

THE FUNCTION OF INTENSITY AND PHASE IN THE BINAURAL LOCATION OF PURE TONES. II.

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PART II. PHASE.

SYNOPSIS.

Linear Relation; Phase Difference and Apparent Angular Displacement of the Source of Sound.—That a linear relation exists between phase difference at the ears and apparent angular displacement from the median plane between them, is demonstrated for pure tones within the range 100 to 1,200 d.v. Extended experiments are made with two individuals but additional evidence is adduced to show that the results have a general applicability.

Linear Relation; the Variation of the "Constant" with Frequency.—The "constant" in the above linear relation, or the slope of the curve with the two variables as coordinates, is approximately a linear function of the frequency.

Upper Limit of the Phase Difference Effect.—The upper limit of the phase difference effect seems to be from 1,000 to 1,500 d.v.

Double Images.—It is shown that the phase difference effect, if it be the controlling factor in localization, may produce multiple apparent sources. For a frequency of 1,024 d.v., the double phantom sources are found in actual experiment to have the relative positions indicated by the phase effect.

Intensity-effect and Phase-effect Combined.—It is found that when intensity difference and phase difference at the ears exist simultaneously, neither has a greater effect than when applied separately. Hence quantitative results obtained by using intensity difference only or phase difference only are transferable to the case of the combination.

Direct Perception of Phase.—Phase effect cannot be explained by a direct or by an indirect effect of intensity, for the phase effect at certain frequencies and with some individuals may exist when the intensity effect is wholly absent. Direct perception of phase is thus evident.

Theoretical Computation and Comparison with Experiment.—The phase difference at the ears for various angular displacements of the source from the median plane are computed for three frequencies scattered over the range under consideration. The relationship is not strictly linear but very roughly so. A comparison is made of the theoretical and experimental ratios of angular displacement and phase difference. There is a satisfactory quantitative agreement.

Phase Difference the Most Important Factor in Localization.—The significance of the quantitative agreement of experimental and theoretical results is presented and the conclusion derived that phase difference is the most important factor in localization of the source of a pure tone, 100 to 1,200 d.v. situated in a horizontal plane in front of the observer and 90° either side of the median plane. This conclusion is extended to include the region behind as well as in front of the observer. There are more factors in actual localization than in the case assumed in the theoretical discussion; for example, reflection and alterations in quality are doubtless important factors in the general case. Above the limit of the phase difference phenomenon, viz., approximately 1,200 d.v., intensity must become an important factor, but its importance varies with the individual.

I. INTRODUCTION.

THAT phase difference at the ears affects the localization of the sound source, has been known¹ for a number of years. Recently Hartley² has produced evidence in favor of the conclusion that the phase difference of a pure tone at the ears is the controlling factor in the location of such a sound source by an observer who holds his head stationary. The present paper will present a considerable addition to this evidence, making the conclusion just stated a fact to be accepted with full confidence.

In order that correct conclusions may be obtained in the problem of localization it is important that the simplest elements be involved in the first approximations. Thus the writer has used tones which were reasonably pure and has sought to ascertain not all the factors in localization, but rather the one clearly the most important.

II. APPARATUS.

The object of the experiments was to determine for various frequencies the relationship between the phase difference at the ears and the corresponding apparent angular displacement from the median plane. The observations were in part taken with a source of sound which for simplicity will be called a "phaser." The tones were not pure, but the results have been checked by additional experiments with tuning forks, as hereinafter described, and the use of the phaser may thus be considered as satisfactory for the purposes of these experiments.

The "Phaser."—This instrument consisted essentially of a rotating toothed wheel with two telephone bipolar receiver magnets placed radially close to the teeth and capable of being separated from each other by a variable known number of degrees of rotation of the wheel. Currents of the same frequency and complexity were incuded in the two bipolar receiver magnets, each of which was connected to a head receiver, and the phase difference of the currents could be controlled by the separation of the two bipolar receivers around the circumference of the rotating wheel. Thus the phase difference corresponding to any apparent angular displacement could be secured. A brief description of the phaser will suffice, for a study was not made to ascertain the shape of tooth giving the purest tone attainable or otherwise to produce the best instrument for the purpose. The motor was a small series one, designed for a rotary spark gap of a wireless set, and capable of operating continuously at 6,000 r.p.m. For securing fairly constant speed the field and armature

¹ For a review of literature see Stewart, *PHYS. REV.*, Vol. IX., June, 1917, p. 502.

