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STUDIES IN INTERACTIVE COMMUNICATION: III. EFFECTS OF SIMILAR AND DISSIMILAR COMMUNICATION CHANNELS AND TWO INTERCHANGE OPTIONS ON TEAM PROBLEM SOLVING[1]

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Summary.—16 teams of 2 college students each solved four credible "real world" problems for which computer systems have been or could be useful. Each of the 4 problems was solved on four successive days. A team member sent messages either by voice or by typewriter, and every team was tested with all 4 combinations of the 2 message channels assigned to individual team members. Half the teams could interrupt their partners at any time; half could not. Dependent measures were time to solution, number of messages exchanged, total number of words used per team, message length, messages communicated per minute of channel time, and words communicated per minute of channel time. The results show that communication by voice is much more rapid and wordy than is communication by typewriter. Giving *Ss* the freedom to interrupt had no effect on the time required to solve problems, on the number of words used in the solution of problems, or on the rate at which words were communicated. When *Ss* had the freedom to interrupt, they "packaged" their words differently: they exchanged more messages, messages were shorter, and messages were exchanged with greater frequency per unit time. Practice effects were almost entirely absent. A number of significant differences were attributable to the problems and the jobs assigned to the two communicators.

CONTENTS

This is one of a series of articles originating from a research program designed to provide us with a better understanding of human communication through various machine devices. The research program receives its impetus from problems associated with the design and use of interactive computer systems and is aimed specifically at answering two questions: How do people naturally communicate with one another when they exchange factual information to solve problems? And, how are natural human communications affected by the devices through which people converse? For a review of the literature and the background of the problem, see Chapanis, Ochsman, Parrish, and Weeks (1972).

[1]This article is based on an experiment completed in the summer of 1971 by the second author under the direction of the first author. The experiment was done for a Ph.D. dissertation, as yet uncompleted, while the second author was a National Science Foundation Predoctoral Fellow at The Johns Hopkins University. The research was conducted under Research Grant GN-890 from the National Science Foundation, Office of Science Information Service. This article was prepared under Research Grant No. GN-35023 from the same agency.
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Experiments in this research program have been studying dyadic communication in cooperative problem solving. In particular, the first experiment (Chapanis, 1973; Chapanis, Ochsman, Parrish, & Weeks, 1972; Chapanis, Parrish, Ochsman, & Weeks, in preparation) tested the effects of four communication modes—typewriting, handwriting, voice, and natural unrestricted communication—on such problem solving when both members of the team used the same channel of communication. For example, in the typewriting mode both members of the team communicated through "slaved" typewriters. Similarly, in the voice mode, both members of the team were able to communicate by voice but were not able to see each other.

Another condition of our first experiment was that both members of the team were able to interrupt each other at will. Finally, each team solved only one problem and in only one mode of communication. Performance was assessed on three classes of dependent measures: time to solution, behavioral measures of activity, and linguistic measures. Significant and meaningful differences among the communication modes were found in each of the three classes of dependent measures.

Although the first experiment provided a great deal of useful information, it was not entirely a faithful simulation of man-computer situations. For example, some modern computer systems use dissimilar channels of communication: a computer user may insert information into the computer system through a teletype terminal but receive voice or CRT outputs. Further, many computer systems do not provide the kind of full interrupt capability that we allowed our *S*s in the first experiment. A word of explanation is in order. Most computer systems allow a user to interrupt a computer and some systems allow the computer to interrupt a user. However, the kind of interrupt capability we simulated was unusual in the sense that either problem solver could pick up and continue his message or train of thought with no loss of content following an interruption. That kind of interrupt capability is rare in computer systems.

Finally, most users of computer systems have more than one experience with the system. Our first experiment gave us no evidence of what might happen as teams acquired additional experience in this kind of experimental situation.

The purpose of this study was to provide some information about the questions left unanswered by the first experiment. Specifically, this study (1) compared mixed versus unmixed modes of communication, (2) compared free versus restricted interrupt options, and (3) tested the same *S*s for four successive days.

The study was structured to model man-computer situations rather than to simulate existing or planned systems faithfully. We required two-man teams to communicate in a factually oriented, problem-solving situation. The two *S*s on a team were assigned distinctive job roles which they retained throughout the experiment. Each team solved four credible "real world" problems for which computer systems have been or could be useful. A different problem was solved

on each of four successive days. Each team member could communicate either by voice or by typewriter depending on the experimental condition to which he was assigned. This gave a total of four different communication modes for each team: unmixed voice-voice (V-V), mixed voice-typewriter (V-T), mixed typewriter-voice (T-V), and unmixed typewriter-typewriter (T-T) communication. The V-T and T-V modes distinguish between assignments of the typewriter and voice channels to particular team members or job roles, a matter that will be discussed later in the section on *Modes of Communication.* Finally, half of the teams worked under a free interchange option, i.e., either team member could interrupt his partner at any time. The other half of the teams worked under a restricted interchange option, i.e., a team member was prevented from transmitting a message until his partner voluntarily gave up control of both his own and his partner's channel.

