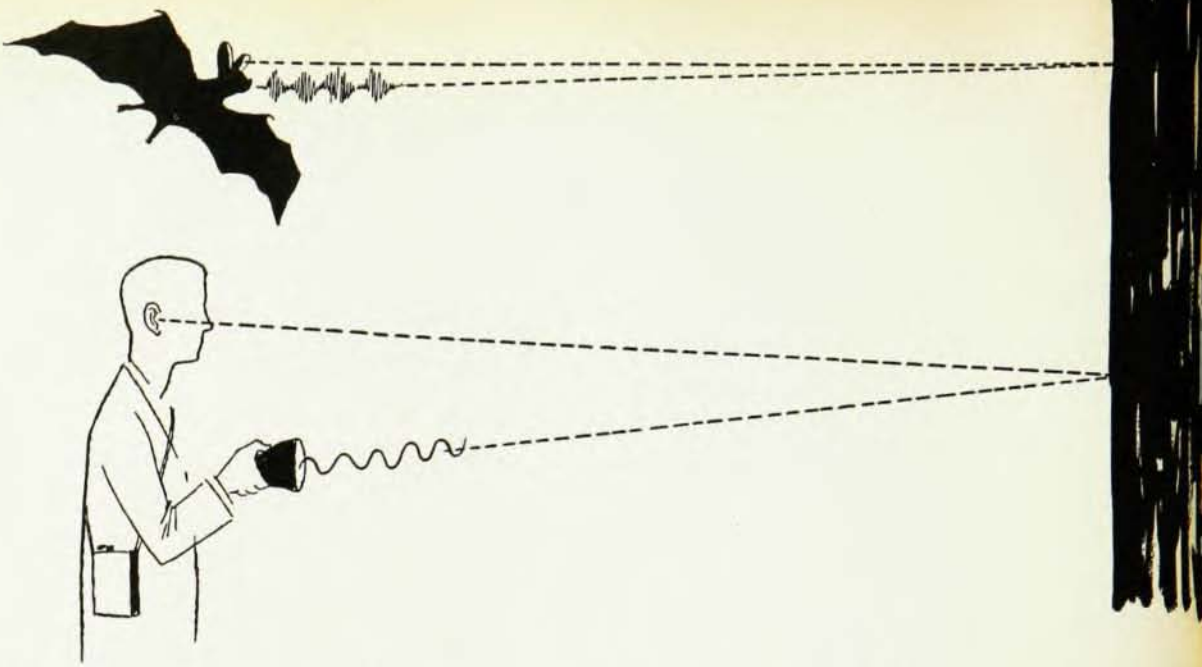


Flashsounds and Aural Construct

In the July issue of *Physics Today,* Franklin S. Cooper presented an excellent survey of guidance devices for the blind. The present article is intended less as a sequel than as a supplement to discuss a basic approach to the problem which led to one of the generic devices mentioned by Dr. Cooper.

With few exceptions the devices discussed in the previous article were probes or "conceptual descendants of the cane"—although their immediate antecedents were rather radar and sonar, since these devices are essentially but echo-ranging mechanisms. The cane is the simplest probe, and furthermore it is also a bumper. As a probe it is unexcelled for short distances if the rhythmic sweep technique taught at Valley Forge Army Hospital by R. E. Hoover is employed (Foot Travel at Valley Forge, *Outlook for the Blind,* November 1946). If we reject the cane as a guidance device it is only because its operating range is so limited.

For longer distances the more sophisticated probes employing modulated light or ultrasonics and artificial methods for signal presentation are successful as anti-collision aids or "obstacle detectors". It is debatable, however, whether these probes could be incorporated into successful orientation aids or guidance devices. In their present form they furnish point-by-point information, but would most likely require auxiliary equipment for automatic scanning, and integration, to facilitate their use as guidance devices. Even were one to ignore the resulting prohibitive increase in size, weight, and cost, the crux of the matter, as Dr. Cooper stressed, would still be whether such information could be assimilated by the user to obtain a mental construct of his environment.

An Alternative Device

An alternative guidance device is one which supplies information from a relatively large area in a convenient and familiar form for integration by the blind person's remaining sensory organs, allowing him to capitalize on his backlog of past experiences.

