The Intelligibility of Interrupted Speech*

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This paper concerns the effects of interrupting speech waves—turning them on and off intermittently or masking them with intermittent noise—upon their intelligibility. The effects were studied with various rates of interruption and with the speech left undisturbed various percentages of the time. Tests were conducted (1) with speech turned on and off in quiet, (2) with continuous speech masked by interrupted white noise, and (3) with speech and noise interrupted alternately, the speech wave being turned on as the noise wave was turned off, and vice versa.

(1) When the speech wave is turned on and off infrequently, the percentage of the message that is missed is approximately the same as the percentage of time the speech is off. When the interruptions are periodic and occur more often than 10,000 times per second, the interruptions do not interfere with the reception of the message. In the quiet it is easy to understand conversational speech so long as the interruptions occur more than 10 times per second.

(2) When continuous speech waves are masked by noise that is interrupted more than 200 times per second, intelligibility is independent of the interruption frequency and of the percentage of time the noise is on, provided the ratio of average speech power to average noise power is held constant. Interrupted masking noise impairs intelligibility least if the frequency of interruption is about 15 per second.

(3) When interrupted speech and interrupted noise alternate at frequencies below 10 alternations per second, the noise does not impair intelligibility. At higher frequencies of alternation the temporal spread of masking becomes appreciable.

The general features of these results are approximately the same whether the interruptions occur periodically or at random.

STUDIES of frequency and amplitude distortion have made it evident that undistorted speech waves contain more information than is necessary for intelligibility. Because they do it is often possible to economize on the band width or on the peak-power capacity of a speech-transmission system. It is also possible to economize in the time domain without sacrificing performance. One of the simplest ways to save time is to turn the speech off at intervals so the system can be used for another transmission. Effects of such interruptions upon intelligibility, as determined in a series of articulation tests, are described in this paper.

INTERRUPTED SPEECH IN QUIET

The kind of interruption used in these studies is equivalent to 100-percent amplitude modulation by a train of rectangular pulses. Periodic interruptions are illustrated in Fig. 1. The undistorted speech wave at the top of Fig. 1 is multiplied by the modulating wave to produce the interrupted speech wave at the bottom of the figure. The basic variables are: (a) The number of interruptions per second, the *frequency of interruption;* (2) The proportion of the time the speech is on, the *speech-time fraction;* and (3) The degree of *regularity* of the interruptions.

The speech materials used in the articulation tests were the phonetically balanced ("PB") lists of monosyllabic words published by Egan.[1] They were recorded phonographically by two talkers and reproduced for the articulation tests by an equalized playback. A crew of five listeners (male college students with normal hearing) was used, and each datum point is based upon the results of at least two 50-word tests, one with each talker. The electronic switch used to produce the interruptions was the one described by Miller and Taylor.[2] When it turned the signal off it in fact reduced the level approximately 80 db. With that much attenuation, no speech sounds could be heard during the interruptions. The listeners heard the speech through Permoflux dynamic receivers PDR-8. The frequency-response characteristic of the entire system (earphones terminating in a 6-cc coupler) was essentially uniform from 200 to 7000 c.p.s. This characteristic has been published by Licklider.[3]

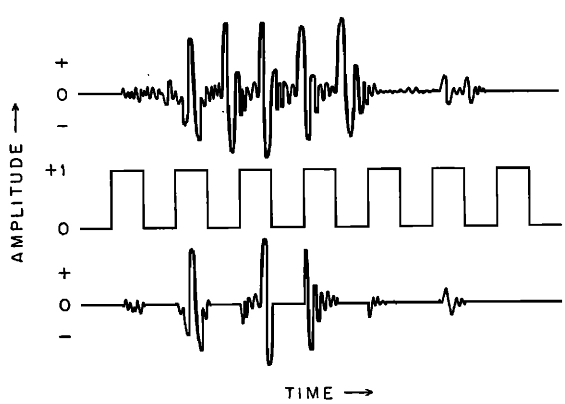

FIG. 1. Multiplying the continuous speech wave (top line) by the square wave (middle line) produces the interrupted speech wave (bottom line).

* This research was carried out under contract between Harvard University and the ONR, U. S. Navy, Project NR147-201, Report PNR-50. Reproduction for any purpose by the U. S. Government is permitted.

[1] J. P. Egan, "Articulation testing methods," Laryngoscope 58, 955-991 (1948).

[2] G. A. Miller and W. G. Taylor, "The perception of repeated bursts of noise," J. Acous. Soc. Am. 20, 171-182 (1948).

