inside surface of right fore arm	53	80	121
11. Inside surface of right fore arm shaved	53	79	124
12. Outside surface of right fore arm	49	76	114
13. Outside surface of right fore arm shaved	52	83	119

We are careful to distinguish between sensitivity and discriminatory capacities, since we find there is little correlation between the two—popular opinion to the contrary. Our interest in this was aroused a number of years ago when we discovered that one of our very best observers—best because he was able to make accurate discriminations of subtle differences in vibratory pattern—was quite insensitive in comparison with our other observers. We followed this up with a careful study and found very little relation between ability to sense and ability to discriminate.

As to the differential sensitivity we have found that trained observers can distinguish a difference in frequency of two vibratory stimuli provided the difference is at least 2½ per cent when the standard frequency is 400 d.v.sec. As to the ability to discriminate difference in intensity, a difference of 4 to 12 per cent, depending on the absolute intensity, is sufficient to enable trained observers to detect a difference.

Today accurate and specific data are available on the sensitivity of the vibro-tactile organs—their capacities and limitations. The following statements from laboratory findings indicate that all the important physical characteristics of speech can be detected by the finger-tip.

(a) The finger-tip can detect vibrations as high as 8,000 per second.

(b) It can differentiate intensity differences comparable to the ability of the normal ear.

(c) It can differentiate two pitches when the frequencies concerned differ by as little as 2½ per cent of the standard—400 d. v.

(d) It can detect differences in tones and beats.

(e) It can detect the individual tones in a chord and can discriminate between consonance and dissonance.

(f) It can detect differences in short intervals of time with 90 per cent of the accuracy of the ear.

(g) It is only one one-hundredth to one one-hundred-thousandth (depending on pitch) as sensitive as the normal ear. This is the only score on which the senses of touch and vibration do not compare favorably with the ear, but it is a deficiency which can be compensated for to a considerable degree by apparatus such as the Gault Phonotactor.

The ultimate success of the Phonotactor as a sole means of communication depends on the ability of the individual to interpret complex vibratory patterns. The deaf person will have to learn the meaning of each vibratory disturbance that he feels in his finger just as the normally hearing person has to learn the meaning of sound—the vibratory disturbances at his ear-drum. The task is not simple and a great deal more research is needed. However, three experiments done in this laboratory suggest that individuals can interpret complex vibratory patterns.

The first is an experiment in which a long series of four different musical intervals was presented to observers both auditorially and tactually. The result showed correlation of .53 $\pm$ 0.11 between a person's ability to identify intervals by hearing and his ability to identify them by touch. Furthermore, training in recognition of intervals by ear caused considerable improvement in the ability to recognize the same intervals by touch. In short, our observers soon learned to recognize a musical interval by touch.

The second experiment is one in which two deaf and two normally hearing persons who had had no previous experience with the Phonotactor were given three half-hour periods of training in identifying five vowel and diphthongal sounds by touch. Then they were tested on the sounds and the results are shown in Table III.

TABLE III.—THE RECOGNITION OF SPEECH SOUNDS BY TOUCH (BASED ON 500 OBSERVATIONS BY 2 DEAF AND 2 HEARING PERSONS AFTER THREE HALF-HOUR PERIODS OF TRAINING).

Sound pronounced	Observer's response in per cent					Energy in milliwatts
	A	E	I	O	U	
A	70	12	6	6	6	0.27
E	12	60	14	9	5	0.08
I	6	13	72	4	5	0.17
O	11	8	6	66	8	0.46
U	7	5	5	7	76	0.12

The data in the table show, for example, that when "A" was spoken the observers interpreted it as "A" 70 per cent of the time. Twelve per cent of the time it was interpreted as "E" and 6 per cent of the time as "I", and "O", and "U".

The sounds were produced from a victrola made from the speech of an instructor in the School of Speech. The average value of the electrical energy going into the Phonotactor was measured for each sound and is given in Table III. It is clear from the data in the table that our observers did not differentiate these vibratory patterns on the basis of differences in intensity alone as is sometimes suggested by our critics. "A" and "E", it will be observed, were the most frequently confused, yet they differed widely in intensity in this particular experiment. On the other hand, "U" and "I" are frequently confused yet their respective intensities are of a similar magnitude. It must be pointed out that these simple experiments by no means prove that our observers detect quality differences but until further research is done we consider it quite likely that such is the case. The experiment is being repeated more carefully, using all the vowel sounds between the letters "b" and "t" (e.g., boot, boat, but, bit, bite, etc.) Tentative results indicate the same conclusions.

The third experiment on the interpretation of vibratory patterns is one in which observers were trained to recognize sentences as they were felt over the Phonotactor. The experimenter had before him a list of sentences of twelve syllables each. The observer had before him the same list except that the even numbered sentences had been omitted, and were represented by their number only. The experimenter gave the signal "one" and read sentence number one several times. The observer, in this case, knew exactly what was being read. At the signal "two" the experimenter read sentence number two. This time, however, the observer did not know the actual sentence read but knew only its position in the list. After an extended period of training, the observers were tested on their ability to identify each vibratory pattern. In all cases, our observers learned to identify vibratory patterns when they were represented merely by a certain position in the list just as readily as when they were represented by the actual sentence being read. In brief, learning was necessary and then interpretation became possible.

We have presented data showing the great sensitivity and the discriminatory capacities of the vibro-tactile organs. Although we do not as yet know the exact anatomy or physiology involved, we have had considerable success in making this more or less neglected form of sensitivity serve human ends to a hitherto undreamed of degree.

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