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WADC TECHNICAL REPORT 54-203

STUDIES ON AUDITORY MASKING, FATIGUE, AND SPEECH INTELLIGIBILITY

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WRIGHT AIR DEVELOPMENT CENTER

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Central Institute for the Deaf

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FOREWORD

This report summarizes experimental work on auditory masking and fatigue and the intelligibility of speech. The work was initiated under Contract AF 18(600)-131 between the Aero Medical Laboratory, Wright Air Development Center and the Central Institute for the Deaf. Major Horace O. Parrack was the Project Engineer for the Aero Medical Laboratory under the authority of RDO R-695-63, "Vibration, Sonic and Mechanical, Action on AF Personnel."

All of the experimental work has been carried out either by or under the direct supervision of the Principal Investigator. Others who participated directly in the experiments were Graduate Research Assistants: Elizabeth G. Reynolds, Wallace D. Bowman, and Maurice Joseph. The construction, maintenance and calibration of apparatus was carried out by Dr. Robert W. Benson (Research Associate) and Mr. Jules Detchemendy (Technician). Dr. Benson also supervised the analysis and measurement of acoustic stimuli.

In addition to the persons directly associated with this contract, others have contributed to the planning and execution of the experiments. We were particularly fortunate in having available the good counsel of Dr. S. Richard Silverman and Dr. Hallowell Davis of Central Institute.

ABSTRACT

This report summarizes research on auditory masking and fatigue initiated under Contract No. AF 18(600)-131. The main results concern the threshold of intelligibility for spondaic words as a function of the level of various bands of noise and the intelligibility of several types of speech material as a function of either the level of white noise or the amount of frequency restriction in a noiseless system. The bibliography includes two published articles (1, 2) resulting from this work in which the detailed procedures and results may be found. A final section describes further work on masking and fatigue that was initiated under this contract but was incomplete on the termination date.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

JACK BOLLERUD
Colonel, USAF (MC)
Chief, Aero Medical Laboratory
Directorate of Research

TABLE OF CONTENTS

SECTION I

INTRODUCTION

Most of the experimental work to be reported stemmed from a desire to specify more precisely the kind of impairment suffered during exposure to loud noise. These problems fall naturally into two categories. The first has to do with the effect of noise on the audibility and intelligibility of other sounds co-existing with the noise. These problems center around the phenomenon of auditory masking, and we have been concerned primarily with the masking of speech. The second set of problems has to do with the effects of high-intensity noise on the auditory system - - either temporary or permanent effects - - after the noise has ceased; here auditory fatigue is involved.

The more successful experimental work has been chiefly in the area of masking and other matters related to the intelligibility of speech. In these experiments an attempt was made to fill in the gaps among results reported by previous investigators with the long-term view of making the intelligibility of different kinds of speech predictable from knowledge of the type of transmission system to be used and the acoustic environment in which it is used. The results have been published in papers by Hirsh and Bowman (1) and by Hirsh, Reynolds and Joseph (2).

SECTION II

COMPLETED RESEARCH

Masking of Speech by Bands of Noise:

When a sound is made less audible by a second sound or noise, masking has occurred. In the case of speech, masking can be measured in at least two different ways. First, we can measure the increase in the intensity of the speech necessitated by the noise or masking sound so that the speech will be just as intelligible as in the quiet. The simplest method for such a measurement involves the shift in the threshold of intelligibility brought about by the noise or masking sound. In the second procedure, the speech is held at a given level while the decrease in intelligibility or articulation score brought about by the noise is measured.

1. Background

The first procedure was used in a study by Hawkins and Stevens (3) to measure the threshold of intelligibility for continuous discourse as a function of the intensity of a white noise (constant energy per cycle up to 7000 cps). In general, their results show that when the speech level (peaks) is as little as 8 db below the overall level of the white noise, the gist of continuous discourse is still understood by listeners.

On the basis of such information alone, we cannot predict the masking that would be effected by the variety of different noises found in the vicinity of military aircraft. It was decided, therefore, to use bands of noise as masking sounds in order to measure the different masking effects associated with various frequency regions and to aid in predicting the amount and kind of masking that would be brought about by different noises of known but complex spectra.

