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The Effects of Transmission Delay in Four-Wire Teleconferencing*

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The effects of transmission delay upon the performance of a three-party teleconference were investigated using a problem-oriented task. The teleconference was simulated in the laboratory using 4-wire telephone sets interconnected to form a three-party conference network without echo sources or echo control devices. The two experimental conditions were characterized by (a) a network whose three legs provided transmission delays of 600-milliseconds, 300-milliseconds and no delay, and (b) a network each of whose three legs provided no transmission delay. It was found that: (i) time to complete the experimental task was 28 percent greater in the delay condition than in the no-delay condition, (ii) the error rate was less in the delay condition than in the no-delay condition, (iii) time-per-trial decreased with successive trials in both delay conditions; time-per-trial was less in the no-delay condition than in the delay condition, and (iv) no chairmanship pattern developed as a result of time delay in the network. Moreover, not one of the subjects reported having observed the existence of delay in the voice path. There were, however, more complaints of "talking together" in the delay condition.

I. INTRODUCTION

Two technological developments have recently entered the field of international communication. The first is the advent of the communi-

* This paper is drawn from the author's thesis which has been accepted by the University of Pennsylvania in partial fulfillment of the requirements for the degree of Master of Science.

cation satellite. The second is the now widespread ability to establish teleconferences (telephone conference calls).* Relatively little is directly known about either of these by itself, let alone how they may interact. This paper represents an attempt to systematically experiment with time-delayed communication in the context of conference telephony. The research examines the influence of the delay factor upon human teleconferencing performance on a given task and also explores the development of group structure in a network having several time delays.

In the present connection, the significant factor resulting from the use of a satellite is the relatively large amount of time delay introduced into the signal transmission. Riesz and Klemmer[1], in a study of delayed conversation between two people, found that round-trip delays less than 600-milliseconds do not degrade the acceptability of the circuit. Mitchell[2] and Emling and Mitchell[3] have given the significant parameters of time delay for various types of satellites. Low orbit satellites (with a typical round-trip time delay of 100 milliseconds) and medium orbit satellites (with 190 milliseconds) should cause little trouble because of time delay. Hence, this paper investigates the effects on teleconferences resulting from signal delays introduced by a synchronous satellite (with a total round-trip time delay of 540 milliseconds).

We consider first the effects of time delay on the communication process. In a study of the length of reference phrases used in a conversation between two people to describe ambiguous figures over telephone circuits, Krauss and Weinheimer[4, 5] found that the length of reference phrases decreased on each successive occasion the figure was mentioned, eventually reaching a lower limit of one word. In a related but yet unpublished study, they found that when the circuit was degraded by the introduction of voice-operated devices, the mean number of words to describe the ambiguous figure was higher on the first occasion and decreased at a slower rate than when the telephone circuit was of standard quality.

Viewed collectively, these findings tend to indicate that a degraded circuit disrupts the communication process and that learning (evidenced by the decreasing length of reference phrases on successive references) is greatly slowed down. Hence, one might expect that time delay in a teleconference network could also degrade the communication and slow down the learning process.

* In the context of this paper, a teleconference is a conference among at least three people using standard telephone sets.

In their study of naturally occurring conversations between two people, Riesz and Klemmer[1] found that subjects did not find round-trip delays of 600 and 1200 milliseconds objectionable. The criterion used to measure "objectionality" in that circuit was the number of times each of the subjects rejected the delayed circuit for a normal one. Riesz and Klemmer chose to deal with naturally occurring speech since other studies have shown that the subtle conversational difficulties produced by delay do not often occur in structured conversations.

As long as one person does all the talking, it is impossible to detect the presence of even very large delays. The natural speech simply arrives a few seconds late. Likewise, the presence of delay will be unnoticed in highly structured conversation, where it is agreed beforehand that one person will not begin talking until the other has stopped. There are simply longer pauses between talk spurts.