It is known that the blind who travel without auxiliary aids rely to a large extent on ambient or self-produced noise. It is also known that certain of the blind can localize and recognize a wide variety of obstacles by means of reflected sound, as a result of greater attention and increased use of the hearing mechanism. It has also been shown by Griffin and Galambos that the obstacle avoidance ability of bats is due primarily to audition and a self-contained ultrasonic source. These considerations clearly delineate a method of attack in designing a guidance device which would make efficient use of existing senses without impairing their original functions, obviate extensive re-education of the blind, and minimize the use of auxiliary equipment. Some steps have been taken in this direction.

The flashsound, a sort of acoustical flashlight, can help the blind person to "see" by ear. In this, the second article on guidance devices for the blind to appear in *Physics Today*, the approach used by one research group active in the field is described.

By Victor Twersky

or the Blind

A series of studies on the learning time required for blindfolded subjects to perceive obstacles with the aid of either incidental sound or with auxiliary sound sources was undertaken in 1944 by William Etkin, Director of the Guidance Device Project, City College of New York. This led to the development in 1946 of the "flashsound", an acoustic analogue of the flashlight, since it is essentially but a shielded audible sound source to irradiate a portion of the environment.

Situation Models

As was mentioned by Dr. Cooper, the problems encountered by the blind in foot travel are mainly problems of communication: the blind cannot directly acquire (and therefore do not respond to) a great deal of the information of their environment which others obtain through sight.

Before going on to discuss a device which attempts to supply some of this information in the form of audible stimuli, we must recognize the superiority of vision compared to audition as an information channel. Granting this, however, does not preclude the usefulness of such a device since the matter hinges on more than the signal-carrying capacity, redundancy, or storage facilities, of the particular channel. We are not concerned with finding a substitute for vision or attempting to convert the ear to an eye, but rather with the thesis that the normal hearing mechanism can make use of reflected sounds as additional clues to acquire a mental construct of an environment.

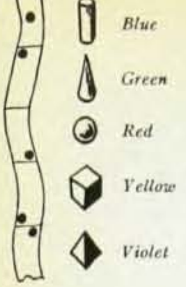
The essential factors involved in foot travel are the directly acquirable sensory stimuli, the frame of reference, and the conditioned responses of the individual. Their influence can be investigated analytically for certain simple models. We will briefly sketch such a procedure which, aside from any heuristic purpose, will serve to familiarize the reader with some of the situations encountered in foot travel.

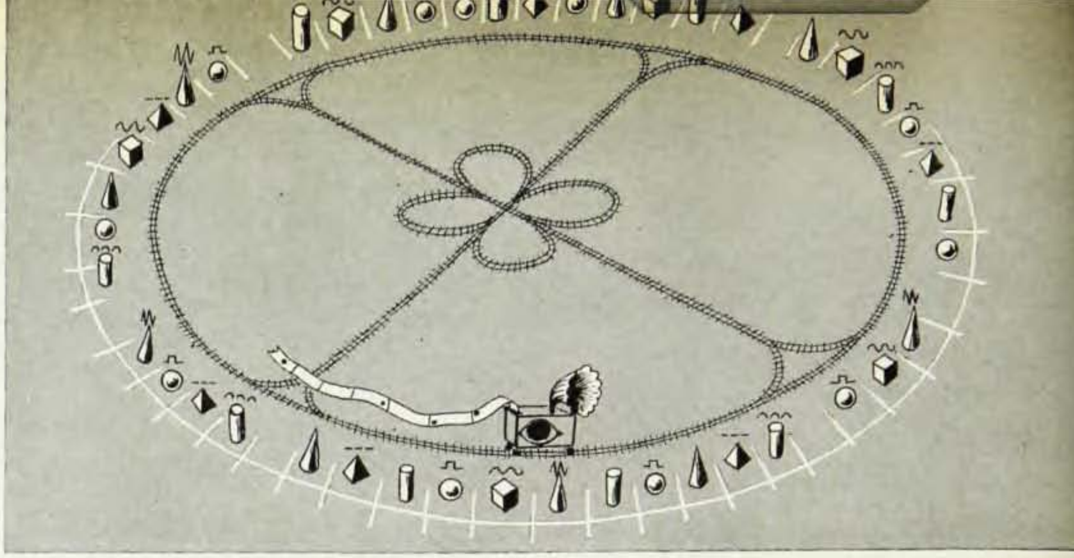
We can devise a mobile mechanism equipped with complementary and overlapping sensory channels to locate and recognize various types of objects, characterized by one or more equivalent sensory stimuli in a series of environments; the position and type of each object in a particular environment at a particular time being defined as the total information. The mechanism could be equipped to obtain this information as its construct, retain it as its memory, and to register recognition of a particular space-time environment. It could also be provided with data as to the statistical characteristics of the distribution. We could then investigate the effect of the loss of one of its sensory channels, say its sight, on its constructs.