² Hartley, *PHYS. REV.*, Vol. XIII., June, 1919, p. 373.

were operated on independent storage batteries. Toothed wheels of two, four, six, eight and twenty projecting teeth were used. The one with two teeth consisted, in fact, of a bar of iron approximately $9 \times 2 \times 0.6$ cm. The tone given by such a wheel is surprisingly pure and presumably so because the tones other than the fundamental are necessarily made up of intermittent vibrations and, as is well known, such intermittent tones are not readily recognized by the ear. For the same reason the tones produced by each of the other wheels were purer than one might anticipate.

By using in each circuit of the bipolar and head receiver an impedance having high self induction, the overtones were cut down relatively more than the fundamental. In the twenty-teeth wheel at high speed there occurred a tone having the frequency of the rotations per second of the wheel. This was practically eliminated by using a small capacity in series. But the excellent check on the phaser experiments with tones from tuning forks will be sufficient evidence that the results of the experiments are reliable and may be, so far as present accuracy is concerned, considered to be those obtained with pure tones.

Throughout the experiments with the phaser, in order to insure a sufficiently constant sound conductivity from each head receiver to the ear, stethoscope binaurals were inserted in the ears and were connected by rubber tubing to brass cylindrical plugs which fitted the openings in the head receivers.

The Circular Scale.—The observer sat at the center of a scale, 170 cm. in radius, prominently marked at 5° intervals up to 90° on each side of the zero which was directly in "front," or in the median plane between the ears. The scale was mounted at a convenient level, about that of the chin.

Tuning-fork-time-test.—Sounds from two electrically actuated tuning forks, slightly different in frequency, were led one to each ear by rubber tubing and stethoscope binaurals. As described in a former paper,¹ the apparent location of the sound rotates about the head with the changing of the phase difference of the two tones. By recording on a chronograph the time required for a rotation of the image² through an angle and comparing that with the time of a complete beat or phase difference variation of 360° , the phase difference corresponding to the apparent angular displacement from the median plane could be secured.

Tuning-fork-phase-difference-test.—In this test electrically driven tuning forks were used. The apparatus is that described by Miss M. Simpson.³

¹ Stewart, loc. cit.

² The word "image" is here used as in physics: it is the apparent source of the sound.

³ Simpson, *PHYS. REV.*

With it settings of phase differences could be made at will and thus the relationship between these differences and the apparent angular displacements from the median plane could be ascertained.

III. EXPERIMENTAL RESULTS.

Linear Relation.—That the apparent angular displacement from the median plane, θ , is a function of φ , the phase difference at the ears, was already well known, but the relationship between θ and φ was to be ascertained. This was accomplished as follows: The observer sat at the center of the scale and listened to the sound from the phaser. The assistant closed the circuits for two to five seconds and then opened them for one or two seconds' rest, repeating the operation until the observer signalled that he had determined the apparent location of the fused sound. Settings of the phaser were chosen so as to make the observations "at random." Fig. 1 shows the general nature of the results always obtained not only with the phaser but also with the tuning fork phase difference apparatus mentioned above. It is clear from Fig. 1 that a

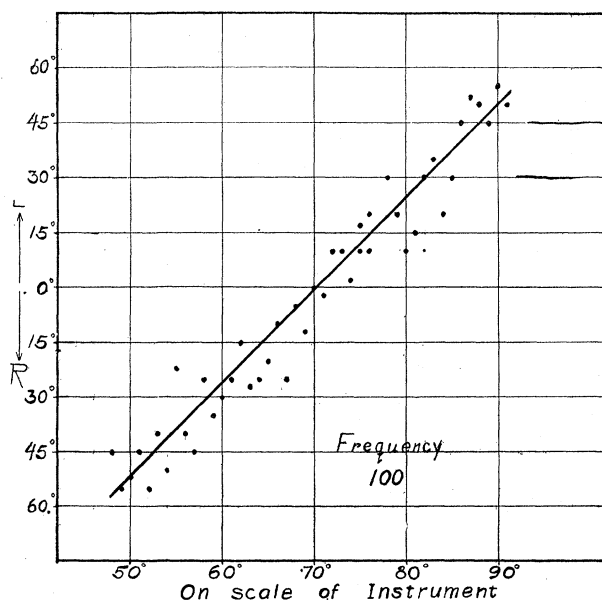


Fig. 1.

straight line will represent the mean of the observations more satisfactorily than any other curve. This was found to be the case at all frequencies. Hence the experiments were planned so as to determine merely the ratio φ/θ for each frequency, and this was accomplished by

plotting a curve from each observational "run" consisting of 16 to 20 observations. Since the completion of these observations another method of procedure, equally fair, has been found to produce much less individual error than shown in Fig. 1.