[3] J. C. R. Licklider, "The influence of interaural phase relations upon the masking of speech by white noise," J. Acous. Soc. Am. 20, 150-159 (1948); see Fig. 1, p. 152. The function labeled "electrical" is essentially the response of the system preceding the electronic switch, and the function labeled "acoustic" is the response of the entire system, including earphones.

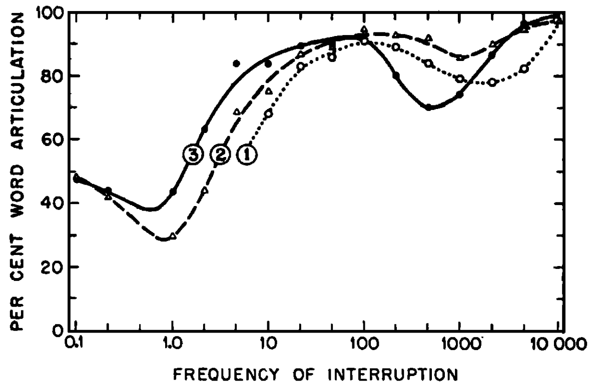

FIG. 2. Word articulation as a function of rate of interruption for a speech-time fraction of 0.5. Curve (1) was obtained with naive listeners, (2) with the same listeners after a few days practice, (3) again with the same listeners, but with a system having a more uniform frequency-response characteristic.

Regularly Spaced Interruptions

Consider first the results obtained with regularly spaced interruptions and a speech-time fraction of 0.5. The frequency of interruption was varied between 0.1 and 10,000 per second. In Fig. 2 the percentage of the words heard correctly is plotted on the ordinate, and the frequency of interruption is given on the abscissa.

The three curves of Fig. 2 were obtained under slightly different conditions. Curve 1 is based on the tests conducted at the beginning of the experiments. The listeners had never before served as subjects in articulation tests. Curve 2 was obtained after a few days practice. Note that the scores are consistently higher. At this point the frequency-response characteristic of the phonograph playback was equalized. (In the preliminary tests—curves 1 and 2—the system had a response that de-emphasized the low frequency components of the speech.) Curve 3 shows the results obtained after the response was equalized. Here the dip at 460 interruptions per second is greater, and intelligibility is less affected at the lower frequencies of interruption.

The general shapes of the three functions are approximately the same, and about what we should expect on the basis of an analysis of the experimental conditions. If the frequency of interruption is low enough, the articulation score must be equal to the product of the speech-time fraction (here 0.5) and the articulation score for uninterrupted speech (here almost 100 percent). With the speech on 5 seconds, then off 5 seconds, the listeners heard half of the words correctly. At the other extreme, if the frequency of interruption is high enough, the words must be just as intelligible as if they were not interrupted at all. The very rapid oscillations between on and off were not transduced by the earphones, but even if they had been transduced, the mechanical transmission system in the middle ear would have acted as a low pass filter to eliminate the interruptions and restore the speech wave essentially to its original form.

Between the very low and the very high frequencies of interruption the functions pass through a minimum, a maximum, then another minimum. The first minimum occurs in the neighborhood of one interruption per second. It is reasonable to expect intelligibility to be low when the duration of the "on" period is approximately equal to the duration of one word. The entire word can be heard correctly only if the "on-time" coincides rather exactly with the occurrence of the word. The word is likely to be missed if either its initial or its final phoneme is chopped off. However, as the listeners grow more familiar with the word lists they become better able to recognize the mutilated words. In curve 3, which was obtained after the listeners had considerable experience, the minimum has almost disappeared.

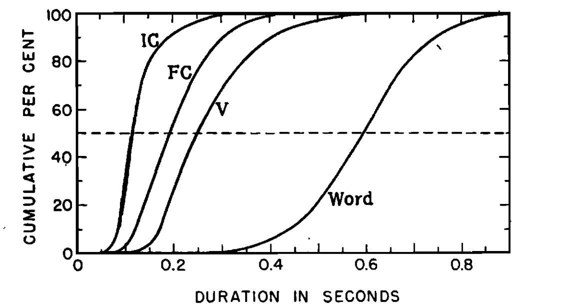

FIG. 3. Durations of speech sounds in the monosyllabic words used in the articulation tests. Initial consonants (IC) were shortest, final consonants (FC) next, and vowels (V) were longest. The average word lasted about 0.6 second.

