ARCHIVES OF ACOUSTICS
4, 2, 89-108 (1979)

INVESTIGATIONS OF THE BARRIER PERCEPTION MECHANISMS OF THE BLIND

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Researches carried out in different countries have shown that the capability of recognizing and interpreting the information carried by audible sound waves plays a decisive role in the space orientation of the blind.

This article presents the results of: acoustical measurements of test acoustical signals used by the blind such as steps, the tapping of a walking stick and clapping; model investigations analyzing acoustical phenomena occurring in the environment of a conventional barrier such as a screen; open space experiments with a group of blind people in order to define a perception distance for the above barrier under different acoustical conditions; investigations carried out under laboratory conditions defining a relationship between the threshold distance of barrier perception and the area of the barrier surface when using a sonic aid (the so-called *sound torch*) and without such a device.

The results have shown that the threshold distance is proportional to the logarithm of the area of the barrier. Thus for the group of psycho-physical phenomena discussed we may use the Weber-Fechner law where the reaction is measured by the the distance of perception and is stimulated by sound waves reflected from the screen surface. The efficiency of perception is influenced by the difference between the acoustical absorption coefficients of the screen and the environment, and also depends on the individual capabilities of the subjects.

1. Introduction

The *space orientation* can be defined as the capability of moving and orientation in a physical environment whether inborn or acquired (for example through learning). It means the capability of localization, i.e. of limiting or confining an object such as a source of an acoustical signal, a barrier etc. to a particular place by means of stimuli acting on the senses through factors carrying particular information. When those factors are represented by acoustical waves, which indirectly cause auditory sensations, the range of such sensations for a given man in given circumstances is called his *auditory horizon*.

The capability of localization is very important in all those circumstances where it is difficult or impossible to use sight. Such circumstances occur mostly at night under conditions of poor lighting, for example during railway works, in and outside industrial halls and in mines when the lights go out. They may also occur during a foggy day, a fire which causes heavy smoke and a battlefield at night. The extreme case, very important from the cognitive point of view, is the case of the blind. An explanation of the perception of barriers and acoustical signal sources by means of hearing should facilitate the learning of space orientation by the blind. It will also permit definition of the basic criteria for designing efficient rehabilitation equipment, as well as criteria for building architectural interiors destined for use by the blind.

Until recently, a number of theories have been developed in order to try and explain the mechanisms of the perception of barriers by the blind. We can mention TRUSCHEL's acoustic theory, KUNZ's compression theory, the thermic theory of CROGIUS, VILLEY's auditory theory, the pressure theory of LAMARQUE as well as HELLER's theory of the complex reception of impressions. All these theories describe the phenomena of perception, interpreting the mechanisms of their creation from specific points of view.

Most of the research, however, has tended to presume that a decisive role is played by hearing (W. DOLAŃSKI [4] and W. S. SWIERŁOW [11]) or (e.g. M. GRZEGORZEWSKA [5]) by the "sense of barriers" which acts first of all by means of hearing and touching. Generally speaking, those mechanisms are based on the capability of reception and interpretation of the informational content of acoustical waves. They allow the receiver to assess the directivity of the acoustical field in a given area and, consequently, to obtain a more or less exact orientation depending on the images received and the capability of association.

The latest investigations, by M. KOTZIN, J. KOHLER, and others have shown that auditory impressions are necessary and sufficient for the perception of barriers. As an example, measurement results of the perception distance of a single barrier by a blind person are presented in Fig. 1. A cardboard disk of area $S_e = 1962\ \mathrm{cm}^2$ served as a barrier in this test. That disk was moved noiselessly in the direction of the subject from various sides. The dashed line shows the results of the experiment when using a "sound torch", and the continuous line — the results without such an aid. In subsequent and other current researches [2, 7, 8] we can observe a tendency to standardize the methods of measuring the threshold distance and the limits of perception of a barrier by children, people who were born blind, those who have recently become blind, and also blindfolded people. The experiments were performed in silence, under natural conditions and with a "sound torch" having specific acoustic characteristics.

2. Characteristics of natural acoustical signals

The sound of steps, the tapping of a stick and clapping are all sound signale which help the blind in space orientation (Fig. 2). They were registered in three rooms of different acoustic characteristics, namely: in a reverberation chamber,

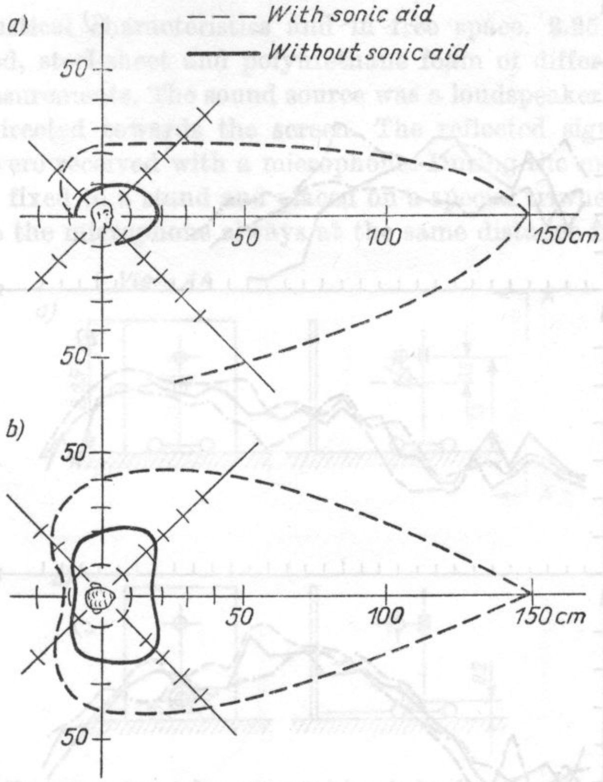

Fig. 1. Directivity characteristics of barrier perception according to J. Kohler [7]

in an average room and in an anechoic chamber. As is shown in the figure, the highest values of the particular groups of spectra occur in different frequency ranges and, therefore, each of the described signals will be optimally heard on a background noise of different acoustical characteristics.