Values of ϕ/θ .—The values of ϕ/θ , or the ratios of phase difference to apparent angular displacement, are shown in Fig. 2.

The dots represent the values obtained from experimental curves

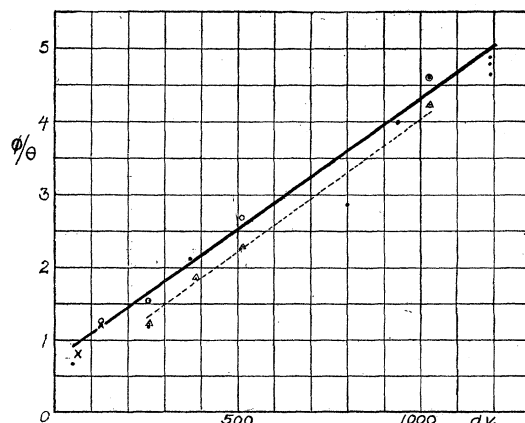


Fig. 2.

similar to that of Fig. 1, each involving 16 observations, the method being the use of the phaser with the additional aid of Helmholtz resonators presented to the head receivers and connected to rubber tubing leading to the stethoscope binaurals.

The circle with a dot center is the average of the values of ϕ/θ taken from four curves, the observations being made without resonators but with great care to secure a tone as nearly like that of a tuning fork as practicable by the use of inductance. Such a tone was not difficult to obtain for the rubber tubing caused rapid absorption of the overtones of this frequency of 1,024 d.v.

The crosses represent the observations taken by means of timing the rotation, the one for 64 d.v. being the average of 61 observations, and for 128 d.v. the average of 81 observations.

The small circles represent the average of curves similar to that of Fig. 1 obtained in the tuning fork-phase-difference-test. In fact, they are the observations reported by Miss Simpson.¹ The number of curves for the 128, 256 and 512 d.v. were eight, seven and nine respectively.

The deltas represent observations taken by a second observer *F*,

¹ Loc. cit.

using the phaser, each point being the average value of the ratio taken from five curves. The method of observing was modified, the experimenter adjusting the phaser at will by a mechanical connection. The observations became more consistent without any other error being introduced.

It should be here recalled¹ that as the phase changes the sound travels about the head from the median plane in front and external to the head to the side leading in phase, then approaches and enters the ear, passing through the head quickly at 180° , then to the other ear and from thence around to the front along a path symmetrical to the one just described. This seems to be the movement of the image, but in the paper last cited the frequency used did not reach 500 d.v. The curve now shown, Fig. 2, shows that this complete movement is impossible for the higher frequencies. For, with the frequency of 1,024 d.v. the ratio of φ/θ is 4.4 which means that when φ is 180° , θ has become 41° , thus the image does not pass to the side of the head but, at $\varphi = 180^\circ$, jumps from $+41^\circ$ to -41° , and then proceeds to 360° or 0° in a path symmetrical to the one from 0° to $+41^\circ$. This jump has already been mentioned by Bowlker.² The fact that two different observers should obtain similar curves indicates the generality of the nature of the results. In all, four observers were tested for the extreme limits of the frequencies. The values of φ/θ for the four at 1,024 are 4.6, 4.5, 5.4 and 4.2. At the lower limit they were likewise in reasonably close agreement. Thus it is obvious similar curves would be had in general. One observer, *M*, a fifth, did not have a similar curve, the values obtained being reported by Miss Simpson.³ But this observer was unusual in the effect of phase difference, being unable to get the image located external to the head.

There seems thus to be no reason to doubt the general conclusions from Fig. 2, though individual exceptions will be found. It should be pointed out that experiments thus far made indicate that the curve for φ/θ may bend sharply toward the origin at lower frequencies, but this region remains to be studied carefully.