The maximum between 10 and 100 interruptions per second is also attributable to the temporal characteristics of the spoken words. The average duration of a word in these tests was 0.6 second. Five interruptions per second would, on the average, give the listeners three 'looks' at each word. For the majority of the words this is enough to ensure a glimpse of every phoneme. It appears that one glimpse per phoneme is sufficient.

Since, according to this interpretation, the durations of the phonemes are important in determining the articulation scores over the range from 1 to 10 interruptions per second, an attempt was made to measure the durations. Cathode-ray oscillograms were made of the recorded words, and from them the durations of the initial consonants, the vowels, the final consonants and the entire words were measured to the nearest 0.01 second. The results are shown in Fig. 3. The durations are somewhat longer than would be obtained for conversational speech. Even with no time allowed for spaces between words, the median duration of 0.6 second corresponds to only 100 words per minute. Since conversational rates average around 130 words per minute, including pauses and polysyllabic words, it appears that the two talkers pronounced the words slowly and carefully when they made the records. If they had used normal conversational rates, the word articulation scores probably would have reached their maximum at a slightly higher rate of interruption.[4]

Intelligibility remains high until the frequency of interruption reaches 100 per second, but between 200 and 2000 per second there is a slight, though significant, deterioration. Consider the speech as a carrier modulated by a 1000-cycle square wave. Each component in the speech spectrum will have sidebands spaced at 1000-cycle intervals on either side of it, and these sidebands will constitute a noisy masking signal to interfere with intelligibility. Apparently such sidebands are not a serious consideration when the modulating frequency is less than 100 per second. When the frequency is greater than 3000 interruptions per second, on the other hand, the sidebands do not seriously overlap the range of speech frequencies, and intelligibility is high.

It is possible to account in the manner just outlined for the various inflections in the functions of Fig. 2 when the interruptions are regular and the speech-time fraction is 0.5. Does the picture change when different speech-time fractions are employed? The answer is given by the set of functions shown in Fig. 4. These functions were obtained with speech-time fractions ranging from 0.063 to 0.75 and with periodic interruptions. These functions follow roughly similar courses. However, as the speech-time fraction decreases, the maxima grow lower and narrower. Fewer words get through between gaps, and interference due to modulation products becomes more serious.

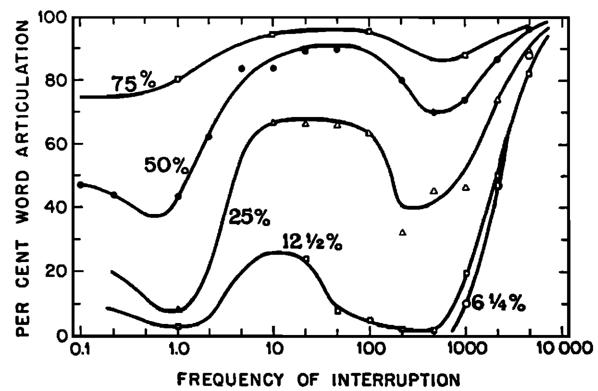

Fig. 4. Word articulation as a function of frequency of interruption, with speech-time fraction as the parameter. The interruptions were spaced regularly in time.

[4] An incidental but related observation concerns the effect of an interrupted sidetone on a talker's normal rate of speaking. If slowly interrupted speech is fed back at a high intensity to the talker's own ears, there is a strong tendency to slow down. At 1 interruption per second, the talker tries to drawl out his words until each speech sound is heard at least once. At somewhat higher rates of interruption, he tends to synchronize his vowels with multiples of the frequency of interruption. (Our attention was called to this last point by J. M. Stroud, who suggests that our articulation scores might have been slightly higher had we used 'live' talkers and sidetone monitoring.)

Irregularly Spaced Interruptions

The data we have just examined are represented in another way in Fig. 5: the speech-time fraction is plotted against the frequency of interruption. The resulting curves are equal-articulation contours. The solid curves of Fig. 5 are based upon the data of Fig. 4 and hold for regularly spaced interruptions.

The dashed curves of Fig. 5 are for irregular interruptions. The electronic switch was arranged in such a way that it could be triggered on and off by pulses derived from two noise generators. Every time the randomly fluctuating voltage of one of the noises rose past a predetermined amplitude the switch turned on and stayed on until the other noise voltage rose past its predetermined amplitude level. By varying the two levels at which the switch would trigger it was possible to produce random interruptions at various rates and speech-time fractions. Because the triggering was random, however, it was not possible to tell exactly what the frequency and speech-time fraction were going to be until the test was completed. It was necessary to run the test and then see what had happened. The average frequency of interruption during the test was determined with the aid of an electronic counter, and the average speech-time fraction was determined from the time integral of the triggering voltage. Once these values were determined, the articulation score could be indicated at the proper point on a graph like that of Fig. 5. From these points the dashed curves of Fig. 5 were obtained.