On the basis of the described investigations and other studies it can be stated that at low frequencies the stick tapping spectra include information connected with the nature of the vibrations of stick-hand system, as well as with the construction, material and primarily the length of the stick, whereas at medium and high frequencies the information is rather more connected with the vibration of the ground caused by the tapping, i.e. with the elastic characteristics of the ground. It can be assumed, therefore, that the employment of a stick should be more useful when moving around an unknown territory, with unpredictable obstacles and irregularities in the ground due to changing structure and surface quality. In the case discussed the propagation of structure borne waves through the stick, received by hand as vibrations, can be treated as a parallel, additional and complementary information channel, especially when the informational content of aerial sound waves is masked by acoustic disturbances of the environment, as for example in a noisy street.

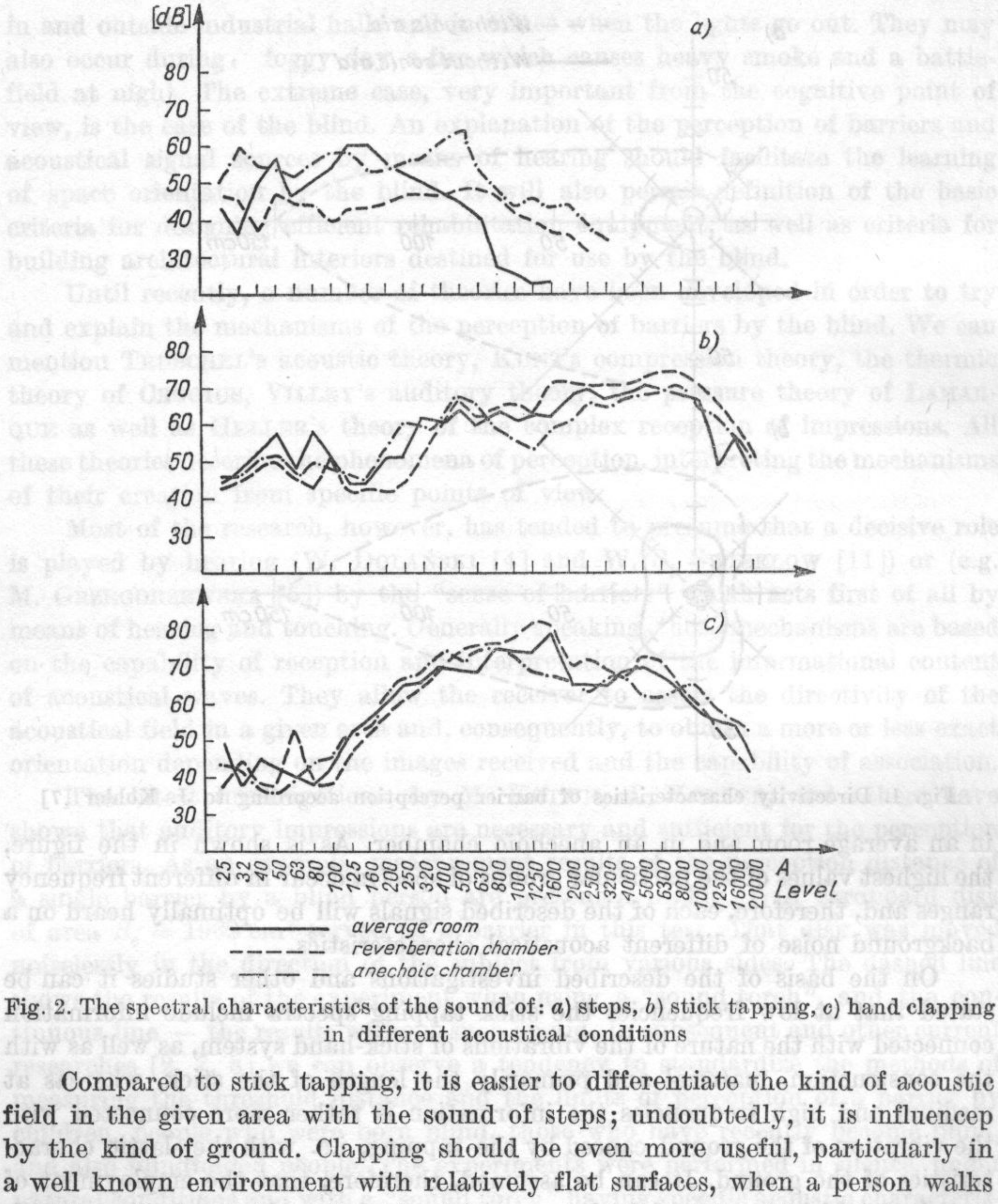

Fig. 2. The spectral characteristics of the sound of: *a*) steps, *b*) stick tapping, *c*) hand clapping in different acoustical conditions

Compared to stick tapping, it is easier to differentiate the kind of acoustic field in the given area with the sound of steps; undoubtedly, it is influencep by the kind of ground. Clapping should be even more useful, particularly in a well known environment with relatively flat surfaces, when a person walks quickly and when information about fragments of the route with special acoustical characteristics is valuable.

3. Results of model experiments

In order to test the theoretical hypotheses discussed in practice, a series of experimental model investigations were performed. They were carried out under different acoustical conditions, i.e. in a reverberation chamber, in a room of average acoustical characteristics and in free space. 2.25 m high screens made of plywood, steel-sheet and polyurethane foam of different widths were used for the measurements. The sound source was a loudspeaker which produced sound signals directed towards the screen. The reflected signals (or masked by the screen) were received with a microphone. During the measurements the microphone was fixed to a stand and placed on a special triwheeled car (Fig. 3) in order to have the microphone always at the same distance from the ground.