If we assume suitable stochastic processes to govern the distributions of the objects and their stimuli, we may employ the techniques of the information theory of Wiener and Shannon to predict the directly obtained construct. Hence, even if the mechanism had no memory, it could be equipped to take advantage of the probability basis for the distributions and to utilize the stimuli to which it responds to obtain a more complete construct of an environment. This is crudely analogous to foot travel in unfamiliar territory, since the blind encounter certain obstacles whose positions in space and time seem to be governed by just such processes. As Merrit Clark, one of the blind who travel without auxiliary aids, pointed out in the final report on guidance devices of Haskins Laboratories: "The general pattern of a sidewalk is known—such things as lamp posts, ash cans, fire hydrants, mail boxes and the like are so laid out that one can be expecting them and therefore can avoid them."

The factor of time was considered by Mr. Clark

Victor Twersky, a theoretical physicist with the Mathematics Research Group, Washington Square College of New York University, is at present working on non-specular reflection and multiple scattering of acoustic and electromagnetic waves. His interest in the special problems of the blind is of long standing and he is now acting as technical adviser for the Guidance Device Project at the City College of New York.





Simple situation model. Punched tape corresponding to particular section is engine's "construct", and "memory", if retained. With both senses operating, the engine has a "unitary construct" since each object gives either a characteristic color or sound, or both. When "blind", however, its construct depends on the available audible signal, memory, and prior knowledge of distribution of objects. This situation is analogous to a noisy, discrete source.

as one of the most significant in governing his traveling ability: "I think the primary [factor] is the time of day. Mid-day traveling is far more hazardous than that of evening. There are many obstacles that one encounters, such as things set out on the sidewalks, heavier traffic, more people and the like. Another major factor is weather conditions. On days that are windy, rainy or snowy, one's ability to hear where he or she is going is definitely cut down."

The situation with a complete memory is somewhat akin to the problem of reconstructing a mutilated version of one of several known passages of literature. Quite often the presence or position of a single word or letter suffices to identify the passage, which can then be re-created from memory. Similar situations exist in foot travel, when for example a single clue and memory enables one to recognize a relatively large fragment of the environment. We again quote Mr. Clark: "If a building is being looked for that is more or less familiar to me, it might be recognized by an awning, a grating near the entrance, a certain lamp post or other such identifying land marks which can be heard."

The more general case would involve but a partial memory and some knowledge of the basis for the distribution of objects, or for brevity, the frame of reference. To introduce the question of rate of travel and conditioned responses we could differentiate the time for recognition required by the several sensory channels and equip the mechanism with two speeds: the slower for exploratory purposes and the faster for traveling through an environment, once it was positively identified by means of the first few objects encountered and frame of reference. Such a mechanism learns to proceed more rapidly by acquiring a conditioned response effected by the first few stimuli which serve to identify the particular environment after initial exposure.

Various models of differing degrees of complexity can be readily constructed from electronic circuits or even a toy electric train set. It is even conceivable that an ambulatory mechanism could be equipped with electromagnetic and acoustic sources to irradiate its environment, and with sensory channels to analyze and map the reflected radiation fields of various objects. The mechanism could also determine the size and shape of the obstacles on direct contact, and correlate the various maps to obtain its construct and store them as its memory. A mechanism of this type could be instilled with the purpose of obtaining a construct as rapidly as possible, and provided with pathways for future conditioned responses to facilitate this purpose. Such models could be investigated for impairment of purpose resulting from loss of sight and might be used to structure certain problems related to foot travel and guidance devices on a physical basis amenable to mathematical analysis.

