A Statistical Analysis of On-Off Patterns in 16 Conversations

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This is a summary of data from an extensive analysis of on-off speech patterns in 16 experimental telephone conversations. The on-off patterns are determined by a fixed threshold speech detector having certain rules for rejecting noise and for filling in short gaps (for example, from stop consonants). Distributions are obtained for ten events, including talk-spurts, pauses, double talking (simultaneous speech from both parties), mutual silence, etc. Particular emphasis is placed on events surrounding interruptions. The entire analysis is performed for three speech detector thresholds, since most of the data are strongly influenced by choice of threshold. Observations are made about the influence of threshold on the data, properties of speech invariant with choice of threshold, and differences between male and female speech patterns.

I. INTRODUCTION

A statistical analysis of the on-off speech patterns of 16 recorded conversations has been obtained by a computer program written by Mrs. N. W. Shrimpton in 1963, and recently modified by the author. The data can serve the following purposes.

(*i*) They can illustrate the effect of variation of threshold setting on the resulting speech data. This problem has been plaguing virtually all researchers who have attempted to arrive at the "basic" talkspurt-pause patterns, that is, patterns which represent the subjective on-off behavior, either as intended by the speaker or as perceived by the listener. (There is, of course, no certainty that such on-off classification actually occurs during normal talking and listening.)

(*ii*) They can guide the design of voice operated devices, such as conventional echo suppressors[1] or an adaptive transversal filter echo canceller,[2] both of which have critical timing problems in the intervals surrounding interruptions.

(*iii*) They can provide material for building stochastic models of speech patterns in conversations. Several studies have already used basic models (such as Markov processes) to approximate talkspurt and pause durations.[3,4] These models could be useful in predicting conversational behavior over special circuits, such as those containing transmission delay.

Applicability of the data to the above-mentioned purposes is influenced by the source and nature of the speech material and by the speech detector used to obtain on-off patterns. Section II is a description of the speech material, and Section III contains a description of the speech detector. This detector tries to yield patterns as close as possible to the original waveform, while making certain corrections to make the pattern representative of perceived speech patterns. These corrections, requiring two arbitrary parameters, include rejection of impulse noise operation and bridging of gaps caused by stop consonants. The third parameter, threshold, has such an effect on the data that the analysis is performed for a range of thresholds. In other respects however, the detector preserves fine details of timing of events; for example, the attack and release times are less than 5 msec.

Characterization of speech for speech detectors in the telephone system is a different problem from characterization of speech for modeling conversational speech patterns. The data of the present study are not intended to provide a basis for characterizing speech for telephone system speech detectors. Within the constraints of the corrections described in the preceding paragraph, however, the data can be extended to predict the behavior of certain speech detectors as explained in Section 5.2.

II. THE CONVERSATIONS

2.1 *Source*

Of the 16 conversations, eight, obtained from four male pairs and four female pairs, lasted about 7 minutes each and were documented in a previous paper.[5] The remaining eight, also four male and four female pairs, lasted about 10 minutes each. The subjects talked over a 4-wire circuit such as illustrated in Fig. 1. The losses were typical of a long distance call, and there were no degrading factors such as noise, echo, or delay. The voices were recorded at the zero transmission level points (0 TLP), determined to be 6 dB "away from" the transmitters. The 0 TLP is an arbitrary reference level used to establish relative levels in a telephone circuit.)

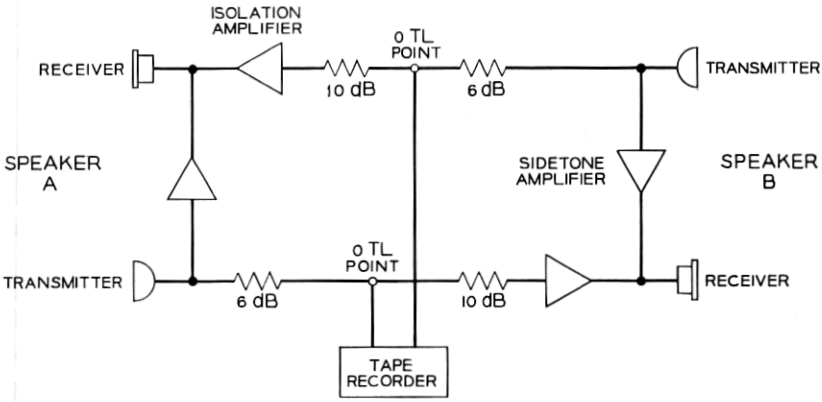

Fig. 1 — Circuit over which subjects talked.

The members of each pair were close friends; we have found that conversation between strangers can be restrained and halting. Their instructions were as follows.

"Your task in this experiment will be to converse with each other for approximately 10 minutes. You may talk about anything you wish, but keep in mind that you will be recorded. The recording will be kept private and will be used for computer analysis of speech. We ask that you *both* talk frequently; if only one person talks the conversation will be of almost no value to us."