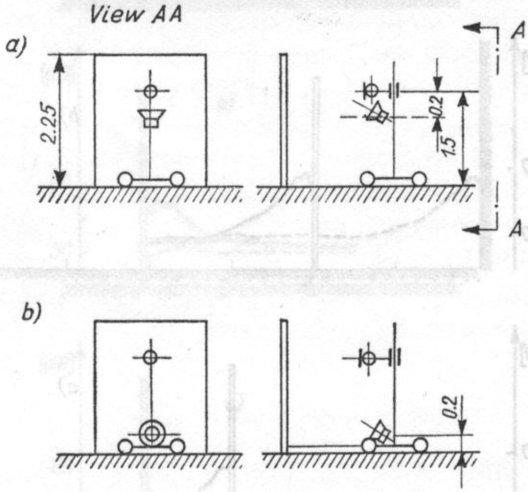

Fig. 3. Schematic diagrams of sound source position (a loudspeaker) in relation to the ears (a microphone) during man-barier model investigation referring to *a*) clapping (talking), *b*) sound of steps (stick tapping)

The distance was 1.5 m corresponding to the standard distance of the ear from the earth. Four basic positions of the loudspeaker, corresponding to every-day situations, were employed: firstly the loudspeaker was placed on the stand, a little below the microphone and during the measurements it was moved together with the microphone (Fig. 3a) – this corresponded to the situation of the person approaching the barrier clapping or speaking for example. In the second situation the loudspeaker and the microphone were placed on the same stand just above the earth (Fig. 3b), corresponding to the situation in which the source of information is represented by the steps of the person approaching the barrier or by stick tapping. Measurements were made to define the value of the acoustical pressure level as a function of the distance along an axis perpendicular to the given barrier. The curves in Fig. 4 show the changes of the level: in the reverberation chamber (Fig. 4a), in an interior with average acoustical characteristics (Fig. 4b), and in free space (Fig. 4c); in two situations – with the screen (continuous line) and after removing it (dashed line).

It can be observed that in an acoustical field that is almost perfectly diffused (anechoic chamber – Fig. 4a) the curves were flattest and the level

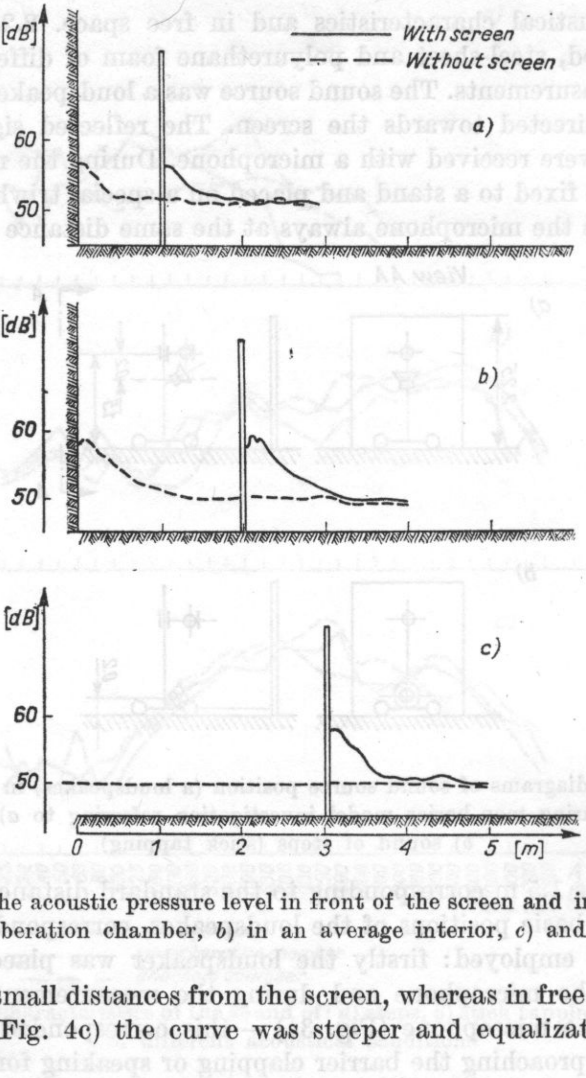

Fig. 4. Increase of the acoustic pressure level in front of the screen and in front of the wall, *a*) in the reverberation chamber, *b*) in an average interior, *c*) and in free space

was equalized at small distances from the screen, whereas in free field conditions (in free space — Fig. 4c) the curve was steeper and equalization occurred at longer distances.

In all cases, removal of the screen caused equalization of the acoustic pressure level in the previous location of the screen.

On the basis of the investigations described above and other tests we can differentiate two areas of increased acoustic pressure level in front of the barrier (shown in Fig. 4c). We can distinguish a narrower area whose width is close to a quarter of the wavelength of incident wave and a wider one embracing the region between the barrier and the place where equalization of the pressure of the waves occurs.

To illustrate the influence of the absorbing properties of the screen on the widths of the described areas, Fig. 5 shows the results of measurements made in a similar way to those described above when using three screens — one made

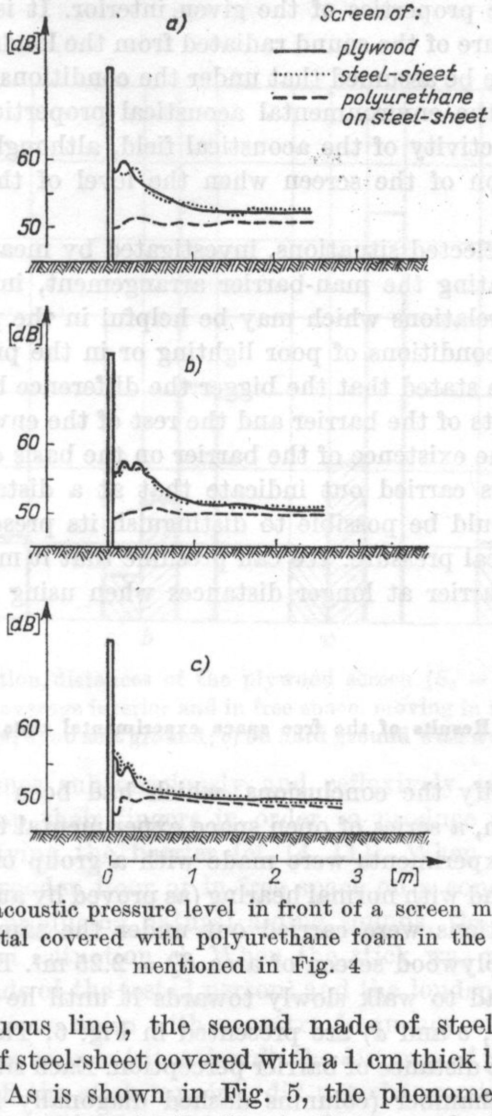

Fig. 5. Increase of the acoustic pressure level in front of a screen made of plywood of sheet metal and of sheet metal covered with polyurethane foam in the three situations *a*, *b*, *c* mentioned in Fig. 4