The Frequency Limit.—By means of the phaser, observer *S* found that at 1,280 d.v. the phase difference continued to give an apparent displacement of the source, but that at 1,536 d.v. the source did not seem to move. All the observers tried, four in number, were found to have the same experience. Probably, then, this phenomenon ceases at from 1,000 to 1,500 d.v. with individuals generally. More⁴ states that with

¹ Stewart, *PHYS. REV.*, Vol. IX., June, 1917, p. 502.

² Bowlker, *Phil. Mag.* (6), XV., 1908, p. 318.

³ Loc. cit.

⁴ More, *Phil. Mag.*, XVIII., 1909, p. 308.

1,024 d.v. his judgment became untrustworthy and that with 3,000 the effect ceased entirely. Rayleigh¹ gives his limit as 768 d.v. Myers and Wilson² state that with high frequencies the effect ceases. Preliminary experiments have shown the writer that the effect does not recur at frequencies of 2,000, 3,000, and 3,500 d.v.

Double Images.—It will be noted that, as already described, for 1,024 d.v., when ϕ has reached 180° , θ has become 41° . Experimentally, at 180° one should then have two images, $+41^\circ$ and -41° ; and this was found to be the case. But if ϕ is made greater than 180° , will there continue to be two images, one being between $\theta = 0^\circ$ and $\theta = -41^\circ$, and the other between $\theta = +41^\circ$ and $\theta = +90^\circ$? Such was found to be the fact, but the distinctness of the second image differs with the observer.

In view of the above result a test was made in the open as follows: A blind-folded observer seated himself upon the ground and located without rotating his head, an electrically driven tuning fork, mounted on a resonator and situated on the ground at selected points of a semicircle of five meters radius. Experiments were conducted in such a manner that the only assisting sound was the pure tone of the tuning fork. For example, during transport from one point to another, the electromagnet operating the fork was short-circuited and the observer covered his ears. The fork had 1,024 d.v. and was driven in tandem by an electrically driven 512 d.v. tuning fork. The ground was heavily grassed, the observer held his body and head strictly stationary; the source was placed close to the ground and every precaution taken to avoid the influence of reflection. The typical results obtained are shown in Table I. A similar experiment by observer *H*, gave an average of 96° and, by observer *F*, a 90° separation. Observer *F* found a similar average with the phaser of 88° . In the 16 observations in Table I., there were four cases where the observer was incorrect in his impression as to which of the two locations was actually that of the source.

The significance of these outdoor experiments will appear in a later portion of this paper.

Combined Effect of Phase and Intensity.—In Part I. of this report was discussed the experimental effect of intensity only and in Part II. the chief variable is phase only. If either intensity or phase has any additional effect when in combination with the other, this should be ascertained. The following method was adopted. The phaser was set for a frequency of 512 d.v. At this frequency, according to the theory referred to in Part I., the ratio of intensities at the ears would be 0.6

¹ Rayleigh, Phil. Mag., XIII., 1907, p. 214.

² Myers & Wilson, Proc. Roy. Soc., LXXX., 1908, p. 260.

TABLE I.

Position of Fork.	Position of Image at Right of Front.	Position of Image at Left of Front.	Separation of Images.
40° L	20°	50°	70°
80° L	10°	80°	90°
50° L	20°	60°	80°
20° L	—	15°	—
30° R	20°	70°	90°
60° R	60°	50°	110°
90° R	90°	10°	100°
10° R	0°	0°	—
70° R	65°	30°	95°
0°	10°	—	—
30° L	45°	40°	95°
90° L	15°	80°	95°
50° L	15°	70°	85°
10° L	—	5°	—
40° R	40°	40°	80°
60° R	50°	50°	100°
Av.			91°

for a displacement of 90° from the median plane. Using the experimental value of $K = 14^\circ$, for observer F at approximately this frequency, it is found that a ratio of 0.6 would actually produce a displacement of 7.5° from the median plane. One of the tubes leading to the ears was pinched so that a displacement of approximately this amount was produced. Then a series of observations with varying phase difference was made with this selected intensity ratio. If intensity had any peculiar effect when in combination with phase, then it would be expected that a curve between phase difference and angular displacement would not be the same as that with equal intensity. But experiment showed that the same curve was always produced, though of course shifted on the θ axis by the same amount at every point. In other words, a difference in intensity merely caused a constant shift in the displacement θ . This experiment was repeatedly tried with differences of intensity causing a shift as great as 15° and yet without altering the nature of the phase difference curve. The ratio ϕ/θ was unchanged in every case. Thus neither intensity nor phase has any peculiar effect when in combination with the other and our results for either acting alone are to be considered as correct in all cases with pure tones. Thus although one may produce at the ears the same intensity ratio and phase difference as that occurring in actual localization, the effect of intensity is practically nil and the location is determined chiefly by phase difference.