This method seemed to produce natural conversational speech which was not restrained by the subjects' knowledge that they were being recorded.

2.2 *Scope of the Conservations*

Since the experimental conversations do not represent a random sample of calls in a telephone office, they cannot provide documentation of speech patterns on subscriber circuits. They are, however, of interest in their own right and even possess advantages over customer calls.

(*i*) The experimental calls are recorded, and can be studied for contextual material, etc.

(*ii*) The subjects are indeed conversing, rather than momentarily setting the phone down, or even switching off to other persons. In short, in the experimental calls, the subjects and tasks are known.

(*iii*) Interest in transmission work is often centered on those parts of a call with active interchange, as our experimental calls generally had. This is especially true in echo suppressor[1] and speakerphone[6] studies.

III. THE SPEECH DETECTOR

The technique of obtaining on-off speech patterns, although already documented,[5] is summarized as follows. A flip-flop is set any time speech (full-wave rectified and unfiltered) from speaker A crosses a threshold. This flip-flop is examined and cleared every 5 milliseconds, with the output being a 1 if the threshold was crossed, 0 otherwise. The resulting string of 1s (spurts) and 0s (gaps) is examined for short spurts; all spurts $\leqq 15$ msec* are erased. After this is done, all gaps $\leqq 200$ msec are filled in to account for momentary interruptions, such as those due to stop consonants. The resulting on-off pattern consists, by definition used here, of *talkspurts* and *pauses*. An identical procedure is used for speaker B.

Three thresholds have been chosen: -45 dBm0† (most sensitive), -40, and -35. These values seemed to bracket the range between excessive noise operation and insufficient speech operation. The average peak level (apl)‡ for all 32 speakers was -18.9 dBm re 0 TLP, 26.1 dB above the most sensitive threshold. If one prefers VUs, a previous study[7] showed that VUs obtained by Miss K. L. McAdoo (an experienced VU meter reader) are roughly 6 dB below the apls, hence, the average VU for that observer would have been near -25 dBm.

IV. DATA

4.1 *Approximation in the Medians*

Although all means reported here are exact (in that they equal the total time in an event divided by the number of event occurrences) the medians are not exact because the measuring intervals are arbitrarily categorized. For example, the median talkspurt at the -45 dBm threshold is somewhere between 750 and 800 msec, and is reported at 775 msec, the interval midpoint. The measuring intervals are roughly proportional to the lengths of events; the intervals are as short as 10 msec for events $\leqq 200$ msec and as long as 1 second for events $\geqq 6$ seconds.

* This was originally 10 msec, but 15 msec seems to be required for good impulse noise rejection.

† —45 dBm measured at the 0 TLP.

‡ Average peak level is a measure of speech level based on the average log rectified speech voltage.[7]

4.2 *Percent of Time Spent in Different States*

Table I shows three measures made per person or per conversation:

(*i*) Percent of time each person talked, averaged over 32 persons, obtained for each person by dividing his total speech time by the length of his conversation.

(*ii*) Percent of time in double-talking, averaged over 16 conversations.

(*iii*) Percent of time in mutual silence, averaged over 16 conversations.

Table II shows two measures made on the entire sample of 137.4 minutes of conversation: the percent of time in double talking, and the percent of time in mutual silence. Notice that mutual silence is the complement of the event that one or both speakers are talking.

4.3 *Categorized Events*

Ten events were defined and measured. Figs. 2 through 11 are cumulative distribution plots of the events. The arrows show which event is being measured. For example, in Fig. 2, which shows the talkspurt cumulative distribution, there are three events illustrated and indicated by the arrows.

The defined events are:

(*i*) Talkspurt—defined in Section III.

(*ii*) Pause—defined in Section III.

(*iii*) Double talk—a time when speech is present from both *A* and *B*.

(*iv*) Mutual silence—a time when silence is present from both *A* and *B*

Table I—Percent of Time in Different States*

State	−45 dBm Mean	σ	−40 dBm Mean	σ	−35 dBm Mean	σ
Talking (per person)	43.53	9.10	39.5	8.37	35.00	8.31
Double talking (per conversation)	6.58	3.47	4.49	2.41	3.10	1.81
Mutual silence (per conversation)	18.97	6.55	25.01	7.28	32.55	9.77

* Average of 32 persons or 16 conversations.

TABLE II—PERCENT OF TIME IN STATES FOR ENTIRE SAMPLE*

State	−45 dBm	−40 dBm	−35 dBm
Double talking	6.78	4.62	3.22
Mutual silence	19.07	24.99	32.37

* 137.4 minutes, including all 16 conversations.

(*v*) Alternation silence—the period of mutual silence between the end of one speaker's talkspurt and the beginning of the other's. Event 5 is a subset of 4. If a speaker alternation results from an interruption so that there is no mutual silence period, then an alternation silence has not occurred. (There are no negative alternation silences.)