The functions for random interruption turn out to be straighter than the functions for regular interruption. This result is to be expected because random interruption gives rise in some parts of the test to frequencies of interruption that are higher than average and in other parts to frequencies of interruption that are lower than average. Similarly, a range of speech-time fractions is involved in every test. The effect is to smooth out the variations in the curves, just as a running average smooths out fluctuations in a column of numbers.

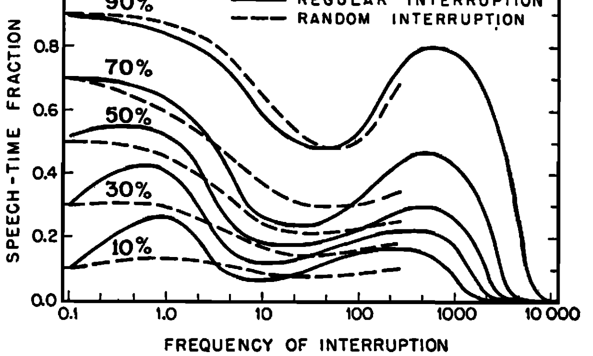

Fig. 5. Equal-articulation contours obtained with regularly spaced and with randomly spaced interruptions of speech.

These results are displayed in still a third manner in Fig. 6. The word articulation score is plotted against the speech-time fraction, with the rate of interruption as the parameter, for both regular and irregular interruption. At nearly all points the articulation score lies above the speech-time fraction.

Gradual Modulation, Periodic Inversion, and Double Talk

A few tests were conducted with regularly spaced interruptions that were gradual rather than abrupt.

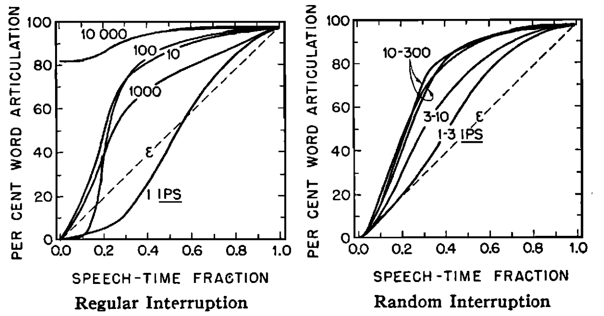

FIG. 6. Word articulation as a function of the speech-time fraction, with frequency of interruption as the parameter, for both regularly spaced and randomly spaced interruptions.

The modulating voltage took various proportions of the time to rise from 0 to 1 and to return. The results of these tests are shown in Fig. 7, where the articulation score is plotted as a function of the percentage of the time occupied by the build-up and decay of the speech burst. These data were obtained with regular interruptions 4 and 16 times per second and, figuring the speech to be "on" whenever it is more than half-way on, with a speech-time fraction of 0.5. Changing from abrupt to gradual modulation improved both the quality and the intelligibility of the interrupted speech.

Returning to abrupt modulation, a curious effect was obtained when, instead of turning the speech wave off, we simply turned it over. At low frequencies, periodic inversion of the speech wave form did not affect intelligibility, but as the frequency of inversion is increased a number of the speech sounds acquired a W-like character. The process of reversing polarity turned itself into "the pwowess of wewersing."

In a short series of tests, we examined the listeners' ability to hear two talkers at once. In some of the tests, the talkers' voices were interwoven as the electronic switch alternated between them 10 or 100 times per second. In other tests the talkers spoke together and their speech waves were superposed without switching. And, in still other tests for purposes of comparison, the talkers spoke singly. The results are summarized in Table I. When both voices were on continuously the listeners heard correctly more than half the words spoken by each talker. The total number of words heard correctly was greater (126) than when either talker spoke alone (99). When the talkers' voices alternated 10 times per second the listeners got 92 words correct which is the same number of words they heard when one talker spoke alone. When the voices alternated 100 times per second, the listeners got fewer words correct (75) than when either talker spoke alone (98). Alternating the two voices does not reduce the interference between them: if two talkers are going to speak to a listener at the same time, no advantage can be gained by switching back and forth between the two voices. In the series of tests with two talkers only about two-thirds of the words that were heard correctly were attributed to the talker who had uttered them.