IV. THEORETICAL CONSIDERATIONS.

φ a function of θ .—The results of computations from theory of the phase difference at the ears with the source in a horizontal plane and at an angle of θ from the median plane, were first presented by the writer.¹ For clearness the original curve is herewith reproduced as Fig. 3.

The ordinates, θ , refer to the angular displacement of the source of

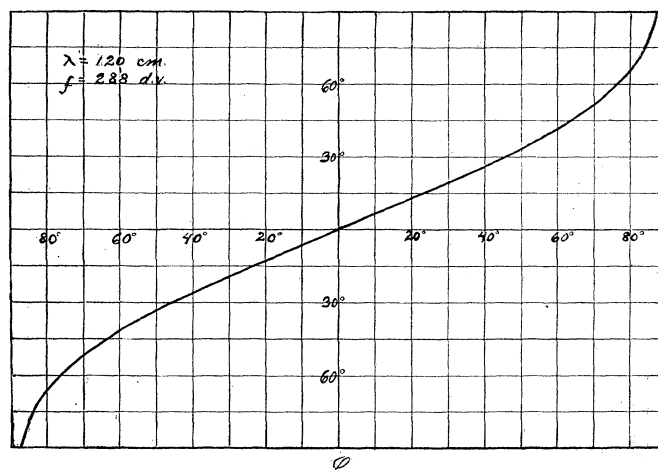


Fig. 3.

sound from the median plane, and the abscissæ, φ , refer to the phase difference at the ears. The computations assume the source at a distance of 477 cm., the wave-length 120 cm., the head a rigid sphere 60 cm. in circumference, and the ears diametrically opposite. The similarity of the curve to that obtained experimentally as in Fig. 1, is obvious.

Values of φ/θ .—The question arises as to whether or not the values of φ/θ for the theoretical case of the source actually displaced at an angle θ , correspond to the experimental values where φ is produced and θ chosen. If the values are in agreement, it would seem that the cases are similar, and this means that in the location of a sound source without head rotation, the phase difference is the important factor.

In order to compare the theoretical and experimental values, certain approximations were made. The experimental curve is linear so far as observations could determine. The straight line drawn was influenced largely by the observations of θ having a mean of 25° . Hence the theoretical values of φ/θ to be used in comparison should be those for θ about 25° . These values do not differ from $d\varphi/d\theta$ by more than nine per cent. on the average.

¹ Stewart, PHYS. REV., N. S., Vol. IV., September, 1914, Fig. 3.

The theoretical values were obtained from the results published in the article last cited and from the curves of Hartley¹ who assumes the circumference of the head 55 cm. and the ears 165° apart and the source of sound at a great distance. They are plotted as indicated in Fig. 4. The curves drawn are those of Fig. 2 and represent the experimental results. It is obvious that the theoretical and experimental values correspond remarkably well, the nature of the results being considered.

Intensity Effect.—In Part I. of this report the results of a study of the intensity effect, with frequencies 256 to 1,024 d.v., have been presented and the conclusion definitely drawn that intensity differences at the ears cannot be important factors in localization over this range of frequency.