of plywood (continuous line), the second made of steel-sheet (dotted line) and the third made of steel-sheet covered with a 1 cm thick layer of polyurethane mats (dashed line). As is shown in Fig. 5, the phenomenon of the acoustic pressure increasing very close to the barrier is true only for the plywood and steel-sheet screens since it is barely noticeable when the screen is made of steel-sheet covered with polyurethane foam. It seems that the perception of a screen by means of the auditory organ should be influenced by the absorbing properties of the surface layer. For example, the presence of a wall "masked" by a curtain hanging on it, or a brick enclosure "masked" by grape leaves, might be more difficult to perceive.

It is worth-while to mention that, especially in a reverberant chamber but also in an average interior, the introduction of the screen covered with polyurethane mats (in comparison to the plywood and steel-sheet screens) changes the acoustic properties of the given interior. It is shown by decrease in the acoustic pressure of the sound radiated from the loudspeaker in the tested area. It can therefore be assumed that under the conditions discussed we should notice a change in the environmental acoustical properties and, particularly, a change in the directivity of the acoustical field, although it is more difficult to define the position of the screen when the level of the source of acoustic signals is the same.

The described selected situations, investigated by means of electroacoustic apparatus and imitating the man-barrier arrangement, indicate the existence of specific physical relations which may be helpful in the proper design of the environment under conditions of poor lighting or in the presence of the blind.

Hence, it can be stated that the bigger the difference between the acoustic absorption coefficients of the barrier and the rest of the environment, the easier it is to distinguish the existence of the barrier on the basis of acoustical stimuli.

The experiments carried out indicate that at a distance relatively close to the barrier it should be possible to distinguish its presence on the basis of an increased acoustical pressure. We can presume that it might also be possible to distinguish the barrier at longer distances when using aiding, intermittent sounds.

4. Results of the free space experimental tests

In order to verify the conclusions, which had been drawn on the basis of the model research, a series of open space experimental tests were performed in free space. The experiments were made with a group of people born blind, 20-30 years of age, and with normal hearing (as proved by audiometer tests).

These investigations were carried out under the same conditions as the model tests, with a plywood screen of area $S_e = 2.25$ m². Each of the subjects, facing the screen, had to walk slowly towards it until he or she perceived it. Four situations (*a*, *b*, *c* and *d*) are presented in Fig. 6. The columns in Fig. 6 represent the average distance of barrier perception. Each situation was repeated in a reverberation chamber (columns dashed diagonally left), in an average interior (columns dashed diagonally right) and in free space (columns not dashed). In the situation *a*, when the subject was wearing ear-protectors, the protectors considerably limited the inflow of sound information of the presence of the screen. The distance of perception was relatively small and was identical with the region of increased acoustic pressure around the barrier. Generally, most of the tested subjects put the ear-protectors on unwillingly, complaining that they did not feel well wearing them.

The distance of perception increased when the subjects were not wearing ear-protectors and when they were walking on a soft carpet or in free space along a grassy path (situation *b*). The individuals tested (not obeying the instruc-

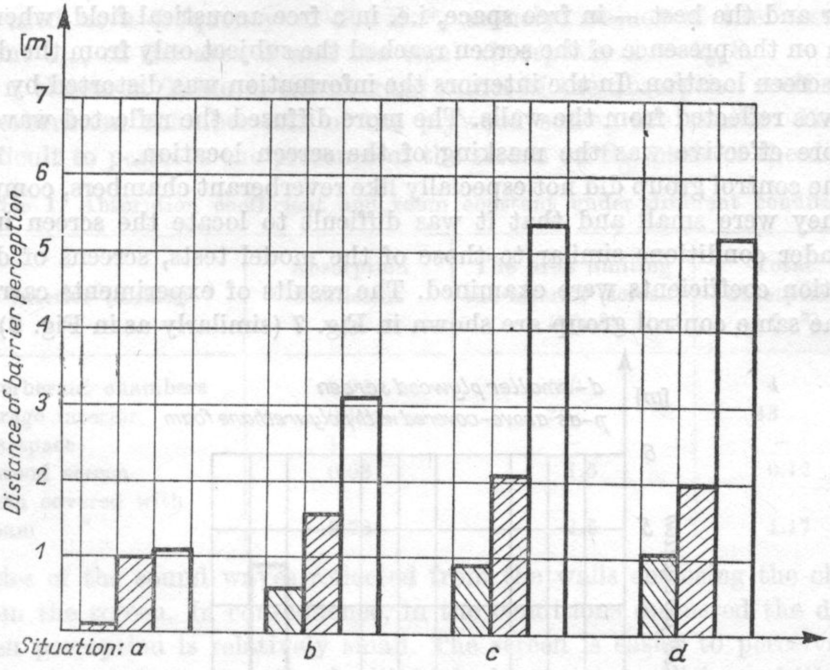

Fig. 6. Average perception distances of the plywood screen ($S_e = 2.25/\mathrm{cm}^2$) in the reverberation chamber in an average interior and in free space, moving in the following situations: *a*) wearing ear-protectors; *b*) on soft ground; *c*) on hard ground with a stick; *d*) with a sonic aid

tions given) sometimes subconsciously and reflexively tried to shuffle their feet, murmur or snap their fingers in order to produce sounds which would help them in perceiving the barrier (cf. [4, 11]). When the subjects moved on the concrete or wooden floor or in free space on a concrete path with help of a walking stick, producing natural aiding sounds, the perception distance was further increased (situation *c*). When the stick was replaced by a loudspeaker (held in hands of the tested person) and the loudspeaker intermittently emitted one-third octave noise with a centre frequency of 4000 Hz, thus producing artificial aiding sounds (situation *d*), the distance of perception, compared to that obtained with the stick tapping, did not change significantly. This was perhaps due to the fact that the subjects were not used to carry a cumbersome, heavy loudspeaker, although some of them said they did not mind it nor found it helpful whereas others were satisfied with being able to direct the beam of sound waves aside. Most of the persons, however, complained that the signal of a frequency of 4000 Hz was unpleasant. Signals were said to be pleasant when limited to 400-2500 Hz.