Environment and the Individual

This discussion of models could of course be carried further, and within certain limits extended to the individual and his environment. The sensory organs and their connections to the cortex may be considered as mechanisms for receiving and transmitting certain spatial and temporal patterns of stimuli to the cortical association areas, where recognition and integration are effected and the impressions stored. There are also indications that to a certain extent correlated memories for the various sensory channels exist and that tactual-kinesthetic perceptions of shape and size, and even verbal descriptions or other aural cues, can give rise to spatial perceptions of the visual form, provided that a visual memory exists—and this is essentially all we would require to carry over any inferences drawn from the simple models. If we attempted to go still further, however, we would find that we do not possess the knowledge (pertinent to the individual and his environment) that would be required for any quantitative calculations. Whereas for the models we could completely specify the limitations of the various sensory channels, the characteristics of the sensory stimuli, the role of the frame of reference, and the abilities of the mechanisms to acquire conditioned responses, these are precisely the factors which must be investigated empirically for the case of the complex animal before the problem can be analyzed. We then conclude that the significance of these factors can only be resolved by fundamental psychophysiological research, coupled with physiotechnical efforts to facilitate the investigation.

Since we wish to make optimal use of the hearing mechanism, we should first examine the extent of the aural construct, as obtained either with ambient sound or with the aid of auxiliary sound sources. A certain amount of related work with ambient sound has been done by Supa, Cotzin, and Dallenbach (Facial Vision. The Perception of Obstacles by the Blind, *American Journal of Psychology,* 1944) who showed that aural, if not audible, stimulation was a necessary and sufficient condition for perceiving obstacles either by the blind or the blindfolded, and also that sighted subjects readily acquired the ability to perceive obstacles. Some interesting work was done at military rehabilitation centers with blinded veterans by initiating their training with unaided foot travel. A detailed discussion has been presented by Jacob Twersky (The American War-Blind as Aided by the Federal Government, Thesis, NYU, 1947; American Foundation for the Blind, 1948). It is regrettable that more positive steps were not taken to encourage this practice and that performance data was not retained. There are enough blind who travel without auxiliary aid to indicate that first effort to acquire the skills for foot travel should be in this direction, and that auxiliary aids (if used at all) should be for those situations where ambient stimuli are insufficient. Needless to say, this discussion precludes an additional handicap such as deafness.

Unfortunately, little has been done in regard to the maximal construct obtained with the aid of auxiliary sound sources. Such an investigation would yield the optimal characteristics for the auxiliary source, and therefore essentially reduce the problem of obstacle detectors to the developmental one of embodying these characteristics into a portable model meeting certain technical requirements. This obstacle detector could then be modified on the basis of field tests to enhance its value as a guidance device. It is in this respect that the development of an audible device, such as the flashsound, differs from that of other proposed guidance devices. This is because it is the only generic device (with the possible exception of the cane) for which the external information need not be modified for presentation to a sensory organ.

An Auxiliary Sound Source

An investigation of this sort was neither undertaken nor contemplated by the City College group, which possessed neither the personnel nor the facilities for a protracted series of studies.

The purpose of the initial studies as undertaken by Arthur DiDea (Detection of Obstacles by Blindfolded Persons, *Biological Review,* CCNY, March 1947) were: "1. To study the characteristics of the learning process involved in the development of the ability to detect obstacles by sighted blindfolded subjects using incidental stimuli; 2. To determine the smallest dimensions of an obstacle which can be detected; 3. To find the maximum distance at which an obstacle of known dimensions can be detected; 4. To observe the individual variations of a group of twenty-five subjects in detecting an obstacle of known dimensions."

The aims of the second phase as undertaken by Hilda Laufer (The Detection of Obstacles with the Aid of Sound Directing Devices, *Bio. Rev.,* CCNY, March 1947) were to: "1. Compare the effectiveness of sound radiating in all directions with beamed sound in the detection of obstacles by blindfolded subjects; 2. Compare the effectiveness of sound sources over incidental sounds made in walking; 3. Establish the limitations of the particular sources used as regards frequency and wave form; 4. Determine the rate of learning involved in the use of the sources as an aid in obstacle detection; 5. Estimate the best way of testing apparatus designed with the above use in mind."