V. DISCUSSION AND CONCLUSION.

Significance of Fig. 4.—Two obvious factors in localization are found in the differences in phase and intensity at the ears. The remarkable quantitative agreement between theory and experiment shown in Fig. 4

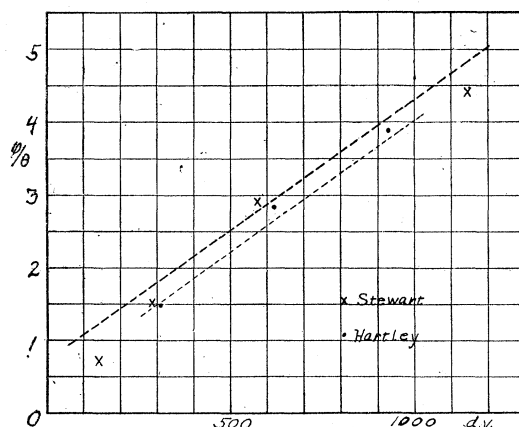


Fig. 4.

has the following significance: the angular displacement from the median plane produced by a given phase difference at the ears proves to be the very position for the source of sound that will, theoretically, produce the aforesaid phase difference at the ears. This quantitative agreement, although approximate, is highly satisfactory if appropriate allowance is made for the nature of the experiments. The conclusion must be that the phase difference is a factor of high importance in the frequency range considered.

The experiments of Bowlker² are in close agreement with Fig. 2. He

¹ Hartley, *PHYS. REV.*, Vol. XIII., June, 1919, p. 373.

² Bowlker, *loc. cit.*

found that a wave-length of 36 inches was the one giving a displaced image of 90° for a difference of 180° . This would be a frequency of about 380 d.v. Reference to our curve, Fig. 2, shows that the frequency in our experiments would be 352 d.v. for one observer and 440 d.v. for the other. Bowlker used organ pipes for the source and hearing tubes $2\frac{1}{4}$ inches in diameter. With such a narrow aperture the relative intensities in the two tubes, one to each ear, would be fairly independent of the directions of the axes, and thus he was dealing with practically equal intensities as in our experiments.

Inasmuch as in Part I. of this report, intensity was found not to be an important factor in the binaural location of pure tones, our conclusion as the high importance of phase, is given additional weight.

Extension of Limited Application of Experimental Curve.—The results as presented in Fig. 2, do not cover all values of displacement either side of the median plane, but strictly speaking only up to the values of displacement for which the phase difference is 180° . Does phase difference remain the most important factor for these higher frequencies, where, as we have shown there is more than one image? Since the multiple images are found both with the phaser and in the open in actual localization, the additional factor of intensity entering the latter case does not modify or alter the effect of phase and hence its importance. In other words, phase difference remains the most important factor in localization throughout the range of frequency considered and for displacements of 90° from the median plane. Moreover, computations from the theoretical values of Hartley and of the author already referred to show that the separation of the images for 1,024 d.v. is approximately that obtained in the open, viz., 90° .

The evidence in hand both experimental and theoretical seems to establish beyond reasonable doubt that localization in the horizontal¹ plane for pure tones of 100 to 1,200 d.v. depends almost entirely upon phase difference at the ears. But the above discussion refers to localization within the region 90° on either side of the median plane and in front only. This first approximation in the explanation of localization need not be considered as limited to the front region only, for the well known confusion between locations in the front and in the rear indicates that the discrimination between such positions symmetrical to the median plane, rests upon additional factors probably of secondary magnitude. Indeed, many observers find that the difference of phase at the ears causes them

¹ All of our experiments refer to the horizontal plane, but a note should be made of the fact that in the experiments with the phaser and the forks the rotation was usually not strictly in a horizontal plane but could be made so by a slight forward tilt of the head.

to locate the source in the rear rather than in front. For the present, then, we are to assume that the most important factor in the frontal region is also the most important factor in the localization in the rear, leaving for future consideration the factors that distinguish between the positions symmetrical with the line connecting the ears. It is to be admitted freely, then, that the present paper does not offer a complete explanation of localization, but rather proves that the difference of phase phenomenon is the most important single factor in sound localization of a pure tone in a horizontal plane.

Complexity of Factors in Actual Localization.—One might decide that, since the only physical factors in a pure tone of given frequency are phase and intensity, and since we have all but eliminated intensity as a factor in localization, the only important factor left is that of phase difference. But this cannot be true in the sense that the phase difference is that produced merely by a single source and diffraction about the head as a sphere. For there are always present reflecting surfaces which are extensive enough to produce images. This is especially true of frequencies of the order of 1,000, having a wave-length of 34 cm. Although the effect at the opening of the external meatus is still expressible in phase and intensity, yet, in contrast to the case of a simple source, we have, in general, the equivalent of several sources, with most of them on the same side of the median plane as the source. Now while it has not been demonstrated that the two ears have a "resolving power," yet there would result from reflections an apparently diffused source of sound instead of the original source only. Consequently the observer could distinguish between a location on the right and left side of the median plane. Thus, assuming that phase difference is the most important factor in localization, it by no means follows that the case is as simple or needs to be as simple as that of a source and a rigid sphere with the two ears located diametrically thereon. The complexity of conditions involving reflection gives the single factor, phase difference, a greater opportunity to secure accurate location than the simple theoretical case exist.