Applications

Interruptions that do not seriously impair intelligibility are of practical utility. Time-multiplex and pulse-code systems of speech transmission take advantage of the fact that intelligibility is not impaired by regular interruptions at a high frequency. These systems sample the fluctuating amplitude of the speech wave at very frequent intervals and the sample contains all the information that is carried by the original wave. (Shannon has shown that a signal confined to band width W can be described uniquely by $2W$ samples per second.)[5]

A related but quite different application would take advantage of the maximum between 10 and 100 interruptions per second in the curve relating intelligibility to interruption rate. In 1936 Marro, who repeated the earlier work of Poirson,[6] suggested the use of two-way transmission in a single frequency channel by switching from transmit to receiver and back about 20 times per second.[7] Switching would allow the transmitters at both

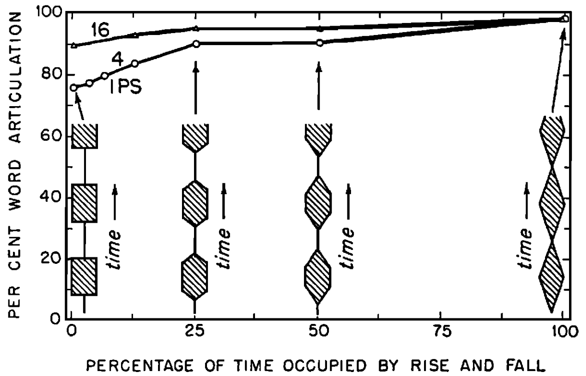

FIG. 7. Effects of reducing the abruptness with which the speech is turned on and off. Gradual transition from off to on and back produces less interference than abrupt transition if the speech is "half-way on" for the same fraction of the time.

[5] C. E. Shannon, "Communication in the presence of noise," Proc. Inst. Rad. Eng. 37, 10–21 (1949).

[6] E. Poirson, "Sur les déformations systematiques des courants téléphoniques. Application à un procédé de téléphonie secrète." Bull. Soc. Franc. Élect. 103, 147–161 (1920).

[7] M. Marro, "On the persistence of the sensation of speech," Phil. Mag. 22, 847–854 (1936); "Amplificateur téléphonique duplex employant un phénomène de persistance d'impressions sonores sur l'ouïe," Rev. Gén. Élect. 39, 458–461 (1936); "Two-way speech by wireless. Method of utilizing persistence of hear-

TABLE I. Articulation scores obtained with two talkers speaking alone and together.

	Interruptions (or alternations) per second None	10	100
Talker H alone	99.8%	89.0	97.6
Talker L alone	98.8	94.6	98.4
H and L together:			
H's words	64.5	34.3	32.8
L's words	62.1	58.0	41.9
Average	63.3	46.2	37.4

ends of the link to operate in the same frequency channel without blocking the adjacent receivers.

Recently the idea of infrasonic switching was proposed again by Montani.[8] Montani made the statement, however, that—because of the persistence of hearing—15 interruptions per second are inaudible. We agree that interruptions are inaudible, but only in the sense that little is heard during interruptions. Despite 15 gaps per second, it is easy to understand what is being said, but the talker sounds as though he has a strange defect of phonation. A very similar effect is obtained by patting the lips lightly and rapidly while speaking.

SPEECH INTERRUPTED BY NOISE

We turn now to the situation in which speech is left on continuously but is heard in the presence of interrupted masking noise. The speech is not intermittently attenuated—it is intermittently masked. The experiments already described must be duplicated to explore the same variables—noise-time fraction, frequency and regularity of interruption—but now these apply to noise rather than to speech. To these three variables we must add a fourth, the signal-to-noise ratio.

The signal-to-noise ratios to be given will refer to the intervals during which the noise is on. These ratios, which will be stated in decibels, can be changed to averages for the entire cycle by expressing the silent-time fraction in decibel notation and subtracting it. Thus, if the noise is on half the time, the silent-time fraction is 0.5 or −3 db, and the signal-to-noise ratio averaged over the cycle is 3 db higher than the signal-to-noise ratio measured during a typical burst of noise.

The signal-to-noise ratios, measured during bursts of noise and in the frequency band from 100 to 7000 c.p.s., were −18, −9, 0, and +9 db. The average speech level was held constant at 90 db re 0.0002 dyne/cm². The tests with interrupted noise were run during the same sessions and with the same equipment and personnel as the tests with interrupted speech that are summarized in Figs. 4, 5, and 6. Therefore the results to be discussed now can be compared directly with the results discussed in the preceding section.