These tests were completed in 1945, and although much of the data was not considered particularly significant because of the small number of test subjects and poor indoor operating conditions, certain valid conclusions could be drawn. These studies showed, for example, that a shielded or collimated beam of sound was superior to both nondirectional or incidental sound and also required much less learning time for purposes of obstacle detection and distance judgment. They also showed that pulses of sound were pleasanter to work with and yielded better localization cues than pure tones, but that as far as actual performance was concerned, equally good results were obtained with either low frequency notes of 250-cps or high frequency notes of 15,000-cps, although the latter required greater concentration. (The poorest results were obtained with 1000 and 4000-cps notes.) It was also indicated that the collimator was most effective when it completely shielded the subject from the actual sound source.

On the basis of these findings, it was decided to develop a portable obstacle detector, the work on the device to be correlated with performance tests on outdoor obstacle courses. The critical problem was considered to be that of developing a small shield or horn to isolate the source from the user and for this reason high frequency continuous tones, rather than pulses, were employed, since the latter made it difficult to either estimate or perceive the effect of even relatively large variations of horn shape or size. In late 1946 a small fairly efficient model, about the size and shape of a flashlight, —comprising a high frequency audio-oscillator, a head phone transducer, and a paraboloidal plastic reflector (4″ in axial length and mouth diameter and 1″ focal plane diameter)—was developed. Details of this phase of the work and of later innovations will be found in articles by the writer (An Obstacle Detecting Device for the Blind, *Bio. Rev.*, CCNY, March 1947; Sound Flashlight for the Blind, *Electronics*, p. 156, November 1948; and Obstacle Detector versus Guidance Device, *Bio. Rev.*, CCNY, March 1949). In the present model a one-tube signal generator is carried on the chest and is equipped with interdependent frequency and gain controls, a cathode toggle switch, and a 3″ extension cord ending in a female plug. The papier-mâché horn (whose inner surface is the above paraboloidal reflector) varies in thickness from 1/4″ at the mouth rim to 1″ at the rear, and has a male plug and a plate micro-switch imbedded in its base. The transducer employed is a miniature crystal element, the Brush "Sound Cell".

The Flashsound in Action

The main developmental problem is still that of shielding the user from the source. The sound transmitted through the sides and back of the horn has been almost completely eliminated, but that reaching the user by leaking around the rim of the horn from the side lobes is troublesome, particularly at high gain. When used on outdoor performance tests the gain is adjusted so that the sound produced when there is no obstacle in the path of the beam is barely audible above ambient noise. (One soon learns to differentiate between the "background" sound of the device and the sounds reflected from obstacles, but its presence is detrimental for perception of detail.) The frequency is then adjusted for individual response and intermittently touched up to prevent aural fatigue. The sound is also cut off frequently to obviate the effects of prolonged exposure.

Obstacles can readily be detected and avoided even by those using the device for the first time, if they are told of its analogy to the flashlight and instructed to listen for marked changes in the background sound. It is interesting to note that the subjective reactions of some initial users employing the device indoors are in some respects similar to those described by many of the blind for obstacle perception with incidental stimuli. Both are quite conscious of the presence of the obstacle as they approach it, and both describe their sensations in terms of shadows or pressures across the eyes or other parts of the face and ears; but whereas few of the blind indicate that they are aware of hearing anything, except for some cases where finger snapping or whistling is employed as an aid, the initial users of the device are quite conscious of "being enveloped in a sound field which draws the obstacles" to them. The analogy is clear: the ambient sound field, which aids in perceiving obstacles, is also the background noise against which the stimuli from the obstacles must be differentiated. With continued use of the device binaural localization becomes effective and yields additional clues for distance judgment. It has also been found possible to avoid obstacles either by positioning the horn on the chest or by holding it vertically downward to enclose the user in a spray of sound.