Delay plays an increasingly significant role in a nonstructured conversation. When the communication involves elements of information exchange, persuasion, or negotiation, the quality of the communication channel becomes more critical. For instance, in such teleconferenced conversations it is sometimes necessary to cut a person off for questioning or voicing objection. Consider a time-delayed conversation between two people, A and B where t is the one-way delay of the circuit. When A cuts into B's speech, he is heard by B t seconds later at which time B stops talking (assuming B has zero reaction time). A, however, continues to hear B for another t seconds. Hence, for period $2t$ (the round-trip time delay of the circuit) both people are talking simultaneously. If there are more than two people in the conference and some (or all) of them are talking simultaneously, disorder may result.

An alternative to the naturally occurring speech technique in evaluating a communication system is the use of a problem solving task. The advantage of using a specified task over the naturally occurring speech technique is that the nature of the communication can be more closely controlled. Conceivably, naturally occurring speech could range from idle chit-chat to high-level negotiations with the characteristics of the conversation varying greatly even within a given class of teleconference. Consequently, it is desirable to test the teleconference facility using a task that simulates the pertinent characteristics of anticipated conferences.

We next turn to the aspects of group behavior which apply to teleconferences. Here a number of parameters are of importance such as

nature of conference, size of group, network configuration, and whether or not a chairman is designated. The nature of the communication will be the most important factor governing the proceedings of the conference. A large conference in which one member gives instructions or information to all others will certainly be quite different from a conference in which three of four heads of state attempt to negotiate a settlement to an impending crisis. Consequently, it is difficult to investigate teleconferences without first defining the nature (information exchange, lecture, problem solving, persuasion, negotiation, etc.) of the conference.

The size of the group is a particularly significant parameter in teleconferences. It is of even greater importance than in face-to-face conferences because of the greater difficulty in identifying participants due to the lack of nonverbal cues (Sinaiko[6]). A group size of three is the simplest form of teleconference possible. Here, the possibility of a deadlock is minimized since the minority is an isolated single person.

The third important parameter is the network configuration. Bavelas et al[7] have found that two basic configurations are of importance: one having a common circuit and one having a central control. Common circuit networks are those in which all participants can hear when any one of them talks. Central control networks are those over which all parties transmit to a single station which in turn can relay the message to all others. Note that the central control network lends itself naturally to strong chairmanship; while the chairman in a common circuit network must depend on rules and protocol to maintain order.

In a study on teleconferencing, Heise and Miller[8] found that an information collection task (completing a list of words; each subject having part of the list) was performed most rapidly using a common circuit network while a task requiring assembly plus coordination was performed most rapidly using a central control network with a chairman in charge. They also found that the differences between networks become more pronounced as "noise" is introduced into the communication channel. As "noise" they used white noise.

Sinaiko[6] found that in one teleconference, the chairman did not add to the effectiveness of the meeting because he had no means of enforcing his decisions. He found also that when using four conferees and acceptable circuits it was not difficult to consistently identify each voice. In a large teleconference of 12 participants in which the issue of chairmanship was deliberately left vague, a chairman did seem to emerge. When the conferees were asked whether a chairman emerged they generally agreed that the man who volunteered to call the roll

during the first few minutes of the conference was regarded as the chairman.

In a time-delayed multiparty teleconference in which a chairman has not been designated, it is of interest to determine whether or not any one position in the network would be favored for the emergence of a chairman. Consider the network depicted in Fig. 1 to be used in the present study. The three positions A, B, C are separated from a central point (telephone company conference operator) by one-way delays of 600, 0, and 300 milliseconds, respectively. The psychologically relevant factor here is the round-trip delay between any two given persons in the network.

One might anticipate (Bavelas[9] and Guetzkow and Simon[10]) that the person occupying the position of "relative centrality" would most likely emerge as chairman. The central position is that position which is closer than any other position to all other positions. Hence, using time delay as a measure of distance, this theory predicts that B will emerge as chairman. It is felt, however, that the delays depicted in the figure are insufficient to overshadow those personality factors which are thought to determine the normal development of group structure.