(*vi*) Pause in isolation—a pause in which the other speaker is silent throughout the pause. Event **6** is a subset of both **2** and **4**.

(*vii*) Solitary talkspurt—a talkspurt which occurs entirely within the other speaker's silence. Event **7** is a subset of **1**.

(*viii*) Interruption—if A interrupts B, the time at which A's talkspurt begins determines the start of an interruption. The interruption terminates at the end of A's talkspurt, unless B stops and then interrupts A, in which case A's interruption terminates upon B's counter interruption.

(*ix*) Speech after interruption—if A interrupts B, the remainder

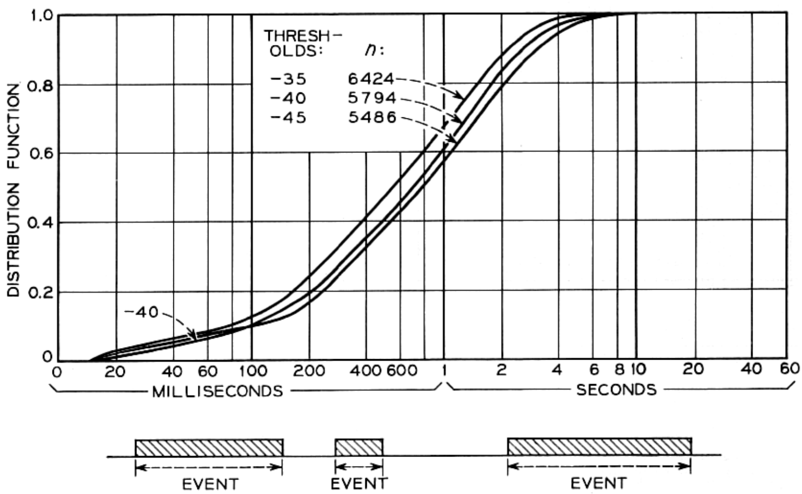

Fig. 2 — Talkspurts for 32 speakers.

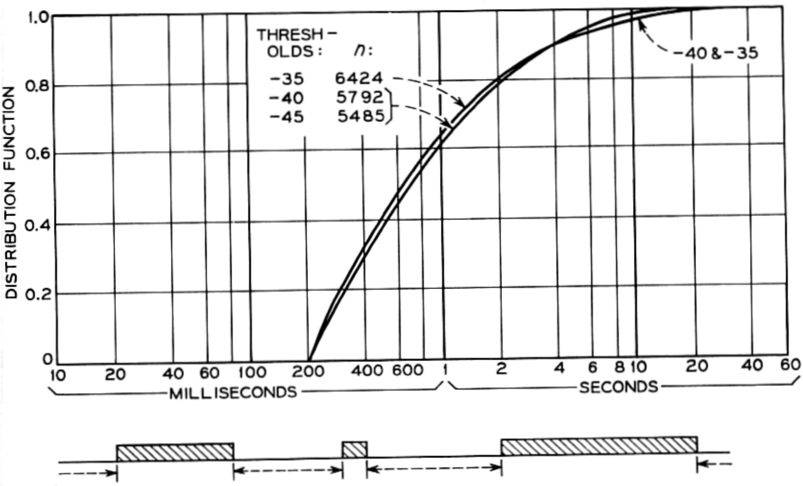

Fig. 3 — Pauses for 32 speakers.

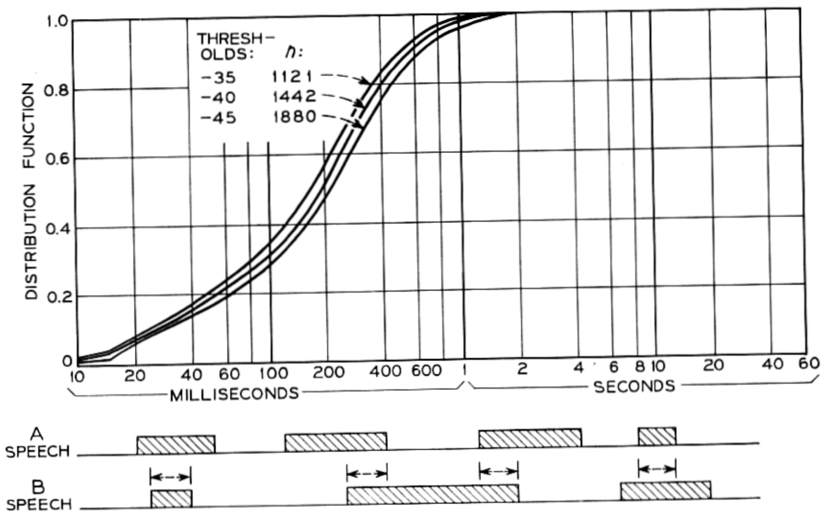

Fig. 4 — Doubletalk for 16 conversations.