As an obstacle is approached without scanning, the reflected sound becomes louder and its pitch alters, usually increasing. The increase in pitch, observed for all but highly absorbent surfaces, is on the whole due to the increase of pitch with increasing intensity for this frequency region. Binaural localization cues are obtained for all obstacles, but are weakest for smooth flat planes such as large store windows. These are perceived, however, by changes in the sound and the user's knowledge of the position of the horn. For such surfaces the marked increase in pitch while approaching might also in part be due to the Doppler effect for an observer and source approaching each other. (A speed of about 3 ft/sec yields an apparent frequency change of about 50-cps at 10-kcps.) There are other audible effects characteristic of such surfaces, but these have as yet not been completely correlated with the known physical behavior of such specular reflectors. Scanning, however, obviates these considerations, since edges or mouldings yield pronounced "edge effects" (resulting physically from scattering or diffraction phenomena) which are perceived as sounds of different quality originating at the edges themselves. These effects, therefore, yield additional clues for distance judgment as well as for estimating the dimensions and recognizing the obstacle.

Irregularly shaped obstacles, or those with non-specular surfaces (hedges, fences, tree trunks, rough or broken walls, etc.), yield definite localization cues as well as additional clues which make it possible to differentiate various surfaces. The physical bases for these effects are on the whole different from those involved in the optical range of phenomena, which enable us to perceive the roughness or texture of a surface by means of reflected light. For the optical case, these are most likely due to statistical phenomena which are the end result of many specular or geometrical reflections occurring at the surfaces of irregularities large compared to the wavelength. The acoustical bases for the audible non-specular effects, however, are on the whole "true" scattering or diffraction phenomena arising with irregularities small or on the same order of magnitude as the wavelength (2–4 cm).

Audible effects due to selective absorption might also prove significant as recognition clues with a device employing white sound, or some other wide-band complex sound. Simultaneous effects, arising from selective non-specular reflection and from selective absorption, might be sufficiently pronounced to allow for the recognition of a wide variety of surfaces. Further discussion and some attempts at analysis will be found in papers by the writer (On the Theory of the Non-Specular Reflection of Sound, Thesis, NYU, 1949; *Jour. Acoust. Soc. Amer.*, 22: 539, Sept. 1950, and On the Scattered Reflection of Scalar Waves from Absorbent Surfaces, Math. Res. Grp., NYU, 1950).

A manual sweep or scan is employed primarily to obtain additional information for orientation purposes. This helps in maintaining a fixed distance from a wall, hedge, or fence; in locating a particular object or a sequence of objects (such as trees, lamp posts, fire hydrants, etc.) and in judging one's distance from a particular obstacle or estimating its dimensions. It is thus possible for the user to enter a familiar environment consisting of a building or hedge line and certain permanent obstacles and certain temporary obstacles (such as ash cans, boxes or people, positioned without the subject's knowledge) and successfully avoid all obstacles, occasionally recognizing them, and also successfully maintain his orientation in the environment by obtaining clues from the permanent obstacles.

It has occasionally also been found possible to detect depressions by employing the sound of the ground (which is heard only for relatively small angles with the vertical) for comparison purposes: this is facilitated by audible edge effects for depressions with pronounced edges. Attempts to evolve an all purpose sweep technique commensurate with a normal rate of walking have thus far proved unsuccessful, although fairly promising results were obtained with an alternating horizontal-vertical cross sweep.

Masking has not proved to be the problem anticipated and is only noticed when transient effects, such as rapidly moving automobiles, sharply alter the ambient noise level. On the other hand, the sound is usually ignored by bystanders or passersby, the user only occasionally being berated for employing a flashlight in the daytime.

We acknowledge the criticism that the above results were obtained with blindfolded sighted subjects rather than with the blind whose spatial concepts, depending on the age at loss of sight, may be quite different. Sighted subjects are preferable for preliminary testing since blind subjects usually find such devices either inferior or distracting to their accustomed means of orientation. The experienced blind are also far too clever in making use of incidental and non-audible stimuli such as smells, air currents, and irregularities in the terrain to yield a fair evaluation of any device on a protracted series of tests. Needless to say, the final tests can only be performed with the blind.