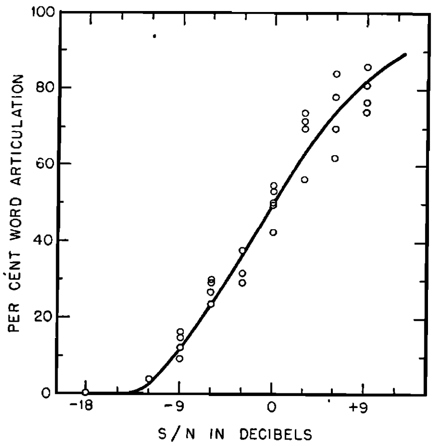

FIG. 9. Word articulation for continuous speech heard in the presence of continuous noise, plotted as a function of the signal-to-noise ratio in decibels. The average level of the speech was held constant at approximately 90 db re 0.0002 dyne/cm².

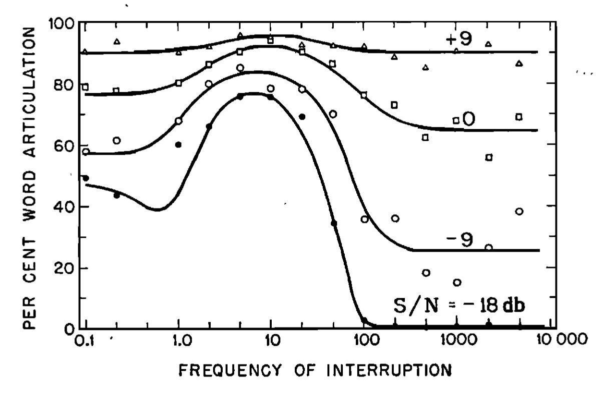

FIG. 8. The masking of continuous speech by interrupted noise. Word articulation is plotted against the frequency of interruption of the noise, with the speech-to-noise ratio in decibels as the parameter. Noise-time fraction, 0.5.

Regularly Spaced Bursts of Noise

Figure 8 summarizes the results obtained with regular interruptions of the masking noise and a noise-time fraction of 0.5. At the lowest frequencies of interruption the articulation score behaves in about the same way it does when the speech is interrupted by silence. Consider first the function obtained with a signal-to-noise ratio of −18 db. When the noise is on it completely masks the speech, so 5 seconds of speech and noise alternating regularly with 5 seconds of speech alone gives an articulation score of approximately 50 percent; all the words heard at all are heard correctly. As the frequency of interruption is increased to 10 per second the articulation score rises (see lower most curve of Fig. 8 and curve 3 of Fig. 2). When there were 10 bursts of noise per second the listeners were able to get several glimpses of every word and to patch these glimpses together well enough to record three-fourths of the test words correctly.

ing," Electrician 118, 5 (1937); "À propos d'un phénomène de persistance des impressions sonores sur l'ouïe: radio téléphonie duplex simultanée," Rev. Gén. Élect. 41, 527–530 (1937); "Esperienze relative alla persistenza della sensazione uditiva," Arch. Ital. Psicol. 17, 67–70 (1939); "Two-way speech by wireless," Phil. Mag. 28, 248–251 (1939); "Secrecy by inversion of syllables," Phil. Mag. 29, 205–207 (1940).

[8] A. Montani, "Infrasonic switching," Electronics 19, No. 3, 214–222 (1946).

When the slow bursts of noise do not drown out completely the speech that occurs with them, the articulation score is higher than the silent-time fraction. In a test of 100 words, for example, about 50 of the words will occur in the silent interval and will be heard correctly. The remaining 50 words are heard in the presence of noise, and the articulation score for these masked words depends upon the signal-to-noise ratio. Figure 9 presents the results obtained when speech was masked by a continuous noise. With Fig. 9 it is possible to estimate what fraction of the masked words are heard correctly. For example, with a signal-to-noise ratio of 0 db the listeners heard correctly 50 percent of the masked

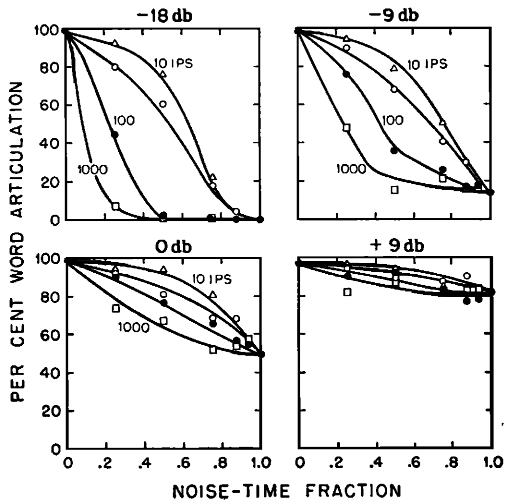

FIG. 10. Word articulation plotted against noise-time fraction, with the frequency of interruption of the noise and the signal-to-noise ratio as parameters.