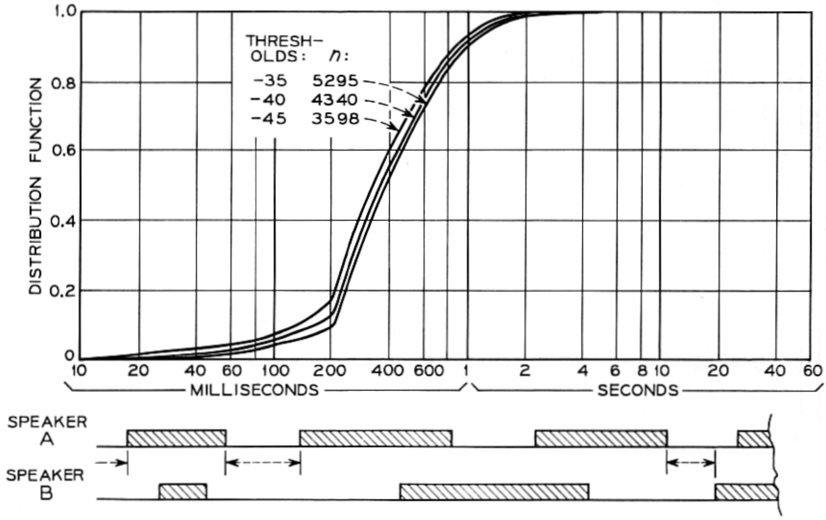

Fig. 5 — Mutual silence for 16 conversations.

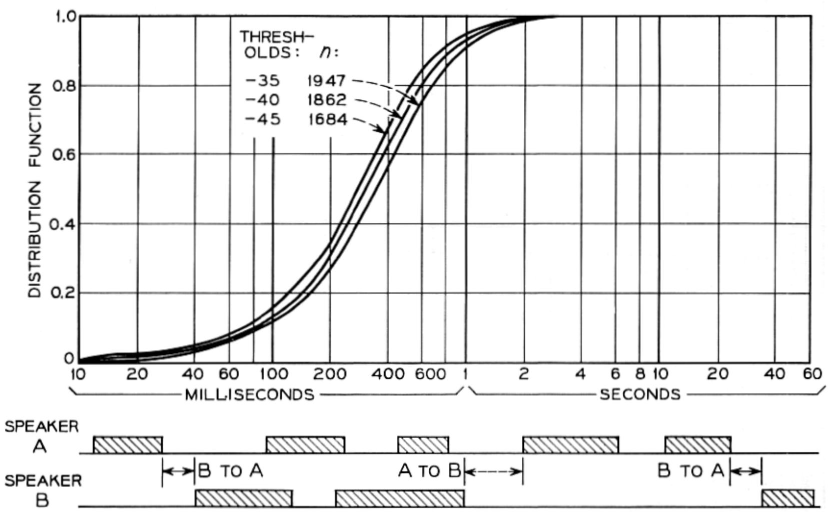

Fig. 6 — Alternation silences for 32 subjects. *A* to *B* and *B* to *A* have been combined.

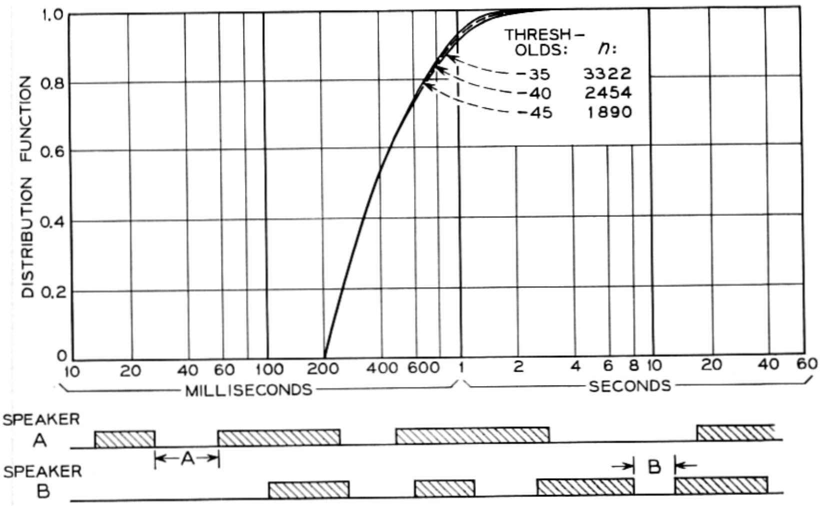

Fig. 7 — Pauses in isolation for 32 subjects. Events from *A* and *B* have been combined.