II. PURPOSE

An experiment was run to investigate the subjective reaction to large time delays (experienced in synchronous satellite communication) in a three-party teleconference. The network simulated a teleconference whose three legs consisted of one satellite link, two satellite links, and no satellite link, respectively. Each satellite link had a one-way delay of 300-milliseconds. The two experimental conditions were specified by:

(*a*) Delay condition — a network, Fig. 1, in which one leg is delayed

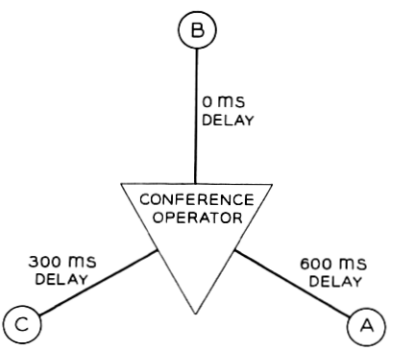

Fig. 1 — Network configuration.

600 milliseconds, another is delayed 300 milliseconds, and the third is undelayed.

(*b*) No-delay condition — a network in which each of the three legs is undelayed.

All other parameters remained the same between experimental conditions. No attempt was made to simulate echo or the effect of echo suppressors even though they would be expected to play an important role in actual satellite communication.

The two experimental conditions were tested using a task which required the subjects to communicate over the teleconference network about ambiguous figures (in the sense that they do not evoke a common reference phrase). Such ambiguous figures have been used previously by Krauss and Weinheimer to test circuit quality in circuits containing voice switching devices and in circuits containing delay. Subjects were faced with the task of describing the figures appearing on each of their stimulus cards and identifying the figures which were common to all three of them. There were 22 such trials.

With respect to the above defined task and the two experimental conditions it was hypothesized that:

(*i*) Time-on-task will be greater in the delay condition than in the no-delay condition.

(*ii*) There will be no difference in accuracy on task between the delay and the no-delay condition.

(*iii*) Time-per-trial will decrease with successive trials in both delay conditions. For each trial, time-per-trial will be greater in the delay condition than in the no-delay condition.

(*iv*) No one position in the network is likely to emerge as a seat for a chairman in the delay condition.

III. METHOD

3.1 *Procedure*

Upon arrival at the laboratory, subjects were introduced to each other. They were then given verbal instructions by the experimenter. Essentially they were told that they were to participate in a conference call as though each one of them were in a different country and that their voices would be transmitted to one another over simulated satellite circuits. They were told that the purpose of the study was to determine the effects of satellites on telephone communication. Subjects were not told whether or not their network contained delay.

After receiving instructions, subjects entered individual rooms and picked up telephones they found there. They were asked by the experimenter over the telephone to give their name, room number, and a listing of letters that were associated with the task. All subjects could hear the questions and answers. This was to identify the names with the voices and to give the subjects a "feel" for the circuit.

Subjects then began their task. If there were any misunderstandings, they were assisted by the experimenter. This rarely happened beyond the first minute of the task. After completing the task, subjects were individually interviewed by the experimenter and were then told not to discuss the details of the task with their friends since they might also be used as subjects later.

Experimental sessions lasted about 30 minutes and were spaced 45 minutes apart. Each group participated in only one delay condition.

3.2 *Experimental Task*

The three subjects, each in an acoustically isolated room, talked together over seemingly normal telephone sets. Before them on a table was a set of 22 cards each numbered, and mounted in a desk calendar holder. The holder kept the cards in order and presented only one card at a time.

Before entering their rooms, the subjects were told that on each card of their set were stamped five nondescript figures. They were told that two of those figures appeared on all of the cards while the other three figures appeared only on their own cards. Fig. 2 shows a sample stimulus card. By describing the figures to each other, they were to find out which were the two figures held in common. After agreeing on the first figure on card 1, each subject read the letter under it. They next located the second figure on that card, and each read the letter under it. They were then told to turn to card 2 and continue.

The two common figures were selected at random (using a table of random numbers) from a set of 11 figures. Any given figure appeared as a common figure twice in cards 1 through 11 and twice in cards 12 through 22. No figure was a common figure on both of two adjacent cards. The common figures were placed at random positions on the cards. Common figures appeared an equal number of times in each position on the cards of each set. The noncommon figures were selected from the remaining nine figures and placed randomly on the cards. The total number of appearances of all figures were equal for each set of cards.