Other investigators had employed bands of noise as masking stimuli but none in connection with the threshold of intelligibility (50% response). For example, Miller (4) held the presentation of lists of monosyllabic words (PB-lists) at a fixed level and then measured the articulation score as a function of the intensity of the noise for each of several bands of noise. Many of his bands were so ineffective as maskers that the articulation score never dropped below 50% and therefore one could not show how the threshold signal-to-noise ratio varied as a function of frequency band for monosyllabic words. For white noise (20-4000 cps), however, Miller's data show that the threshold of intelligibility occurs when the speech level is about 2 db higher than the noise level. The difference between the -8 db signal-to-noise ratio of Hawkins and Stevens (3) and the +2 db of Miller (4) may reflect the difference between continuous discourse and monosyllabic words.

In this first study, it was planned to measure the threshold of intelligibility for relatively easy material as a function of the level of bands of noise. The basic measurement was similar to that of Hawkins and Stevens (3) while the band limits of the noise were almost the same as those of Miller (4).

2. Experimental Procedure

Spondaic words on phonograph records were employed as speech material (CID Auditory Test W-2, see Hirsh _et al_, 5). Eleven bands of noise, each equivalent to a pitch interval of 250 mels, and a white noise (20-6600 cps) were used as masking stimuli. The basic datum reported was the threshold of intelligibility (50% articulation score) for spondaic words as a function of the level of each of these bands, from the quiet up to 120 db per band. The details of procedure and of the stimuli used are given in the report of Hirsh and Bowman (1).

3. General Results

When the speech level and the noise level are plotted on absolute scales (in db relative to 0.0002 microbar), the resulting masking function is linear between 50 and 120 db noise level, indicating a signal-to-noise ratio of about -15 db for the threshold of intelligibility of spondees. This means that in the presence of a broad-spectrum noise, the speech peaks corresponding to vowel energy may be as low as 15 db below the overall noise level and still yield a 50% score for spondaic words. This threshold S/N ratio is about 7 db lower than that reported by Hawkins and Stevens (3); the difference is probably due to the difference between spondees and continuous discourse (see below).

An equivalent amount of energy squeezed into any one of the bands used is a less effective masking sound than white noise. The most effective bands lie in the frequency range 670-1900 cps. The bands involving higher frequencies yield slightly less masking, but the lowest bands (20-160 and 160-394 cps) are the least effective. A typical threshold signal-to-noise ratio for the middle frequency bands is about -25 db, while a similar value for the highest and lowest bands is as low as -60 db. These relations hold generally whether the noise level is given as level per band, level per cycle or sensation level.

The shapes of the functions that relate the masked threshold to the level of masking noise are also of importance. The masked threshold increases linearly with the level of white noise or of those middle-frequency bands that yield the most masking. Bands of noise involving frequencies above 1400 cps, however, all show a slight positive acceleration which appears to remain to the highest level tested (120 db). This fact is of extreme importance so long as we must extrapolate the effects of masking to even higher (untested) levels. The two lowest bands also show positive acceleration, but these functions appear to inflect and show negative acceleration by the time the noise level has reached 120 db. <u>It appears, therefore, that the extrapolated effects of noise bands above 120 db would be relatively more severe for frequencies above 1400 cps than for frequencies below 400 cps. Reasonably good prediction, based on a linear function, appears to hold for bands between 400 and 1400 cps.</u>

<u>Noise Threshold and the Critical Band:</u>

1. Background

A critical band is defined as a band of noise that just masks a pure tone and whose width is such that the total energy in the band is equal to that of the pure tone being masked. This concept has been most useful in predicting the masking of pure tones by noise with known spectra. The original definition and the earlier measurements of the critical band width around different frequencies have been essentially corroborated by Hawkins and Stevens (3). An alternative definition, derived logically from a physiological interpretation of the critical band, would be that a critical band of noise should have the same absolute threshold as a pure tone in the center of the band. This second definition was tested in our own experiments.

2. Experimental Procedure

In order to be able to give the level of the noise bands used in the study summarized above in terms of sensation level, a preliminary experiment was designed to measure the absolute thresholds of the 11 bands and the white noise. The details of procedure are given in the Hirsh and Bowman paper (1).