METHOD

Subjects

Thirty-two male students from the freshman class of The Johns Hopkins University were used in this experiment. All were between 17 and 19 yr. of age and could type at a rate of at least 35 words per minute. *S*s were selected from a pool of 248 Hopkins freshmen who had received Scholastic Aptitude Test (Angoff, 1970) verbal scores between 600 and 700. They were paid for their services.

Apparatus

The laboratory consisted of two adjacent rooms connected by a sound-insulated double door. A square opening (15.2 cm. on a side) extended through the wall between the two rooms at a convenient height above a table top in either room. Trap doors on both sides of the opening prevented *S*s from seeing each other. Each *S* sat at a table facing this opening.

Two major pieces of equipment were IBM input-output writers, Model B, one in each experimental room. These machines are essentially IBM electric typewriters built on a platform of electrical components that allow them to send and receive messages. They have been used as input-output terminals in some computer systems. The two machines were slaved to one another through switching networks and cables that ran between the rooms. Messages typed on either typewriter appeared on both at the same time.

An important feature of the typewriter system was the keyboard lock-out which guaranteed that a message could be typed only by *S* who had control. Although *S* could, of course, tell from the status lights on his control box whether he had control of the system, we found from our earlier work that *S* sometimes neglected to check this information in the excitement of the task. As soon as *S* took or was given control of the typewriter system, his keyboard automatically unlocked and he was free to transmit a message.

Another important feature of this typewriter communication system was our specially devised automatic ribbon color control mechanism. This feature was incorporated into only one of the two input-output typewriters. Messages typed by one *S* always appeared in red type and by the other in black type, thus allowing *E*s to identify without ambiguity the author of a particular message.

A second major piece of equipment in each room was a Shure, omni-directional, low impedance microphone, Model 575SB. Each microphone was connected to a Bogen two-channel, 10-watt amplifier, Model CHB IOA. The amplified output of each microphone was fed to a Lafayette 8-ohm wall speaker, Model F 45494, hung on a wall of the adjoining room. Through this system any message spoken by one *S* into his microphone was simultaneously transmitted to his partner. The microphone-speaker communication system was wired in parallel through the same control boxes that controlled the typewriter system. This arrangement ensured that the two *S*s could not transmit voice messages simultaneously, a small but important difference in procedure from that used in the experiment previously referred to (Chapanis, 1973; Chapanis, *et al.*, 1972).

Control of both the typewriter and voice systems was exercised through a small control box beside each input-output writer. Each box contained two push-buttons and an associated status light. Pushing one button enabled *S* to take control of the system at any time. Pushing the other button allowed *S* voluntarily to release the system to his partner. The light on the control box was automatically actuated and provided information to *S* about the status of the system, that is, who had control at any time.

A Standard Electric Time Corporation 60-min. timer, Model S-60-ER, was wired to each control box to record the cumulative time that each *S*'s channel was open during each experimental session. This measure was available for both the typewriter and voice modes of communication.

Modes of Communication

Our communication modes were not designed to simulate particular communication systems but rather to model ideal ones in the following sense: If it were possible to construct a perfect voice-recognition device, a computer would be able to perform this function at least as well as an intelligent person. In conceptualizing our experiment in this way, then, our voice mode of communication is a model of an idealized, interactive computer system, i.e., one that would pass Turing's test (1950). In the rest of this article, we use the terms "source" (as an abbreviation for "information source") and "seeker" (as an abbreviation for "information seeker") to refer to the two members of our teams. It may help to think of the source as a hypothetical ideal computer, the seeker as the user of that computer, and our communication modes as different input-output channels between the computer and its human user.

In the unmixed voice-voice (V-V) communication mode, both the source and seeker communicated with each other only through the microphone-speaker

system described above. In the mixed voice-typewriter (V-T) mode, the seeker used the microphone-speaker system while the source used the typewriter system. In the mixed typewriter-voice (T-V) mode the seeker typed his messages whereas the source spoke his. Finally, in the unmixed typewriter-typewriter (T-T) mode, both the source and seeker communicated with each other only through the two input-output writers described above.

Ss in all modes were supplied with pens, pencils, and note pads.