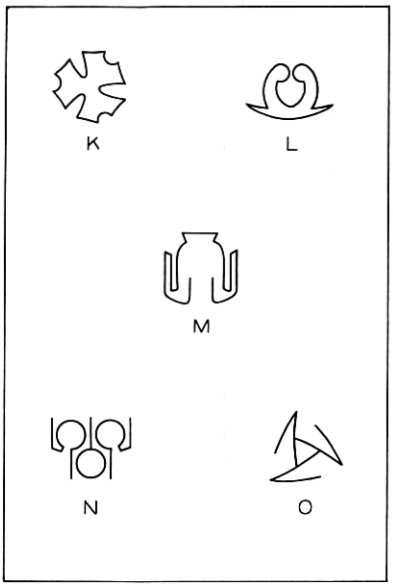

Fig. 2 — Sample stimulus card.

3.3 *Apparatus*

The experiment was run in the Customer Services Appraisal Laboratory of Bell Telephone Laboratories at Holmdel, New Jersey. The laboratory consists of five acoustically isolated rooms designed for psychological testing.

The network configuration for the experiment is given in Fig. 3. When the experiment was run in the no-delay condition, the delay units were physically removed from the circuit. The network employed 4-wire circuits providing isolation between receive and transmit paths. This was necessary to prevent echo and to interface with the magnetic disc delay units (Echo Vox Sr.) which are one-way devices. The delay units were calibrated for 600-milliseconds delay and 300-milliseconds delay, respectively.

Because of the need for 4-wire circuitry, the standard 500-telephone set was modified as in Fig. 4. Artificial sidetone was provided and loss and circuit noise were adjusted to values representative of standard telephone circuits.

The conference bridge was a standard 4-wire 6-branch bridge providing 19.5 dB net loss. Only four of the branches were used in the circuit — three for the participants and one for the monitor. The am-

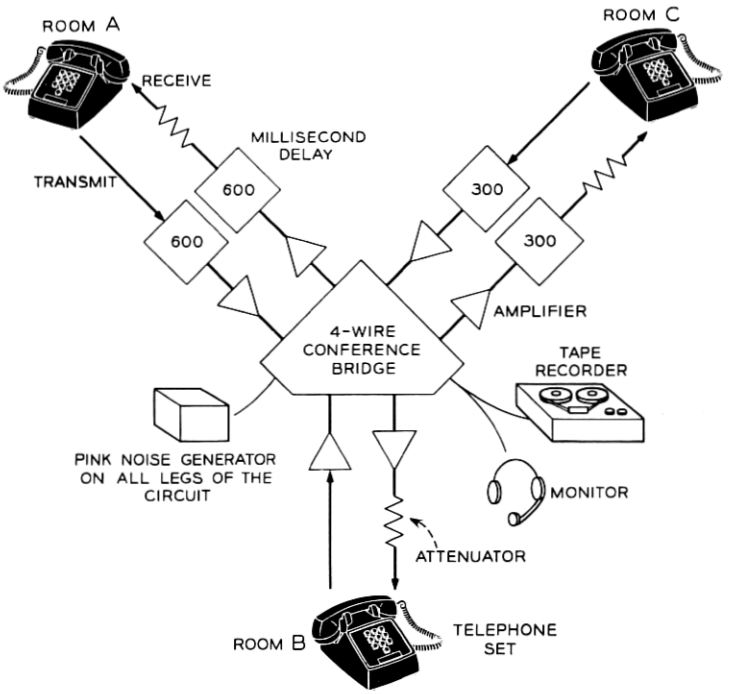

Fig. 3 — Experimental configuration.

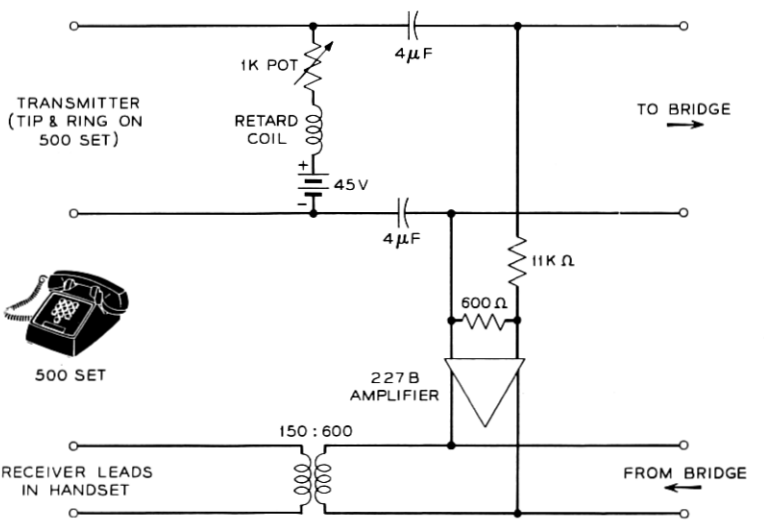

Fig. 4 — Modification of 500 type telephone set.