3. General Results

The original thresholds were measured in terms of the total sound pressure level in a given band. The width of each band (in db = 10 log bandwidth in cps) was subtracted from these measures to give thresholds in sound pressure level per cycle. To these thresholds were added the critical band widths corresponding to the center frequencies, according to the measurements of Hawkins and Stevens (3). The final results, that is, the threshold for each band in sound pressure level per critical band, agreed precisely with the minimum audible pressures for pure tones reported in the classical paper of Sivian and White (6) (see Fig. 2, Hirsh and Bowman, 1). The exception to this agreement occurs in the band 20-160 cps. In future studies it is planned to re-measure this critical bandwidth for low frequencies.

<u>Masking of Different Speech Materials:</u>

1. Background

There are many inconsistencies among studies of the intelligibility of speech like the one referred to above in connection with the signal-to-noise ratio that describes the threshold of intelligibility. Hawkins and Stevens (3) report about -8 db for continuous discourse, Miller (4) reports about +2 db for monosyllabic words, and Hirsh and Bowman (1) report a figure as low as -15 db for spondees. All these pertain to very similar white masking noise. Since it is almost impossible to decide whether all or only part of these differences in threshold are due to the differences in speech material, or to different talkers and listeners, a study of the masking of different kinds of speech materials, all spoken by the same talkers and tested with the same listeners, was planned.

2. Experimental Procedure

Speech materials were composed of four 200-item lists, each containing 50 nonsense syllables, 50 monosyllabic words, 75 disyllabic words (25 of the spondaic, 25 of the trochaic and 25 of the iambic stress pattern) and 25 words with more than two syllables. Four talkers, representing a variety of General American speech, recorded different versions of these lists which were then presented to a crew of five listeners, in the quiet and in the presence of white noise at various noise levels. In this study the threshold of intelligibility was not measured; instead, the speech was presented at four different levels in the presence of each noise level and the threshold of intelligibility was calculated by interpolation on the function that relates articulation score for each type of speech material to S/N ratio. The details are given in the paper by Hirsh, Reynolds and Joseph (2).

3. General Results

Figures 4 through 8 in the completed report of Hirsh, Reynolds and Joseph (2) show the articulation score for the different kinds of syllables and words as a function of the speech level in the quiet and of the S/N ratio at four different noise levels, 50, 70, 90, and 110 db above 0.0002 microbar. In general, these results show that the most difficult material (nonsense syllables and monosyllabic words) reaches maximum intelligibility at a S/N ratio of +5 db while the polysyllabic and disyllabic words are already quite intelligible at S/N ratios of about -5 db. An additional figure shows the threshold of intelligibility (50% articulation score) for these speech materials as a function of noise level. The threshold S/N ratio varies from about -2 db for nonsense syllables and monosyllabic words to -12 db for the most intelligible spondaic words. These ratios hold essentially constant for all noise levels used (50 to 110 db).

Although these results are reliable, it should be emphasized that they hold only for these experimental conditions. A statistical analysis by which one can reckon the influence of different talkers and different listeners is reported in the paper (2). The most important restriction is that the data hold only for white noise.

<u>Effect of Filtering on Different Speech Materials</u>:

1. Background

The results reported in the preceding paragraph show that the effect of noise is different on the intelligibility of different speech materials. We wished, therefore, to study the effects on these same materials of another kind of system impairment. Early studies at the Bell Telephone Laboratories (7) showed the effect of high-pass and low-pass filtering on the intelligibility of nonsense syllables. Very significant theoretical work, culminating in the concept of articulation index of French and Steinberg (8), has been based largely on those studies. French and Steinberg (8) proposed a scheme whereby a quantity, called articulation index, could be calculated from the physical characteristics of a transmission system. Then this quantity was related to measured syllable articulation, the end result being the possibility of predicting syllable articulation from the physical characteristics alone.

The two characteristics needed for calculation of the articulation index are the response-frequency characteristic of the transmission system and the spectrum level of the noise. In brief, the articulation index is contributed to equally by each of 20 frequency bands, and one calculates the S/N ratio in each of these bands to find the articulation index. Since we already had data on the masking of different speech materials (1, 3, 4), we now wished to use the same materials under filtering to note whether or not the same relations among the intelligibilities of these different speech materials would remain under various kinds of system impairment.