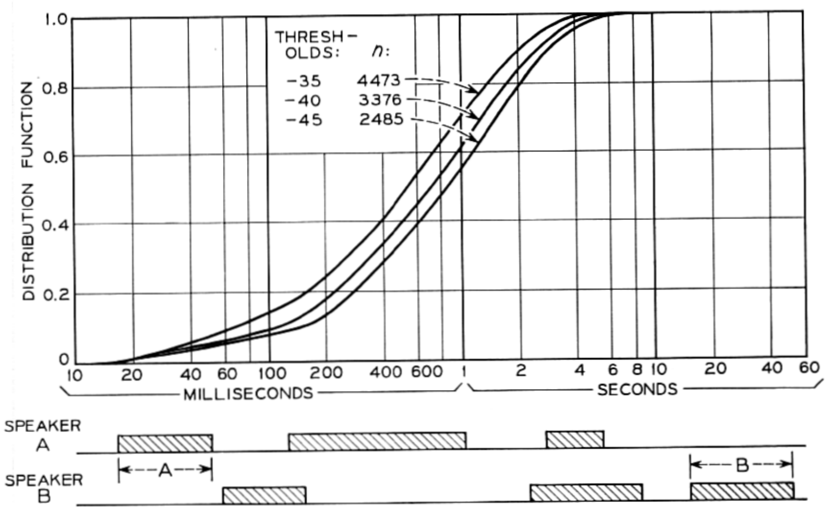

Fig. 8 — Solitary talkspurts for 32 speakers. Events from *A* and *B* have been combined.

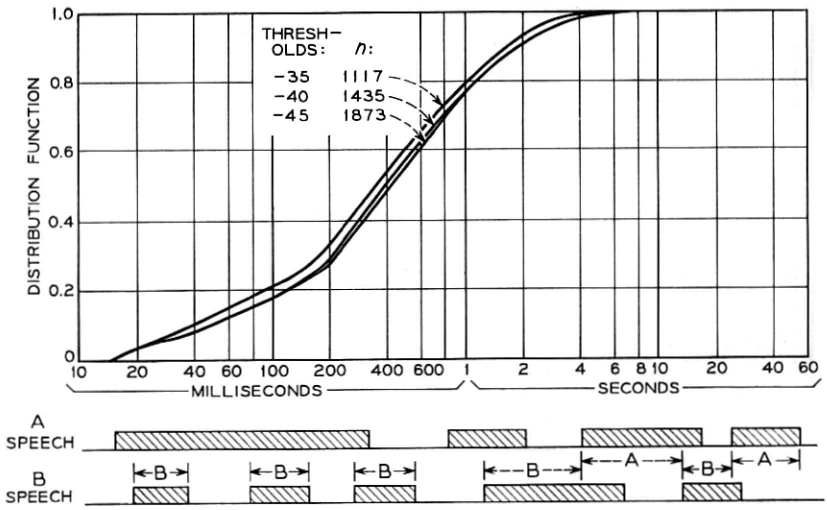

Fig. 9 — Interruptions for 32 speakers. Events from A and B have been combined.

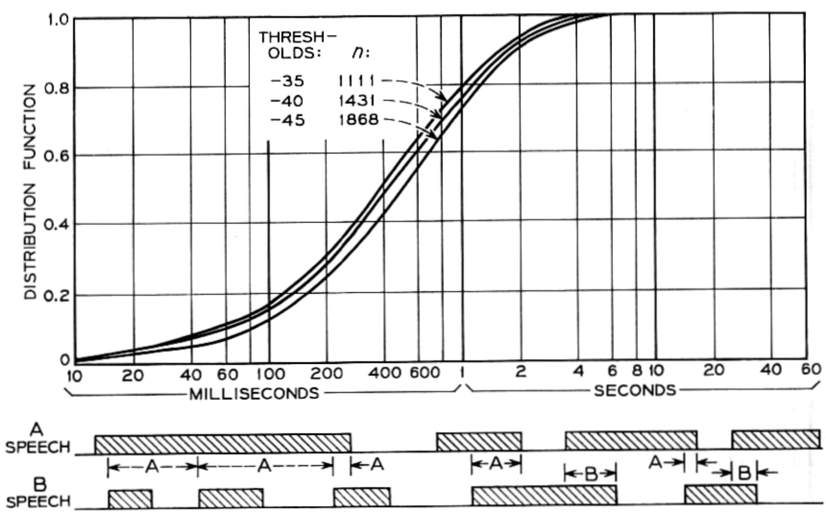

Fig. 10 — Speech after interruption. Events from A and B have been combined.