plifiers at the bridge were adjusted to provide unity gain through the bridge in all directions.

3.4 *Participants*

The 36 subjects were employees of Bell Laboratories and were female clerks with roughly the same job classification. Their ages ranged from 18 through 25. All had at least a high school education. The subjects were unacquainted with the experimenter at the outset of the study and were volunteers recruited by members of the Appraisal Laboratory. Most of the subjects were at least vaguely acquainted with the other members of their experimental group.

3.5 *Scoring*

All measurements were made from the recorded tapes of the sessions. In all but one or two instances, the experimenter was able to identify the person talking from the tape. The tapes were first played to make an overall time measurement, to determine which participant spoke first, to determine which participant offered her letter first, to determine which of the two common figures were found first, to detect any errors, and to become familiar with the progress of the session. The tape was then replayed to obtain time-per-figure measurements. In addition, a questionnaire provided subjective data.

IV. RESULTS

Table I presents the overall time each group spent on the experimental task. The average time to complete the task in the no-delay condition was 13.43 minutes while in the delay condition 17.23 minutes. A t-test was applied to these data to determine whether or not transmission delay had an effect on time to complete the task. The t-test ($t_{10} = 3.81$, $p < 0.01$) indicated that time-on-task was significantly greater in the delay condition.

Hypothesis (*ii*) postulated there would be no difference in accuracy on the experimental task between the delay and the no-delay condition. Accuracy was measured by noting every occurrence of an incorrect identification of a figure made by an individual. For any given figure, at most two errors could be made since the person describing the figure always correctly identified it by reciting the letter appearing under that figure. The data on accuracy are summarized in Table I.

It was possible for the individuals in any one group to make a total of 88 errors on the task. Note that the greatest number of errors

TABLE I — TIME-ON-TASK AND TOTAL ERRORS MADE BY INDIVIDUALS FOR EACH GROUP

Group	No-Delay	
	Time-on-Task (min.)	Errors
1	15.37	3
2	14.47	0
3	13.74	6
4	11.97	4
5	14.01	0
6	11.30	0
	Average: 13.48	Total: 13
	Delay	
7	17.43	0
8	18.58	0
9	16.72	1
10	15.07	1
11	20.02	0
12	15.58	0
	Average: 17.23	Total: 2

(made by Group 3) is 7 percent of this maximum. Of a possible total of 528 errors among all six groups in each experimental condition, 13 errors (2.5 percent of total possible) were made in the no-delay condition while two errors (0.4 percent of total possible) were made in the delay condition. A Poisson distribution test on these data indicates that the no-delay error rate is significantly (0.01 level) greater than the delay error rate (see Ref. 11).

Hypothesis (*iii*) stated that time-per-trial would decrease with successive trials in both delay conditions and that for each trial, time-per-trial would be greater in the delay condition than in the no-delay condition. The time measurements per trial are an average of the times for identfying the two figures on each of the 22 stimulus cards. Fig. 5 presents the time-per-trial averaged over the six groups in each circuit condition plotted on a log scale.

A 2-factor (22 trials × 2 circuit conditions) analysis of variance under a logarithmic transformation of the data was carried out. The logarithmic transformation was employed to reduce heterogeneity of variance and because an exponential-shaped function was found. The logarithms of time-per-trial and trial number fit a least squares linear regression model with 0.9 correlation coefficient.