2. Experimental Procedure

The same speech materials were used as in the preceding study. No noise was used. Instead, the speech was passed through systems in which all of the frequencies above or below a certain cutoff frequency were eliminated. The cutoff frequencies were in octave relation to 200 cps up to 6400 cps. The frequencies were chosen in such a way that even the easiest material yielded very low scores at the worst conditions and even the most difficult material yielded fairly high scores at the best conditions. Again, the details of procedure may be found in the completed report of Hirsh, Reynolds and Joseph (2).

3. General Results

In general, the order of intelligibility among the different speech materials is the same under filtering as under masking, with one exception: the spondees are the most intelligible under masking, with polysyllables and the other two types of disyllables less intelligible, but under filtering, the polysyllables are the most intelligible while all the disyllables stay quite close together in intelligibility.

Using the nonsense-syllable articulation for different filter settings and different S/N ratios as a reference, we have compared the intelligibilities of the other materials. In general, a given syllable score does not yield the same word score under filtering as it does under masking. The differences are smallest for the monosyllabic words and greatest for the easier, longer words. In other words, even if the articulation index were found to predict univocally syllable articulation under a variety of conditions, these syllable scores would not univocally predict the scores for other types of speech material under the same conditions.

As for the validation of the articulation index itself in this study, we find that syllable scores are predicted very well from such calculation when the S/N ratio is high, that is, when the scores are being affected mostly by restricting the frequency band. When S/N ratios are low and, therefore, primarily responsible for decreasing the intelligibility of the speech, the articulation index does not predict well. We believe this lack of prediction to be based on an as yet unspecified relation between the index and the S/N ratio in any given band.

SECTION III

INCOMPLETE RESEARCH

The following studies were initiated under this contract but have not progressed sufficiently to justify publication or the reporting of detailed results.

Masking of Clicks by Noise:

1. Background

One of the interesting results reported by Hirsh and Bowman (1) in connection with the shift of the threshold of intelligibility due to increasing levels of masking noise was that the function relating threshold to noise level was sigmoid in shape when the masking noise contained only frequencies below 400 cps. Such curves bear a striking resemblance to certain curves in the classical study of Wegel and Lane (9) on the masking of tones by tones, particularly those that show the masking of a pure tone by another pure tone of lower frequency. Both of these resemble the somewhat stranger masking functions that show the masking of brief acoustic clicks or transients by noise, as reported by Hirsh, Rosenblith and Ward (10). Particularly this last paper showed masking to increase with noise level over the initial range of intensities, then to remain constant or rise only slightly over the next range of intensities and finally, to rise steeply with noise level over the highest range. It was suggested that such a function might have something to do with the relation between the spectra or frequencies of the masked and masking sounds. Such curvilinearity could be changed to linearity, for example, when both the noise and the clicks were passed through the same filter. Similarly, in the Hirsh and Bowman study (1), curvilinearity resulted when the masked sound (speech) included more frequencies than the masking sound (low-frequency bands of noise).

2. Experimental Procedure

In order to specify more precisely the relations of the spectra of the masked and masking sounds to the shape of the masking function, an extension of the study of Hirsh, Rosenblith and Ward (10) was planned. Acoustic clicks were generated by passing the output of a pulse generator to an earphone. The electrical signals were rectangular pulses of variable duration and a fixed repetition rate of 2 pulses per second. We did not attempt to manipulate the spectrum of the clicks by filtering, but rather only by varying the duration. The assumption was that the shorter the click the more emphasis would be placed on high frequencies. This is highly oversimplified, however, because the earphone itself modifies a rectangular pulse considerably. The spectrum of the noise was controlled simply by varying the upper cutoff frequency of an electronic low-pass filter.

3. General Results

The curves of Hirsh, Rosenblith and Ward (10) were reproduced when brief clicks were masked by noise containing only frequencies up to 6000 or 7000 cps. A linear function was obtained, however, when noise frequencies were allowed to extend to 20,000 cps. The break between curvilinearity and linearity appears as the spectrum of the noise begins to include frequencies above 7000 cps.

Further study is required to determine whether this frequency region depends entirely on the duration of the click (and thus, by inference, on its spectrum) or whether it depends more on the response-vs-frequency characteristic of the earphone. With such dependencies either made fast or eliminated, the role of the ear itself may then be ascertained. It is anticipated that the harmonic distortion introduced by the middle ear mechanism will figure large in determining the shape of the masking function.