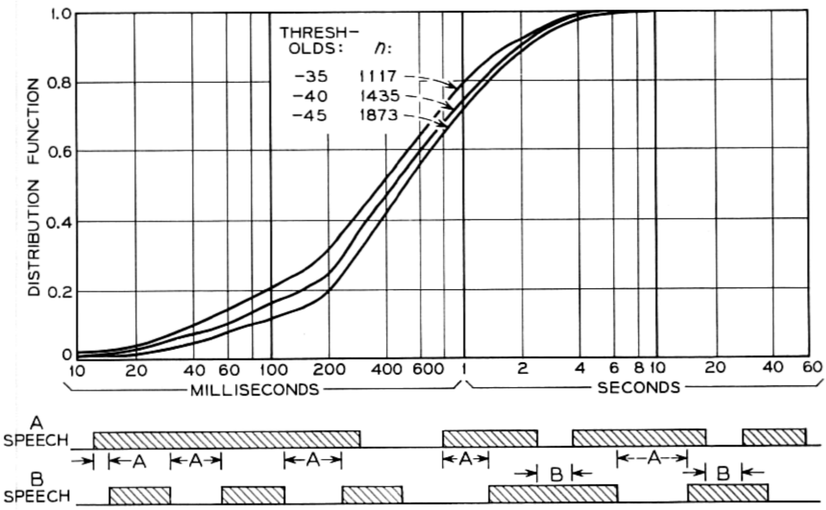

Fig. 11 — Speech before interruption. Events from A and B have been combined.

of B's talkspurt is entered here, unless A pauses and then again interrupts the same B talkspurt. The first "speech after interruption" would terminate upon A's reinterruption, and a second speech after interruption would begin.

(x) Speech before interruption—if A interrupts B, B's speech interval up to the interruption is entered here. If A then pauses at time t_1 and reinterrupts at time t_2, (assuming B continues talking), a new B speech before interruption (t_2–t_1) is entered. If A continues talking and B pauses and then counter interrupts, the length of B's pause is entered as A's speech before interruption.

4.4 *Tabulated Events for the Entire Sample*

Table III lists the mean, median, and number of events for talkspurts, pauses, and doubletalks of the entire 137.4-minute conversation sample. Notice that the talkspurts and pauses represent 274.8 minutes of speech, since the A and B speech samples can be separated and placed end to end.

4.5 *Means and Sigmas for Averages of Events*

Table IV lists the means of the *averages* of the categorized events per person (or in some cases per conversation). For example, the

TABLE III — DURATIONS OF CERTAIN EVENTS FOR ENTIRE SAMPLE*

Event	−45 dBm Mean	−45 dBm Median	−45 dBm No. of Events	−40 dBm Mean	−40 dBm Median	−40 dBm No. of Events	−35 dBm Mean	−35 dBm Median	−35 dBm No. of Events
	(seconds)			(seconds)			(seconds)		
Talkspurt (274.8 min)	1.311	0.775	5486	1.125	0.675	5794	0.902	0.575	6424
Pause (274.8 min)	1.695	0.725	5485	1.721	0.725	5792	1.664	0.675	6424
Double talk (137.4 min)	0.296	0.213	1880	0.262	0.185	1442	0.235	0.165	1121

* 137.4 minutes of conversation, or 274.8 minutes of speech.

mean talkspurt length of 1.366 second for a −45 dBm threshold is the average of 32 numbers, each in turn being the average talkspurt length for a particular speaker. The σ reported* is the standard deviation of the 32 (or 16) averages among speakers (or conversations).

TABLE IV — MEANS AND STANDARD DEVIATIONS OF THE AVERAGES OF EVENTS*

Event (k)	−45 dBm Mean (seconds)	−45 dBm σ	−40 dBm Mean (seconds)	−40 dBm σ	−35 dBm Mean (seconds)	−35 dBm σ
Talkspurt (32) $n \sim 181$†	1.366	0.442	1.197	0.444	0.980	0.425
Pause (32) $n \sim 181$	1.802	0.639	1.846	0.648	1.742	0.663
Double talk (16) $n \sim 90$	0.280	0.061	0.251	0.055	0.223	0.058
Mutual silence (16) $n \sim 271$	0.425	0.088	0.466	0.088	0.495	0.080
Alternation silence (32) $n \sim 58$	0.345	0.104	0.397	0.116	0.456	0.126
Pause in isolation (32) $n \sim 77$	0.488	0.093	0.502	0.092	0.512	0.091
Solitary talkspurt (32) $n \sim 106$	1.359	0.503	1.173	0.453	0.955	0.422
Interruption (32) $n \sim 45$	0.792	0.266	0.742	0.303	0.695	0.354
Speech after interruption (32) $n \sim 45$	0.867	0.366	0.775	0.336	0.650	0.277
Speech before interruption (32) $n \sim 45$	0.895	0.282	0.831	0.358	0.673	0.316

* Per person ($k = 32$) or per conversation ($k = 16$).
† Values of n were obtained by dividing the total number of events for −40 dBm threshold by k. These numbers thus give a rough idea of the frequency of these events per person (or conversation). These same values also apply to Table V.

4.6 *Means and Sigmas for Medians of Events*

Table V lists the means of the *medians* of the categorized events per person (or conversation). For example, the "average of median" talkspurt length of 0.788 second for a −45 dBm threshold is the average of 32 talkspurt medians, with 0.229 second as the standard deviation of the 32 medians among speakers.

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* $\sigma = [(n/n - 1) \times (\text{sample variance})]^{1/2}$ through this paper.