In the two last situations (*c* and *d*), when the distance of barrier perception significantly increased, the effect was achieved by means of the sonic aid.

In each of the described situations the worst screen perception was observed in the reverberation chamber, better results were obtained in the average interior and the best — in free space, i.e. in a free acoustical field, where information on the presence of the screen reached the subject only from the direction of the screen location. In the interiors the information was distorted by acoustical waves reflected from the walls. The more diffused the reflected waves were, the more effective was the masking of the screen location.

The control group did not especially like reverberant chambers, complaining that they were small and that it was difficult to locate the screen in them.

Under conditions similar to those of the model tests, screens of different absorption coefficients were examined. The results of experiments carried out with the same control group are shown in Fig. 7 (similarly as in Fig. 6). Every subject used a walking stick and was moving on a hard surface towards:

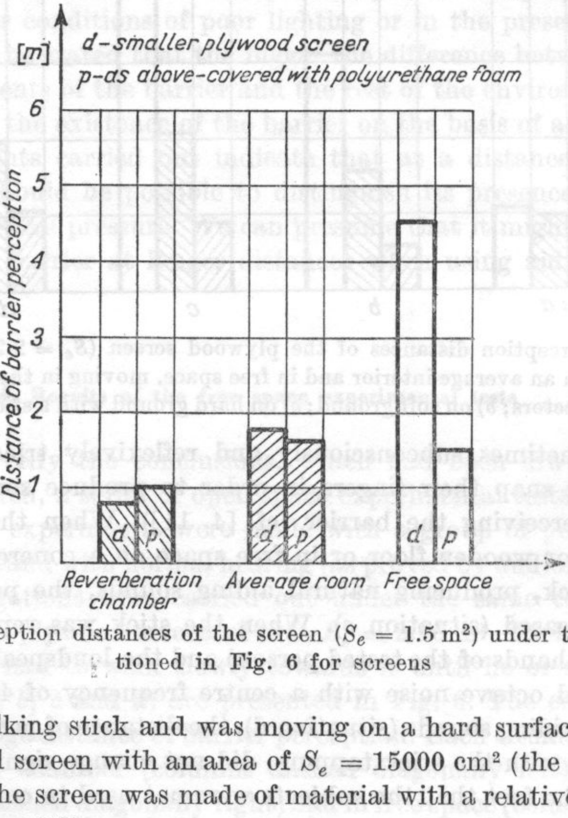

Fig. 7. Average perception distances of the screen ($S_e = 1.5\,\mathrm{m}^2$) under the conditions mentioned in Fig. 6 for screens

(a) A plywood screen with an area of $S_e = 15000\ \mathrm{cm}^2$ (the columns denoted by the letter *d*). The screen was made of material with a relatively small absorption coefficient ($\alpha < 0.2$).

(b) The same plywood screen covered with two layers of polyurethane foam (columns denoted by the letter *p*). Thus the screen had relatively big absorption ($\alpha > 0.4$). As is shown in Fig. 7, the distance of perception of the screen covered with foam is a little larger in the reverberation chamber, a little smaller in the average interior and significantly smaller in free space, compared to the distances for the uncovered screen.

To explain the described results we can compare the average values for the three characteristic interiors where the measurements were made and for the screens used at a frequency of 500 Hz*, namely: values of the absorption coefficient a_{av}, of the area S and the total absorption $A = a_{av}S$.

As is shown in Table 1, the average values of the absorption coefficient of the reverberation chamber and of the plywood screen are similar. Therefore it is difficult to perceive the presence of the screen on the basis of the different intensities of the sound waves reflected from the walls enclosing the chamber and from the screen. In consequence, in the conditions discussed the distance of screen perception is relatively small. The screen is easier to perceive when it is covered with foam, a material with high absorption coefficient which lowers the intensity of the reflections from the screen surface, so that the acoustic field becomes inhomogeneous and shows clear directional characteristics.

Table 1. Absorption coefficient and room constant under different conditions

Interior (screen)	Absorption coefficient a_{av}	The area limiting the interior (screen) S [m^2]	Total absorption A [m^2]
Reverberant chambers	0.05	80	4
Average interior	0.18	267	48
Free space	1	—	—
Plywood screen	0.08	1.5	0.12
Screen covered with foam	0.78	1.5	1.17

The information that the screen is in front of the subject might additionally facilitate the definition of the distance of the screen.

The absorption coefficient of the average room differs from the absorption coefficient of both the plywood and the polyurethane foam. Hence the distances of perception of the screens covered with foam and without foam are relatively small.

In free space, however, the values of the absorption coefficient of the space and the absorption coefficient of the plywood screen are considerably different, and this facilitates good perception of the screen up to 4.5 m in front of it. When the screen is covered with foam (a material with a high absorption coefficient), the absorption coefficient of the screen becomes similar to that of the free space which, as is shown in Fig. 7, considerably decreases the distance of screen perception (to 1.5 m).

In summary, the efficiency of perception of a given barrier depended not only on the intensity of the reflected waves, i.e. on the increased acoustic pressure around the barrier, but also on the difference of the intensity of reflections from the barrier from that of its environment. Thus it was based on an auditory evaluation of the acoustical energy distribution of the waves reaching the subject from the point where he or she was standing.

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* The spectrum of stick tapping (Fig. 2) had the highest values at about this frequency.

5. Results of experimental laboratory tests

The results previously discussed show good agreement between the model and free space investigations. However the relatively small number of persons tested and the relatively large differences of the results – especially in the experiments carried out in free space (the influence of changing weather conditions) – made it difficult for the given acoustical conditions to define precisely the dependence of the threshold distance of barrier perception and the size of the barrier.