As can be seen from Fig. 5, the time-per-trial decreases on successive trials for both circuit conditions. The analysis of variance showed

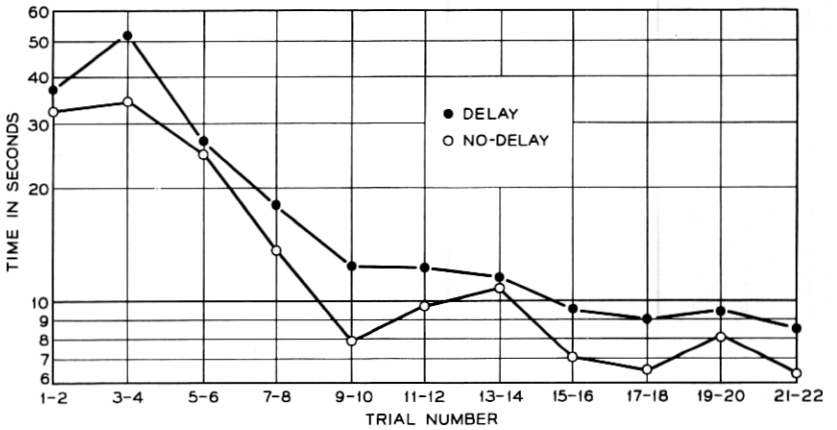

Fig. 5 — Average time-per-trial (log scale) vs trial number (grouped 2 trials per data point).

that the difference in trial times was significant ($F_{21, 21} = 30.8$, $p < 0.001$). Fig. 5 also shows that delay times are greater than no-delay times. The analysis of variance confirms this difference ($F_{1, 21} = 27.5$, $p < 0.001$).

The sharp rise in Fig. 5 on the third trial is the result of the initial appearance of one ambiguous figure which all groups found exceptionally difficult to locate. Note that the curves begin to decrease much less after the eighth trial. By this time the subjects had converged on a single reference phrase for each figure. The twelfth trial marks the beginning of a random repetition of the first 11 trials. At this point the subjects have seen each of the 11 figures twice and now encounter them for the third time.

Hypothesis (*iv*) stated that no one position in the network is favored to emerge as a seat for a chairman in the delay condition. The hypothesis was tested using measurements of who was the first individual to begin describing a figure for each figure on the set of stimulus cards. This means of judging chairmanship was chosen because, to a rough approximation, chairmanship is determined by leadership which connotes the first to act. Also, during the interview the subjects generally stated that their criterion for judging chairmanship was based on who was the first person to speak up. For each group the number of times the subject in each position was first to describe a figure was noted. There were a total of 44 (the number of common figures on each set of stimulus cards) first responses for each group.

An analysis was carried out to test, on the basis of frequency of first responses, whether a chairman actually emerged in each of the 12 groups. Under the null hypothesis the probability of obtaining a chairman was assumed to be one-third. A chi-squared test was used to test the significance of the difference between the observed frequency and hypothesized frequency of one third. Table II presents the results of the chi-squared test (χ^2 with 2 df, $p < 0.05$) indicating the position of the chairman in each of the 12 groups. From Table II the chi-squared test indicates that no chairmanship patterns are apparent in either circuit condition.

In addition, an analysis of variance of the data on number of first responses according to position in the circuit was made for the delay condition. The test resulted in failure to reject the null hypothesis at the 0.05 level that all positions in the network are equally likely for seating a chairman ($F_{1,10} = 4.77$ ns).

A questionnaire consisting of five questions administered at the conclusion of the experiment provided qualitative data. To the first question, "Did you have any difficulty in understanding the other parties in the conversation?", all subjects in both delay conditions answered "NO". But in response to this question, five subjects in the delay condition added that members of their group often were talking at the same time. Only one subject in the no-delay condition complained of talking together.

TABLE II — INDICATED CHAIRMAN FOR EACH EXPERIMENTAL GROUP

Group	No-Delay	
	Chi-Squared[a]	Questionnaire[b]
1	C	C
2	A	None
3	B	B
4	B	B
5	None	C
6	A	A
	Delay	
7	C	None
8	C	None
9	None	A
10	B	C
11	B	A
12	C	C

[a] Chairman indicated by χ^2-test on first person to respond measurements.
[b] Chairman indicated by majority decision rule on questionnaire responses.

The responses to question 2, "Did you find that a conference chairman seemed to emerge during the conversation?", are summarized in Table II. If at least two subjects of each group said that the same person was chairman, then that person is designated chairman of the group; otherwise no chairman is indicated.