4.7 *Male vs Female*

Table VI lists the means of the averages of the events per person or conversation, for the men and women separately. (Data on averages of the medians are available from the author.)

4.8 *Transitional Probabilities*

As we mentioned, some researchers have postulated first-order Markov processes to model speech patterns. A conversation, at any instant, can exist in one of four states depending on who is talking:

TABLE V—MEANS AND STANDARD DEVIATIONS OF THE MEDIANS OF EVENTS*

Event (k)	−45 dBm Mean (seconds)	−45 dBm σ	−40 dBm Mean (seconds)	−40 dBm σ	−35 dBm Mean (seconds)	−35 dBm σ
Talkspurt (32)	0.788	0.229	0.756	0.250	0.652	0.307
Pause (32)	0.759	0.184	0.779	0.193	0.706	0.195
Double talk (16)	0.199	0.048	0.181	0.046	0.153	0.047
Mutual silence (16)	0.332	0.056	0.366	0.056	0.378	0.045
Alternation silence (32)	0.264	0.082	0.312	0.101	0.347	0.096
Pause in isolation (32)	0.397	0.091	0.389	0.079	0.384	0.069
Solitary talkspurt (32)	0.890	0.326	0.799	0.325	0.660	0.344
Interruption (32)	0.418	0.218	0.405	0.218	0.387	0.233
Speech after interruption (32)	0.487	0.156	0.410	0.144	0.383	0.166
Speech before interruption (32)	0.503	0.160	0.439	0.151	0.346	0.148

* Per person ($k = 32$) or per conversation ($k = 16$).

neither, A, B, or both. If the conversation is in state i ($i = 1,2,3,4$) at some time t, it may be of interest to know the probability of being in state j ($j = 1,2,3,4$) at $t + \Delta t$, possibly to establish a crude Markovian model for distributions of times in each state. Notice, however, that the simplest Markovian model will predict that each state will have an exponential distribution, which is a hypothesis not generally supported by the data. (For example, mutual silence is the event representing the first state, and a glance at Fig. 5 shows that this distribution is strongly colored by the 200 msec fill-in time.)

This paper is primarily a collection of data, and is not intended to pursue the problem of modeling conversational behavior. We shall therefore simply list the transition matrix for the −40 dBm threshold*

* Transition probabilities for the other thresholds may be obtained from the author.

TABLE VI—MEANS OF AVERAGES OF EVENTS

Event	Threshold (dBm)	Male	Female	Signif. Level*	M −40† F −45	M −35 F −40
Talkspurt	−45 −40 −35	1.503 1.393 1.221	1.229 1.000 0.739	— 0.01 0.01	—	—
Pause	−45 −40 −35	1.911 2.003 1.885	1.690 1.690 1.598	— — —	—	—
Double talk	−45 −40 −35	0.278 0.247 0.235	0.282 0.256 0.211	— — —	—	—
Mutual silence	−45 −40 −35	0.452 0.491 0.506	0.397 0.441 0.484	— — —	0.05	—
Alternation silence	−45 −40 −35	0.354 0.403 0.448	0.336 0.391 0.464	— — —	—	—
Pause in isolation	−45 −40 −35	0.523 0.533 0.533	0.453 0.471 0.492	0.05 — —	0.05	0.05
Solitary talkspurt	−45 −40 −35	1.510 1.377 1.204	1.207 0.969 0.706	— 0.01 0.01	—	—
Interruption	−45 −40 −35	0.807 0.821 0.811	0.777 0.662 0.578	— — —	—	—
Speech after interruption	−45 −40 −35	0.963 0.840 0.741	0.770 0.710 0.559	— — —	—	—
Speech before interruption	−45 −40 −35	0.793 0.648 0.484	0.997 1.014 0.862	0.05 0.01 0.01	—	0.05

* Compares events at a common threshold.

† Compares males at −40 dBm with females at −45 dBm threshold; similar for last column. All significance levels from *t*-test.

in Table VII. The table indicates transition probabilities for 5 msec time steps. For example, if both are talking, the probability is 0.98095 that they will still both be talking 5 msec later. The conversation will, therefore, leave the state with $p = 1.0 - 0.98095 = 0.01905$. If a Poisson termination process* is assumed for terminating the event, the conversation would leave the state in 1 msec with $p = 0.01905/5$.

V. OBSERVATIONS

Events of one subject that do not involve interaction with talkspurts of his partner include pauses in isolation and solitary talkspurts. Data on behavior during double talking should be contrasted

TABLE VII — TRANSITION PROBABILITIES OF CHANGING STATE*

From \ To	Neither	A	B	Both
Neither	0.98940	0.00529	0.00530	0.00001
A	0.00387	0.99486	0.00001	0.00126
B	0.00367	0.0	0.99510	0.00123
Both	0.00005	0.00885	0.01015	0.98095

* In a 5-msec Period for the −40 dBm Threshold Condition.

with data on these "isolated" events rather than, for example, the distribution of all talkspurts, since this distribution includes events during double talking.