To achieve the assumed objective a series of experimental tests with a group of 19 blind people were performed. A subject was seated in an interior well attenuated with curtains (at a frequency 500 Hz of $a_{av} = 0.58$), and the screen, as in J. Kohler's tests, was moved noiselessly towards the subject's face, until the moment the person perceived it. During the tests square plywood screens of four different dimensions were used: $S_{e1} = 10000$ cm², $S_{e2} = 2500$ cm², $S_{e3} = 625$ cm² and $S_{e4} = 156.25$ cm². The direct results of the tests were converted to functional and statistical relations using a Hewlett-Packard computer, type HP 9810A.

On the basis of the tests performed, Fig. 8 presents the results of the dependence between the threshold distance of perception R and the area of the

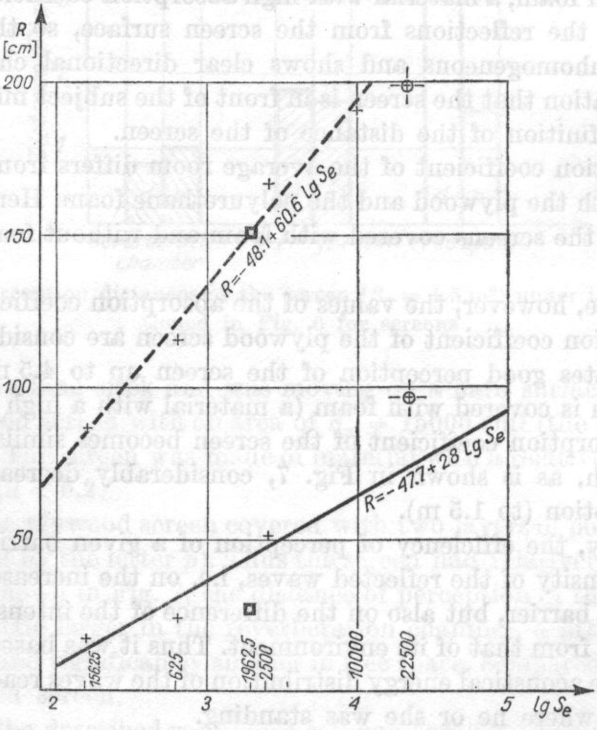

Fig. 8. Relationship between the threshold perception distance R and the **area** S_e of screens made od plywood with the sonic aid device (dashed line) and without it (continuous line)

screen S_e for the situation without sonic aid (continuous line) and with intermittent sonic aid (dashed line) using a purpose-built "sound torch".

For the preliminary verification of the results presented in Fig. 8, the results of the investigations made by Kohler (cf. Fig. 1) who used a standard round screen of area $S_e = 1962\ \mathrm{cm}^2$ are marked with little squares, whereas our own results from the experimental free space investigations with a screen of area $S_e = 22500\ \mathrm{cm}^2$ (cf. Fig. 6) are marked with circles.

As is indicated in Fig. 8, the relations determined are linear. The linear correlation coefficients – without sonic aid $r_b = 0.975$ and with it $r_w = 0.991$ – were significant at the level $\alpha = 0.05$, and the regression equation for both the quoted relations is

$$R = R_0 + k \lg \frac{S_e}{S_0},$$

where R is the distance of perception measured in cm, R_0 – the reference distance in cm, k – the coefficient of the capability of perception, S_e – the area of the screen in cm^2, and S_0 – the reference area equal to 1 cm^2.

The given equation indicates that the perception distance is proportional to the logarithm of the barrier area so that the Weber-Fechner law can be applied in this case, where the size of reaction is measured by the perception distance and the stimulus is represented by the sound waves reflected from the screen.

Investigations carried out in a similar way showed that a linear correlation coefficient for the discussed relationship was important at the level $\alpha = 0.05$ in other situations also, with only the distance R_0 and the coefficient k changing.

Figure 9 presents the results of such investigations in the interiors attenuated with curtains (continuous lines – conditions a), after drawing the curtains together (dashed lines – conditions b) and after shielding the drawn curtains by metal sheets (dotted lines – conditions c), with sonic aid (a group of lines at the bottom of Fig. 9). The results indicate that when the dispersion of the acoustic field increased, the threshold perception distances of the screen localized with the help of the "sound torch" were smaller, implying that the perception was more difficult. The results are in agreement with the results of the field investigations, during which the longest perception distances (up to 5 m) were achieved in free space, i.e. in an unbounded acoustic field.

It is easy to notice, when comparing the free space and laboratory investigations, that the distances for the screens of corresponding areas were similar, irrespective of whether the screen was fixed and the person moved towards it or whether it was moved towards the sitting person. It may thus be concluded that the perception distance was determined by the similarity of the acoustical conditions – for screens of width 1 m the distance amounted to about 2 m.

A somewhat different course of events, presented in Fig. 9, occurred without a "sound torch", in conditions of relative quiet (a group of lines at the bottom

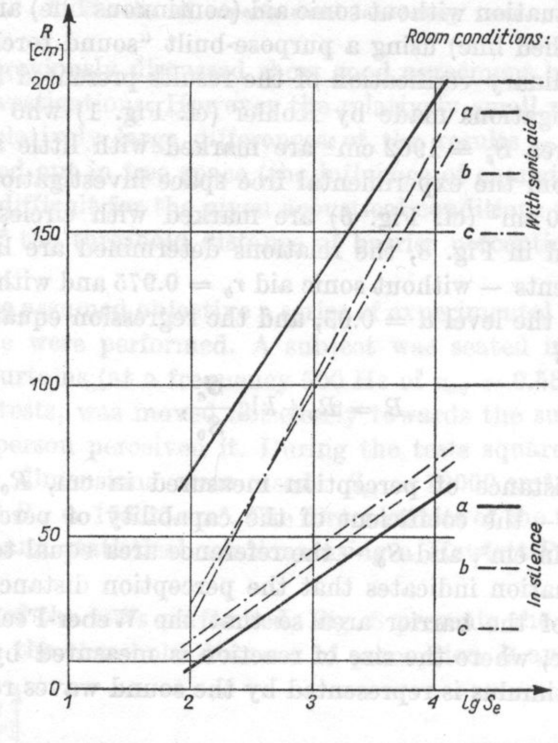

Fig. 9. Results of investigations as in Fig. 8: in silence and with sonic aid; *a* — in the interior with curtains, *b* — after drawing the curtains apart, and *c* — after shielding the curtains with sheet-metal

of Fig. 9). Under these conditions the threshold distances increased when the dispersion of the acoustic field increased. Hence dispersion of the field facilitated the perception of the screen.