words. If the noise is interrupted half the time and once every 10 seconds, the listeners should get 50 percent for the unmasked words plus half of the masked words, or a total articulation score of approximately 75 percent. This method of estimation is relatively accurate for interruption frequencies below one per second.

At the other extreme of interruption frequency, also, the masking produced by interrupted noise can be estimated from Fig. 9. When the noise is interrupted several hundred times each second it is effectively continuous insofar as aural masking is concerned. With a noise-time fraction of 0.5 the level of the noise averaged over a full on-off cycle is 3 db lower than it would have been had the noise been on all the time. Thus the articulation score obtained in the presence of a noise interrupted 1000 times a second and half the total time is the same as the one obtained in the presence of a continuous noise 3 db lower in intensity.

The range of interruption frequencies between 10 and 1000 per second remains to be discussed. This portion of the functions can be estimated with the aid of results obtained by Miller and Garner in their study of the masking of tones by interrupted noise.[9] Their results are summarized in a single function that relates the masking efficiency of an interrupted noise (ratio of masking by interrupted to masking by continuous noise) to the duration of the silent intervals. When the silent interval is shorter than 3 or 4 milliseconds—higher than about 150 interruptions per second at a noise-time fraction of 0.5—the interrupted noise is effectively continuous. For lower frequencies the masking by interrupted noise is a proper fraction of the masking by continuous noise. Miller and Garner's results can be used to estimate the change in the masked threshold for tones, and from the new masked threshold the articulation score can be computed in the manner described by French and Steinberg.[10]

The effects of varying the noise-time fraction are summarized in Fig. 10. Four rates of interruption were used—1, 10, 100 and 1000 per second. At all noise-time fractions and all signal-to-noise ratios, 10 bursts of noise per second produced the least interference and 1000 bursts of noise per second produced the most interference. Since the signal-to-noise ratios refer to the intervals during which the noise is on, the amount of interference of course increases with increasing noise-time fraction.

Irregularly Spaced Bursts of Noise

The effects of irregular interruption of the masking noise were explored at a signal-to-noise ratio of −9 db. The method for turning the noise on and off at random was the same as that described in the preceding section for turning speech on and off at random. The results are summarized in Fig. 11, where the noise-time fraction is plotted against the frequency of interruption, with articulation score as the parameter. The solid functions represent the results obtained with regular interruptions (see Fig. 10), and the dashed functions

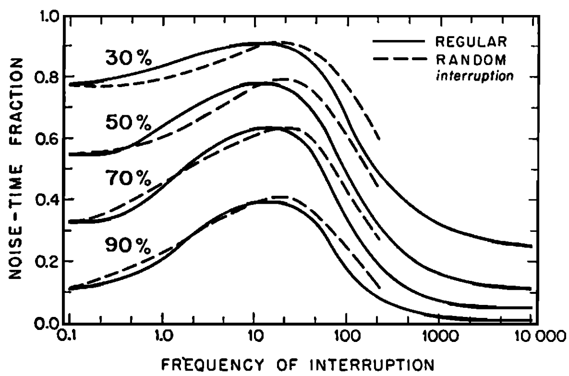

FIG. 11. Equal-articulation contours obtained with a masking noise interrupted regularly and at random. Signal-to-noise ratio, −9 db.

[9] G. A. Miller and W. R. Garner, "The masking of tones by repeated bursts of noise," J. Acous. Soc. Am. **20**, 691–696 (1948), see Figs. 3 and 6, and Eq. (2).

[10] N. R. French and J. C. Steinberg, "Factors governing the intelligibility of speech sounds," J. Acous. Soc. Am. **19**, 90–119 (1947).

represent the results obtained with irregular interruptions. The effect of irregularity is to smooth the functions slightly, but qualitatively the picture is quite similar for regularly and randomly interrupted masking noise.