Other Flashsounds

The City College group, which worked on a limited budget, was aided by many individuals and organizations. In particular, Clifford M. Witcher (research physicist at Haskins, later Co-Director of Technical Research of the American Foundation for the Blind, and now Director of the Physics Department, Roosevelt College, Illinois) was in close touch with the group and made many practical contributions to its activities, as did Charles G. Ritter,

Supervisor of Technical Research of the Foundation. (The three of us, and Prof. Etkin and Dr. J. Twersky, also met frequently for several years as members of the Technical Research Committee of the Foundation to discuss the various problems that arose.) Haskins Laboratories made available to us some of their equipment and facilities; the Foundation furnished us with headphone transducers and some of the crystals sent by St. Dunstan's; and the National Carbon Company provided us with batteries.

The audible sound device developed by Dr. Witcher (Obstacle Detector for the Blind, *Radio News-Eng. Ed.*, Oct. 1947) and that of St. Dunstan's are similar in principle to the City College device and differ essentially only in that they produce high frequency pulses of sound rather than continuous tones. The generators of both these devices are remarkable for their power economy and compactness and the sounds employed yield pronounced localization cues. It is agreed, however, that the optimal sound can only be determined by a protracted series of performance tests employing a wide variety of waveforms.

It can be seen that an obstacle detector of this type has a relatively high potential value as a guidance device. These devices are not essentially probes (although "probe action" facilitates their use) but rather supply information from a relatively large area. For midrange frequencies of about 12kcps, the beam width at the half-power points is about 16–20 degrees, so that the most intense part of the radiation covers a circle at least 3 feet in diameter at a distance of 10 feet from the source. Hence with a minimum of manual scanning the user can create and perhaps learn to interpret the space-time pattern of a portion of his environment.

The difficulty of re-educating a subject to respond to an entirely new set of stimuli, particularly if the stimuli are novel or their presentation is novel, is recognized to be one of the most significant factors in all sensory prostheses. Hence the fact that with these devices the information is presented in a convenient and familiar form is a factor that cannot be stressed too greatly. Another attractive feature of these devices is their small size, low weight and low cost (less than $5). Since the devices are simply shielded sound sources, there is the further possibility that the signal generator and transducer assembly may be replaced by a simpler mechanical component (such as a "finger snapper" or "friction whistle") and consequently still further reduce these factors as well as practically eliminate all maintenance costs.

Preliminary comparative trials with these devices and ultrasonic probes favored the latter at Haskins and the former at St. Dunstan's, but yielded no conclusive results. No formal field tests with the City College device have as yet been undertaken, although a model on loan to the Foundation was exhibited at a conference of workers for the blind at Michigan State Normal College by Mr. Ritter, who, on the basis of observations of blind users, concluded that its advantages were twofold and that aside from its use as a direct aid to the blind, it might also serve as a training aid to accustom the newly blinded to the use of sound cues.

The limitations of such devices have been indicated. An auxiliary sound source is not being offered as a panacea for the loss of sight or even as a solution to all the problems encountered in foot travel. It will obviously not aid in the detection of such rapidly moving obstacles as automobiles, and it is uncertain whether it will be of much use indoors or where there is an unusually high ambient noise level. In leaving the ears unobstructed, however, and in presenting no additional demands on the other senses, it does not interfere with the user; so that in the situations where it is of no aid it will at least not hinder him in making full use of existing senses and abilities to avoid mishaps.

Because of the various considerations of this article, the writer and his associates believe that the flashsound (or the genus of audible quasi-directional sound-producing devices) has the highest potential value as a practical guidance device for the blind.

Since this article was written, it has been pointed out that a great deal of pertinent work has been done by Donald R. Griffin from 1943 to the present with a simpler device consisting only of a paraboloidal brass reflector and a dented piece of steel (as in a finger snapper) which produced brief audible high frequency pulses. Dr. Griffin who is noted for his work with bats and "echolocation", was a consultant for the development of rehabilitation and training procedures for blinded veterans and employed this opportunity for field testing the device.

Detailed work with a loudspeaker source and a microphone pickup leading to earphones used by subjects in an adjoining room has recently been publicized by Cotzin and Dallenbach (Facial Vision—The Role of Pitch and Loudness in the Perception of Obstacles by the Blind, *American Journal of Psychology*, 1950). Their results with a complex sound (thermal noise) and pure tones agree well with those of Dr. Laufer for all but the low frequencies.