Figure 10 shows the investigation results of the relation between threshold perception distance and the plywood screen area (the upper boundary of the area tatched in a given direction) and the plywood screen covered with polyurethane foam (the lower boundary of each area) in an interior with curtains (continuous line), after drawing the curtains together (dashed line) and after shielding the drawn curtains with metal sheets (dotted line). As is indicated in Fig. 10, the threshold distance of perception of a screen covered with polyurethane foam is always smaller than the threshold distance of perception of a screen of identical area but without the foam.

The biggest differences (giving the greatest decrease of perception distance) occur in the interior with curtains (*a*), because the absorption coefficient of the applied foam is similar to the absorption coefficient of the interior (curtains). Thus the screen with foam is more difficult to perceive on the background of curtains. When the curtains were drawn apart (*b*) and shielded with sheet (*c*), the differences were smaller. The difference of perception distances of the screens with and without the foam also decreased when the area of the screens decreased, i.e. when the acoustic absorptivity of their area decreased, which implies indirectly that the value of the stimulus needed for barrier perception also decreased.

Figure 11 presents the results of an investigation of the relation between the threshold distance of perception and the area of the plywood screen when the screen was moved in front of the subject (the upper boundary of the area hatched in a given direction) and when it was moved from the side of his left ear (the lower boundary of each area) under acoustic conditions *a*, *b* and *c* for the interior. It is easy to see that the differences in receiving information with a pair of ears and with only one ear become smaller when the absorption coefficient corresponding to the given conditions of the test is bigger, i.e. when less disturbing sounds reach the right ear facing the interior wall. It should be concluded therefore that in the free space, i.e. in a free acoustic field, there should not be any difference in the threshold distance of perceiving the screen with a pair of ears or with only one ear. Hence, it should be enough to receive

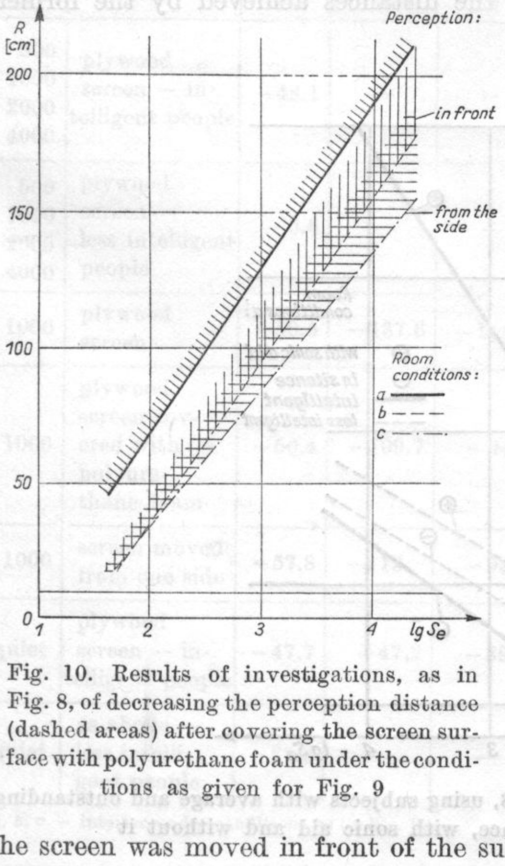

Fig. 10. Results of investigations, as in Fig. 8, of decreasing the perception distance (dashed areas) after covering the screen surface with polyurethane foam under the conditions as given for Fig. 9

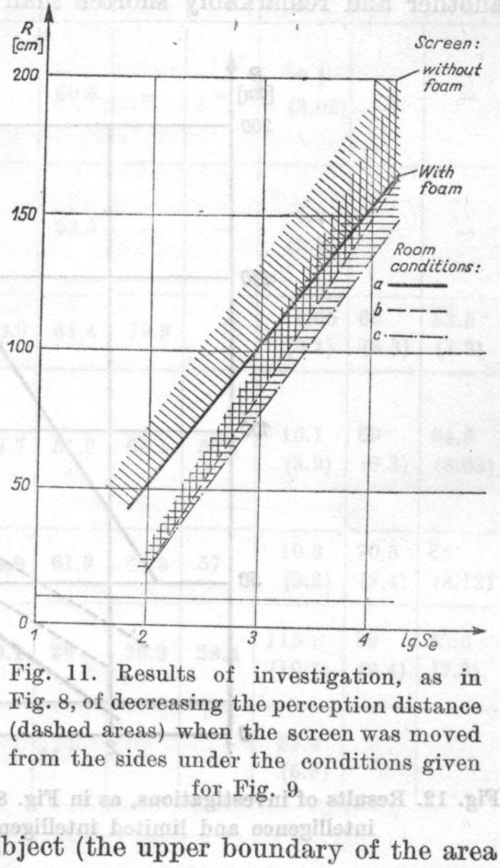

Fig. 11. Results of investigation, as in Fig. 8, of decreasing the perception distance (dashed areas) when the screen was moved from the sides under the conditions given for Fig. 9

the impression of the existence of the screen with only one ear. This may be significant for blind people with a unilateral deficiency of the auditory organ.

The results of measurements, which were made under acoustic conditions *a* with two groups of people — individuals of outstanding skills and intelligence (continuous line) and people with lower, limited intelligence (dashed line) — are shown in Fig. 12. As can be seen from Fig. 12, the perception distances of the screen with and without sonic aid for the latter group were similar to one another and remarkably shorter than the distances achieved by the former group with the help of a sonic aid. The results indicate that skills and intelligence might play a very important role in interpretation and association of acoustic information received through the senses in certain circumstances in free space.