Recovery from Short-Term Auditory Fatigue:

1. Background

One of the outstanding facts in the study of either temporary or permanent auditory after-effects from acoustic stimulation is high variability among individuals. In an attempt to bring some order out of the observed chaos, we wished to set up an experiment in which precisely controlled stimulating conditions might yield a few sets of observations that could be called general.

2. Experimental Procedure

Preliminary investigations involved stimulation by noise or by bands of noise for periods of time ranging from a few seconds to several minutes, while holding the stimulating intensity at either 100 db or 120 db re 0.0002 microbar. An instrument was constructed in our shop that permitted the study of a continuous threshold recovery function for a single pure tone or band of noise. Basically, this instrument is an adaptation of principles laid down in the description of a new audiometer by Békésy (11) and modified specifically for this purpose by Hirsh and Ward (12).

3. General Results

No general observations can be reported at this time. Individual variability and the variability in the same individual from time to time remains large and of enough significance to obscure general relations.

Certain specific problems, however, have been suggested by the data collected so far. For example, it is not certain that the amount of fatigue at a given time after exposure is monotonically related to the duration or the intensity of exposure. It appears possible that there are certain critical durations and/or intensities above which the fatigue may be less.

This study is to be continued and it is planned to change the experimental procedure continually until some kind of variance is revealed. In the scientific faith that order may be brought to empirical observations, we assume that these inconclusive results are not simply the result of a phenomenon that cannot be studied; rather we believe that we have not yet discovered the appropriate method of study.

Masking Spectrum for Bands of Noise:

This study was discontinued almost as soon as it was started because of our interest in and subsequent preoccupation with the masking effects of these bands of noise on speech. It is planned to use our Békésy audiometer in obtaining precise masking spectra for different bands of noise, and to give special attention to the shift in the masking spectrum as a function of the level of the noise band.

Speech Power in the Ear Canal:

At the beginning of the present contract period, some effort was expended in determining the possibility of utilizing speech power radiated from the ear canal. This was a follow-up of certain observations made under a previous contract by Hirsh and Benson (13) Dr. Benson measured not only the power but also the spectral distribution of this power and found, on one observer, that much of the high-frequency energy was absent. He has concluded, therefore, that in spite of certain advantages, such as the remoteness of the ear canal from oxygen valves, this source of speech power is not superior to speech picked up in front of the lips. It may be possible that under extremely adverse conditions such as high noise or high altitude, the ear-canal source may prove more satisfactory than the usual source, but this should be determined in a laboratory where high-altitude chambers and/or real noise sources are available.

SECTION IV

CONCLUSIONS AND SUMMARY

Completed Work:

Although variability among different talkers may introduce errors, it has been determined that the threshold of intelligibility (the level at which 50% of the words in a list are recognized) bears a linear relation to the level of a broad-spectrum noise. The signal-to-noise ratio may be as low as -15 db for very easy words in a highly contextualized, limited vocabulary and does not appear to exceed -2 db even for difficult material like nonsense syllables.

When bands of noise involving different frequency regions are employed to mask easy words (spondees), it appears that frequencies at or near 1000 cps (670-1900 cps) are the most effective.

When the intelligibility of different kinds of speech is studied in relation to the cutoff frequency of high-pass and low-pass filters, it appears that frequencies between 1000 and 2000 cps are critical. These observations crudely corroborate those in the previous paragraph. There is no evidence from these studies that easier words are more dependent on lower frequencies than difficult words. Easier words are easier and therefore require only a limited frequency band of transmission as compared to that required for more difficult words. The most important frequencies are the same in both cases.

It appears that the prediction of word intelligibility from the physical characteristics of a transmission system is only approximate, and then holds only for systems with relatively high signal-to-noise ratios. The prediction of intelligibility from the characteristics of very noisy systems will be possible only after further work.

The concept of the critical band in auditory masking, having already been validated in terms of masking, also seems to hold when defined in terms of the absolute threshold for the band. The exception at low frequencies warrants further study.