That reflecting surfaces are important was readily shown by the effect of rotating the head when attempting to locate the source in the open air experiments described. A slight rotation would sometimes shift the apparent location by as much as 20°. Doubtless there are other factors which enter into the localization of a pure tone. There are at least two additional factors in the case of a complex tone; they are the difference in quality at the two ears produced by diffraction, and the difference in quality of the sound arriving, depending upon the location of the source.

Intensity a Factor.—If the frequency exceeds the limit of phase difference sensitivity, our chief factor, phase difference, ceases to exist and we are dependent upon intensity effects, including not only the intensities produced at the ears by the source, but also by the mirror images. As elsewhere recorded, the writer has found that the effect of intensity-ratio as embodied in the formula presented earlier in Part I. of this article, becomes seriously modified in a limited region of frequency. With some individuals, for this frequency band, there is no displacement law as above given. For others, there ceases to be complete fusion in this region, though it is possible to locate a fused tone as well as to recognize another image at the same time. But it is not the purpose of the present article to cover the region above 1,200 d.v. as this will be left for further experimentation.

The Ear as a Physical Instrument.—Physicists are interested in the ear as a physical instrument and one might well inquire as to whether or not the experimental curve here shown can indicate any mechanical requirement of the ear. If the curve had been a straight line passing through the origin, it might then be said that, since equal time intervals correspond to phase differences that are proportional to frequencies, and since φ/θ would then be proportional to frequency, therefore equal values of θ would be obtained by equal time intervals. But the curve, if linear, does not pass through the origin and equal time intervals correspond approximately to equal angular displacements only at the higher frequencies. Hence we cannot say the angular displacement is caused simply by a time interval. It is more reasonable to assume that the phenomenon we are discussing is not one of the ear regarded merely as a mechanical instrument, but of the entire phenomenon of hearing.

Phase Difference Phenomenon Independent of Bone Conduction.—In binaural beats with a frequency of from 40 to 400 there is a complete rotation around and through the head of the fused sound as φ changes from 0° to 360° . This has been fully discussed and explanations offered,¹ but one writer² has interpreted this explanation as requiring cross-conduction for the phenomenon of localization of sound. This is incorrect and an additional word is necessary. As the fused sound rotates from $\theta = -90^\circ$, through $\theta = 0$, to $\theta = 90^\circ$, the location of the image is external to the head just as in the usual localization of a source of sound. But during much of the other half of the cycle the image is within the head and the experience is wholly different than in ordinary localization. The writer did use cross-conduction to explain this internal half of the

¹ Stewart, PHYS. REV., Vol. IX., 1917, p. 514.

² Hartley, loc. cit.

cycle but in no wise does this mean that cross-conduction enters into the act of localization of sound. In fact, as already indicated, we are interested only in the portion of the rotation $\theta = -90^\circ$ to $\theta = +90^\circ$, anticipating that the chief factor in localization in this region will prove to be the chief factor in general.

Perception of Phase.—As has been mentioned in various articles referring to perception of phase, many psychologists assert that the response of a sensory nerve is independent of the nature of the stimulus and if this is true, phase relations could not be found in the nervous impulses. Thus direct perception of phase could not exist. It would seem that the simplest interpretation of our experiments is the direct perception of phase. An effort has been made by some to explain the apparent perception of phase by the indirect effect of intensity arising from bone conduction between the ears. It would seem that the intensity effect is too small to warrant such an explanation. But what appears to be a crucial experimental test has been found. As recorded in Part I., observers *H* and *S* could not get any intensity effect whatever at, 1024 d.v., yet the same observers responded to phase difference at this frequency without any hesitancy. Thus, the effect of phase difference cannot be explained by any indirect intensity effect. It would thus seem necessary to admit direct perception of phase, at least until a possible different interpretation of the effect of phase is secured.

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