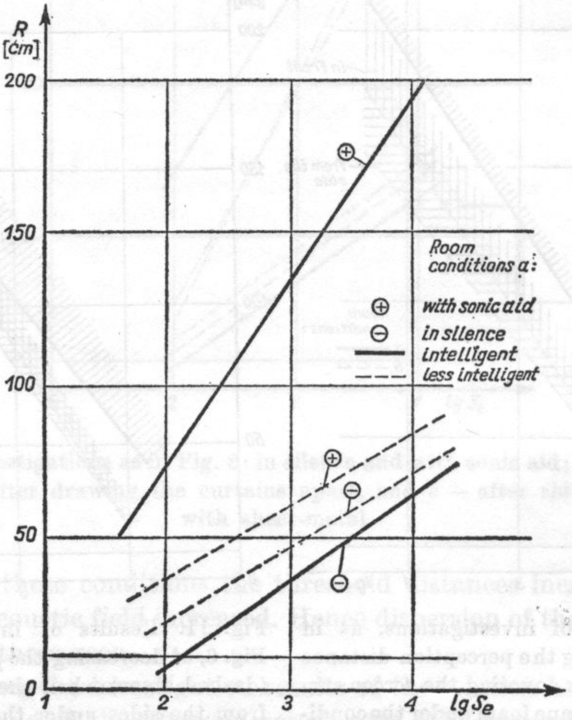

Fig. 12. Results of investigations, as in Fig. 8, using subjects with average and outstanding intelligence and limited intelligence, with sonic aid and without it

As all relations presented in Figs. 8 to 12 may be described by the given regression equation, they can be compared with one another by comparing values of their components which correspond to the particular situations tested.

Table 2 presents (under measuring conditions *a*, *b* and *c*) values of the reference distance R_0, the perception coefficient *k* and real threshold area of perception S_{pr}, i.e. the contact area of the screen and head, when $R = 10$ cm (the lengths of the sides of squares with such areas are given in brackets).

Table 2. Values of equation factors $R = R_0 + k \lg (S_e/S_0)$ corresponding to conditions of particular experiments

Reinforcement frequency	Experiment conditions	R_0 [cm]			k			S_{pr} [cm^2] ($\sqrt{S_{pr}}$ [cm])		
		a	*b*	*c*	*a*	*b*	*c*	*a*	*b*	*c*
500 1000 2000 4000	plywood screen – intelligent people	−48.1	–	–	60.6	–	–	9.1 (3.02)	–	–
500 1000 2000 4000	plywood screen – less intelligent people	−9.6	–	–	23.3	–	–	6.9 (2.6)	–	–
1000	plywood screen	−50.5	−137.6	−110.9	61.4	79.8	70	9.65 (3.1)	69 (8.3)	52.5 (7.3)
1000	plywood screen covered with polyurethane foam	−50.4	−109.7	−94.7	51.2	65.1	57.7	15.1 (3.9)	69 (8.3)	64.5 (8.03)
1000	screen moved from one side	−57.8	−113	−93.9	61.9	66.3	57	10.3 (3.2)	70.5 (8.4)	66 (8.12)
quiet	plywood screen – intelligent people	−47.7	−47.2	−39.1	28	29.3	28.4	115 (10.7)	89 (9.4)	53.5 (7.3)
quiet	as above – less intelligent people	−27.9	–	–	24.7	–	–	33.9 (5.8)	–	–

a, *b*, *c* – interior under conditions as in Fig. 9.

As is indicated in Table 2, when using:

(a) plywood screens and a one-third octave aiding signal with a centre frequency of 1000 Hz,

(b) plywood screens and one-third octave aiding signal at centre frequencies of 500, 1000, 2000 and 4000 Hz,

(c) plywood screens covered with polyurethane foam and a 1000 Hz signal,

(d) a 1000 Hz signal and plywood screens moved towards the tested person from his or her sides,

(e) plywood screens moved from the front towards the tested person without any aiding signals, the values of the reference distance R_0 ranged between -47.7 and -52.8 cm, so the straight line in Fig. 8 was displaced ± 2.55 cm in a parallel manner. We can presume therefore that this distance characterizes the conditions of the interior, and hence the characteristics of the acoustic field which occurs there.

However, the skill of perception, represented by the coefficient k, underwent significant changes. The best perception of the changes of the screen which was moved from the sides ($k = 61.9$) and front ($k = 60.6$) of the tested subject. The perception became worse after covering the plywood with polyurethane foam ($k = 51.2$) and the worst when perceiving the plywood screen without aiding sound, i.e. under the condition of silence ($k = 28$).

For the group of people with a relatively low level of intelligence (as assessed by tests) no essential differences in the perception of the screen with and without sonic aid were noticed. For this group, the value of the discussed coefficient was very low ($k_{av} = 24$). The results indicated that it was difficult for those people to interpret and associate the received sound information of the presence of the screen and the factual situation. Hence such tests may also indicate intelligence level of such people.

6. Conclusions

The discussed investigations show good agreement between the model, free space and laboratory tests, justifying the assertion that for blind people as well as for people with normal sight under conditions of poor lighting the basic source of information about barriers existing in their environment is audible acoustic vibration.

Impediment in the reception of these vibrations (e.g. by the use of ear-protectors, by attenuation of the steps of the subjects or by masking the area of the tests with disturbing sounds) substantially limited the efficiency of barrier perception.

In normal conditions the efficiency depended on the characteristics of the acoustical field. Particularly, with natural or artificial sonic aid, perception distances were the longer, the larger the area of acoustic field of the waves reflected from the barrier became. As the size of the area is defined by the difference between the measured acoustic pressure level and level which would occur in this place if there was only an acoustic field of freely propagating waves reflected from the screen, the perception of the screen was hindered by diffuse sound waves reaching the place from different sides. However, the perception was easier when the difference between the acoustic absorptivity of the barrier and of the environment was increased.

For the relationship between the perception distance and the area of the barrier the Weber-Fechner law can be applied.

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Received on March 8, 1978