Applications for the Air Force:

With the development of more powerful military aircraft, it is apparent that the noise levels to which pilot, ground crew personnel, and air-traffic control personnel will be exposed will increase. We may reach a point where the designers of communications equipment can no longer meet present Air Force specifications under actual operation in noise. The results of our experiments on masking suggest that, unless military aircraft specifications require listeners to recognize isolated items as difficult as nonsense syllables or monosyllabic words, these specifications might be re-examined with the possible view to making them less stringent, requiring, for example, a certain amount of intelligibility for two-syllable words rather than the present 85% intelligibility for monosyllabic words.

The results of the experiments on the effect of filtering on the intelligibility of speech indicate that the potential intelligibility to be realized from a given communications system cannot be predicted precisely from its physical characteristics. It is recommended, therefore, that the acceptance or rejection of military communications equipment continue to depend in part on formal articulation tests.

In the event that higher noise levels or a crowded radio-frequency spectrum necessitate limiting the bandwidth in a given communications system, our results support the conclusion that frequencies below approximately 500 cps or above approximately 4000 cps may be eliminated without any appreciable detrimental effect to intelligibility. This conclusion should be modified by a statement that the detectability, as distinguished from the intelligibility, of speech will be enhanced by frequencies below 500 cps since the bulk of the acoustic power in speech lies in this low-frequency range. On the other hand, if a certain fixed acoustic power is available it would be better to expend the energy between 500 and 4000 cps than to redistribute it so as to include a wider frequency range.

Future Work:

From the results summarized above, certain problems present themselves immediately. First, the critical bandwidth must be measured at low frequencies with a view to correcting extant data. Second, in generalizing about the prediction of intelligibility from physical characteristics, the equivalence of masking a band of speech frequencies to eliminating that band through filtering must be ascertained. Third, and following directly from the second, we must measure the pattern of masking or the masking spectrum set up by given bands of noise in terms of absolute threshold for pure tones, in this case a threshold measured as a continuous function of frequency. These three problems are among those proposed for study under a new Air Force contract.

BIBLIOGRAPHY

1. Hirsh, I. J., and Bowman, W. D. Masking of Speech by Bands of Noise. J. Acoust. Soc. Amer., 25: 1175, 1953.

2. Hirsh, I. J., Reynolds, E. G., and Joseph, M. The Intelligibility of Different Speech Materials. J. Acoust. S . Amer. In Press.

3. Hawkins, J. E. Jr., and Stevens, S. S. The Masking of Pure Tones and of Speech by White Noise. J. Acoust. Soc. Amer., 22: 6, 1950.

4. Miller, G. A. The Masking of Speech. Psychol. Bull., 44: 105, 1947.

5. Hirsh, I. J., Davis, H., Silverman, S. R., Reynolds, E. G., Eldert, E., and Benson, R. W. Development of Materials for Speech Audiometry. J. Speech and Hearing Disorders, 17: 321, 1952.

6. Sivian, L. J., and White, S. D. On Minimum Audible Sound Fields. J. Acoust. Soc. Amer., 4: 288, 1933.

7. Fletcher, H., and Steinberg, J. C. Articulation Testing Methods. Bell Syst. Tech. J., 8: 806, 1929.

8. French, N. R., and Steinberg, J. C. Factors Governing the Intelligibility of Speech Sounds. J. Acoust. Soc, Amer., 19: 90, 1947.

9. Wegel, R. L., and Lane, C.E. The Auditory Masking of One Pure Tone by Another and its Probable Relation to the Dynamics of the Inner Ear. Phys. Rev., 23: 266, 1924.

10. Hirsh, I. J., Rosenblith, W. A., and Ward, W. D. The Masking of Clicks by Pure Tones and Bands of Noise. J. Acoust. Soc. Amer., 22: 631, 1950.

11. Békésy, G. v. A New Audiometer. Acta. Otolarygn., Stockholm, 35: 411, 1947.

12. Hirsh, I. J., and Ward, W. D. Recovery of the Auditory Threshold After Strong Acoustic Stimulation. J. Acoust. Soc. Amer., 24: 131, 1952.

13. Hirsh, I. J., and Benson, R.W. Acoustic Properties of Certain Oxygen Equipment. WADC Technical Report 52-175. United States Air Force, Air Research and Development Command. May 1952.