To question 3, "Did you notice any difference between this circuit and the one you normally use here at the Labs?", 10 of the 18 people in the no-delay condition responded "NO". The remaining eight subjects who answered "YES" responded that the circuit was either "fuzzier", "clearer", or "farther" than their normal circuit. In the delay condition all but four subjects responded "YES" to this question. They commented that the circuit was either "fuzzier", "clearer", "nearer", or "farther" than their normal circuit. Of the 18 subjects in the delay condition, three in Position A, four in Position B, and one in Position C reported having observed a faint echo. The inadvertent echo was due to insufficient attenuation at the conference bridge.

To question 4, "Were you able to identify the other parties from their voices in the conversation?", all subjects in both circuit conditions responded "YES".

To question 5, "Do you have any other comments?", eight persons in each circuit condition responded "That was fun", indicating perhaps that delay can be as much fun as no-delay.

V. DISCUSSION

As was hypothesized, the overall time to complete the experimental task was greater with time delay in the network. The average value of 17.23 minutes for the delayed circuit is 28 percent greater than the average value of 13.48 minutes for the nondelayed circuit. These overall average time values are composed of the 22 individual trial time measurements. As was cited in the previous section, these trial times and the trial numbers, both under a logarithmic transformation, were found to fit a straight line with rather high correlation, thus substantiating the exponential shaped function. The existence of the exponential function would tend to indicate an underlying model that is multiplicative rather than additive. What is meant by this is that any difference in no-delay and delay times would be properly expressed as a ratio rather than an additive difference. During any given trial the control of the circuit (as evidenced by the person talking) transferred many times among the three subjects. It is this behavior which is thought to be the cause of the multiplicative relationship between delay and no-delay trial times.

Although no quantitative data were collected on the components of trial time measurements, the experimenter observed a greater redundancy in communication with the presence of delay. More time was spent in giving descriptions and feeding back confirming information than in the no-delay case. There were also more questions asked of the person describing the figure. Descriptions did not seem to be any longer — there were simply more of them. In addition to greater redundancy, more time was spent in pauses and attempts to speak in the delay case than in the no-delay case. In answer to the first question on the questionnaire, five times as many subjects found difficulty because of talking together in the delay condition than in the no-delay condition.

The increased time-on-task in the delay condition may be thought of as a compensation for the greater difficulties encountered with the delayed network. The data on errors indicate that the increased amount of time-on-task experienced with the delayed circuit induced more reliable communication. The error rate of 2.5 percent for the no-delay network is significantly greater than 0.4 percent for the delayed network.

As hypothesized, the time-per-trial decreased with successive trials for each circuit condition. These time measurements include total elapsed time to select a figure, describe it, entertain all questions and comments, agree that the common figure has been located, and finally read off the letters that appear under the figure on the respective stimulus cards. The decreasing time-per-trial was observed to be a result of decreasing length of reference phrases for the figures as well as agreement among all three participants on a single reference phrase for each figure. A typical sequence of phrases for the ambiguous figure appearing above the letter O on the sample stimulus card (Fig. 2) is "... looks like three Vs connected in the middle with a triangle in the center," "... three Vs with the triangle in the center," "... three Vs."

It is clear from Fig. 5 and supported by the analysis that for each trial, trial times are less under the no-delay condition than the delay condition. Furthermore, Fig. 5 indicates that no-delay trial times drop sooner to a lower level than delay trial times. This graph would tend to indicate, as thought earlier, that learning is impaired by the introduction of time delay into the circuit. This, however, cannot be supported on the basis of data obtained in the present study.

As hypothesized, the delayed circuit imposed no tendency for chairmanship patterns to develop.

Finally, a noteworthy result of the experiment (from the questionnaire responses) was the fact that not one of the participants reported having observed the presence of a time-delayed circuit. Some com-

plained of increased "talking together" but this led no one to guess the underlying reason.

The results obtained here were based upon 4-wire circuits without echo sources or echo control devices. The possibility of echo and speech mutilation due to echo-suppressor action in commercial 2-wire circuits could add degradation beyond that encountered in this experiment.

VI. ACKNOWLEDGMENT

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