The data are notably influenced by threshold changes. The author does not believe it is possible, from results reported here, to establish a single "correct" threshold. It is possible, however, to draw certain conclusions which are threshold independent (see (*vi*) and (*vii*) below, and Section 5.2.)

5.1 *The Data*

We know from the data that:

(*i*) As the threshold is raised (speech detector made less sensitive), events which measure periods of talking tend to decrease in length, since the longer events tend to be broken up into short ones. These

* A good discussion of Poisson and Markovian processes may be found in Reference 8.

events include talkspurts, double talks, solitary talkspurts, interruptions, and speech before and after interruption.

(*ii*) As the threshold is raised, events which measure periods of silence tend to increase in length. These events include pauses, mutual silences, alternation silences, and pauses in isolation.

There are some individual speaker exceptions to these observations. For example, male No. 14 talkspurt averages are 1.683, 1.620, and 1.759 seconds for −45, −40, and −35 dBm thresholds, respectively. Two other male speakers exhibit such a reversal for talkspurts. In general, however, conclusions drawn from the gross data are true of most speakers or conversations.

(*iii*) The distribution functions of events resulting from periods of talking seem in general more strongly affected by threshold shifts than those resulting from silences. Compare, for example, talkspurts vs pauses, or solitary talkspurts vs pauses in isolation. The mutual silence distribution, however, seems strongly influenced by threshold changes.

(*iv*) For all events, the number of times they occur (n) is notably influenced by the threshold. This is particularly true of pauses in isolation, whose distribution remains virtually unaffected while n changes from 1890 to 3322 for a 10 dB threshold shift.

(*v*) As the threshold is raised, the number of talkspurts tends to *increase*. This trend will obviously be reversed if the threshold becomes so high that only a few spurts of energy clear it. But for low thresholds, as threshold is raised, long talkspurts are apparently being broken up into shorter segments at a faster rate than that of low level talkspurts being left below the threshold.

(*vi*) For any particular threshold, the cumulative distributions of speech before and after interruption are practically identical, as seen from a comparison of Figs. 10 and 11.

(*vii*) Interruptions tend to be much shorter than solitary talkspurts, as would be expected because the interrupter might merely be trying to get attention rather than make a statement. Also, some interruptions are really not deliberate interruptions but rather acknowledgments, such as "uh huh" and "um." This effect may be seen, for example, at the −40 dBm threshold for which 17 percent of the interruptions are less than 100 msec long, while only 9.5 percent of solitary talkspurts are less than 100 msec.

(*viii*) Many speech detectors operate with a hangover, rather than a fill-in, to bridge short gaps. By shifting the talkspurt distribution 200 msec to the right and the pause distribution 200 msec left, one can determine the distributions for these events which would have resulted if a 200-msec hangover were used instead of fill-in. However, the "interaction event" (double talking, etc.) distributions will be changed in a manner which cannot be determined from our present data.

5.2 *Male vs Female Speech*

Table VI shows that when male and female speech is compared at the same threshold, four events show a statistically significant difference:* talkspurt, pause in isolation, solitary talkspurt, and speech before interruption. With the exception of pause in isolation, which is significant only at −45 dBm threshold, these are events resulting from talking rather than silence.

Some of the apparent difference in male and female speech may result from a difference in average levels. The average speech level for the females was 5.94 dB below the average male speech level (measured in apl). When male speech at −40 dBm threshold is compared with female speech at −45 dBm, and when male speech at −35 dBm is compared with female speech at −40 dBm, thus roughly compensating for the average 6 dB level difference, the significant differences previously observed tend to disappear. New events—pause in isolation, and possibly mutual silence and speech before interruption—become significant. It thus appears not possible to completely eradicate differences in male and female speech with a simple level adjustment, although a level difference does account for differences observed in certain events.

These conclusions are of particular interest in view of a recent study by Krauss and Bricker,[9] who made measurements of verbal interaction (measured from transcripts of the conversations) when pairs of men and pairs of women talked over a circuit containing voice-operated, fixed threshold devices. The verbal behavior of the two sexes was significantly different in certain tasks. One wonders if the devices operated differently on the male and female speech, as they did in the present study. This could be a contributing factor in bringing about the behavioral difference reported by Krauss and Bricker.

VI. CONCLUSION

We hope that the publication of these data will encourage other researchers to make further observations leading toward a general

* Differences are significant at $\leqq$ 0.05 level.

model of the speech patterns occurring in conversations. We also hope that by emphasizing the events surrounding double talking and other speaker interaction, it may be possible to draw conclusions regarding difficulties in conversing on certain circuits that have voice-operated devices.

VII. ACKNOWLEDGMENTS

I am especially grateful to Mrs. Lynn Evans, who cheerfully spent considerable time making hand tallies and desk-calculator analyses of the computer printouts, and to C. J. Gspann, who set up the interface between the speech detector and computer.

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