SPEECH ALTERNATING WITH NOISE

The preceding sections have discussed the results obtained (1) when speech is interrupted by silence, and (2) when continuous speech is masked by an interrupted noise. A third class of tests explored the effects of alternating speech and noise. These tests are similar to (1), except that the silent intervals are filled with noise. They are similar to (2), except that the speech is not present when the masking noise is on. By comparing the results with (1) we obtain an estimate of how much the masking effect of a burst of noise 'spills over' into temporally adjacent intervals. If the ear recovered immediately from the masking produced by a burst of noise, no effect would be observed when noise was introduced during the silent interval. By comparing the results with (2) we obtain an estimate of how much the speech during the bursts of noise contributes to intelligibility.

Results of Articulation Tests

The articulation scores obtained when speech alternated with noise are shown in Fig. 12. The speech-time fraction was 0.50, the frequency of interruption was varied from 0.1 to 10,000 per second, and the signal-to-noise ratio was varied from -18 to $+9$ db. The top curve in Fig. 12 has been taken from Fig. 4 and represents the scores obtained when no noise is introduced into the intervals between successive bursts of speech. So long as the frequency of alternation is below 4.6 per second the introduction of noise during the "no-speech" intervals has practically no effect upon the articulation scores. With intervals longer than about 0.1 second the alternation between speech and noise is not different from the alternation between speech and silence. The recovery time of the auditory system is negligible (for the noise levels used) in comparison to intervals of 0.1 second or longer.

When the frequency of alternation is increased to or beyond 215 per second, the noise masks the speech with which it alternates just as effectively as if both speech and noise were on at the same time. Thus, although the decay of the masking effect is rapid enough that the intelligibility of a 100-millisecond burst of speech is not impaired by the noise preceding and following it, the decay is not instantaneous. At 215 alternations per second between speech and noise intervals of equal length, the intervals are 2.3 milliseconds long. During a speech interval of that duration the auditory system does not recover sufficiently to derive any information at all from the speech wave.

As an intermediate example we can take 100 alternations per second, which gives intervals of speech and of noise each 5 milliseconds long. In this instance a sur-

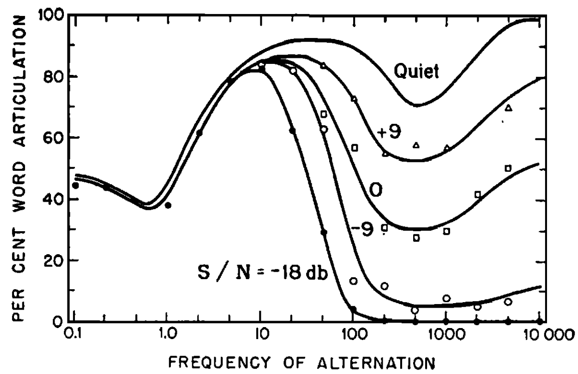

FIG. 12. Word articulation as a function of the frequency of alternation between speech and noise, with signal-to-noise ratio in decibels as the parameter.

round of noise 18 db more intense than the speech lowers the articulation score from 90 to 4 percent (see Fig. 12). From Fig. 9 we find that this shift is equivalent to that produced by a change of 24 db (12 to -12 db) in signal-to-noise ratio. Hence the "spill over" into temporally adjacent regions must be about 24 db greater with 5-millisecond intervals than with 100-millisecond intervals.

The principal difference between alternating speech and noise and masking speech with interrupted noise appears in the region from 200 to 2000 interruptions per second. In that region unintelligible components arising from the modulation of the speech by the interrupter contribute significantly to the masking. We have the dip in the quiet curve of Fig. 12 *plus* the "spill-over" masking due to the noise. Above 2000 per second the functions approach the values indicated for continuous speech and noise in Fig. 9.

The "Picket Fence" Effect

An interesting effect is observed if noise is introduced into the gaps between bursts of speech when the speech is interrupted about 10 to 15 times per second. Without the noise the talker's voice sounds hoarse and raucous. The speech is intelligible, but the interruptions are quite evident. When noise is introduced between the bursts of speech, the on and off transients are assimilated into the noise and, when the noise is somewhat more intense than the speech, the speech begins to sound continuous and uninterrupted. It is much like seeing a landscape through a picket fence—the pickets interrupt the view at regular intervals, but the landscape is perceived as continuing behind the pickets. The same effect can be obtained with pure tones. An interrupted tone will sound quite pure and continuous if the intervals between the bursts of tone are filled with a sufficiently intense white noise. When interrupted speech is made to sound continuous by 'masking the silent intervals,' the listener feels that the speech is certainly more natural and probably more intelligible. As Fig. 12 shows, however, no actual improvement in intelligibility was obtained by adding noise.