Interchange Conditions

In natural spoken human communication, individuals are free to interrupt each other and may even try to talk at the same time. In this experiment *Ss* were prevented from talking at the same time, and in addition were provided with either one of two interchange options. In the free interchange condition either *S* could interrupt his partner at any time by pushing the appropriate button on his control box. In this condition, then, both *Ss* had the option of turning their channels on as well as off. This option was available in both the voice and typewriter modes of communication.

For the restricted interchange condition, one of the push buttons on each *S*'s control box was disabled by *E*. The net result was that *S* could only turn his own channel off. In so doing, he automatically turned his partner's channel on. Having done so, he could neither interrupt nor reply to his partner until his partner had finished communicating and had voluntarily given up control of the channel.

Problem-solving Tasks

The four problems used to elicit communication were chosen to meet several important criteria:

1. They sampled different psychological functions.

2. They were representative of tasks for which interactive computer systems were currently being used, or would be used in the future.

3. They were of recognizable and practical importance in one's everyday world. They were not abstract or artificial problems of the type often constructed to measure hypothetical psychological processes.

4. They had definite, recognizable solutions and the solutions could be achieved within approximately an hour.

5. They required no special skills or specialized knowledge for their solution.

6. They were formulated in such a way that their solutions required the efforts of two individuals working together as a team. This was done by deliberately structuring the problems so that each member of a team received complementary information folios. One member of the team, the seeker, was given a problem for which he had to find the solution. His information folio consisted of certain parts of the problem. The source had a folio with the remainder of the information needed to solve the problem. Therefore, while neither person

could solve the problem by himself, the two of them had all the information necessary to do so. In general, we tried to divide our problems in such a way that the source (our simulated computer) was given the bulk of the library, or file-like, information. We emphasize, however, that our problems were structured to elicit communication between the two members of a team. Our division of a problem did not necessarily represent the way tasks would be allocated to man and computer in any real system.

Geographic-orientation problem.—In this problem, the seeker's goal was to find the office or residence address of a physician closest to a hypothetical home address. In so doing, the seeker was instructed to disregard specialists such as psychiatrists and surgeons. He was supplied with an index of streets, a gridded street map of Washington, D. C., and a card on which the home address was typed. The home address was also marked on the map. The source was supplied with one page of physician's listings from the classified advertisement (yellow) pages of the Washington, D. C., telephone directory. In this listing, the names of physicians and surgeons appear alphabetically, with the address of a physician immediately following or below his name.

Information-retrieval problem.—In this problem, the seeker's task was to find the citations of five different newspaper articles relevant to the following topic: the threat to individual privacy that would be posed by a United States data center based upon a computerized information retrieval system. He was instructed not to count reports of public speeches, editorials, or letters to the editor. His information folio was a single typed page which explained the nature of his topic. The source's information folio consisted of Volume 55 of the *New York Times Index* for the year 1967. *S* who was assigned the role of source was given some preliminary practice in the use of the *Index*.

Equipment-assembly problem.—In this problem, the seeker's job was to assemble a common household article, a trash can carrier. His information folio consisted of all the disassembled parts of that article. To provide easy access and identification, the parts were hung in a standard arrangement on a pegboard panel. Although the assembled device was large (approximately 61 × 91 × 122 cm. in over-all dimensions), it was constructed of light-weight aluminum tubular pieces that could be easily handled by a single person. A screwdriver, pair of pliers, and a mallet were provided but not always used. In his instructions to the seeker, *E* disclosed neither the name nor the function of this article. This information was, however, invariably communicated by the source at different times during the solution. The source's information folio consisted of a set of drawings and assembly instructions exactly as provided by the mail-order company from which the disassembled article had been purchased. Although it was theoretically possible for someone to assemble this device without instructions, three graduate students who tried to do so gave up in frustration after 15 min.

Object-identification problem.—In this problem, the seeker's task was to

identify and obtain a replacement for a small pilot light socket. He was given the pilot light socket without any further elaboration. The source's information folio consisted of a large tray containing 65 Leecraft pilot light sockets arranged in individual receptacles. Although all 65 sockets in the source's inventory were similar in many ways, each differed from all the others in one or more respects, e.g., in kind of base (bayonet vs screw), size (⅜ in. vs ½ in. vs ¾ in.), and material (metal vs bakelite). One and only one socket in the source's folio exactly matched the seeker's. When the source thought he had picked the correct socket, he passed the socket to the seeker through the passageway described above.

Experimental Design

The experimental design used in this study is shown in Table 1. Latin squares and Greco-Latin squares are always more difficult to analyze and to interpret than other less complex designs, e.g., factorial designs. However, we picked the design in Table 1 as the best compromise possible between the conflicting requirements of statistical nicety on the one hand, and experimental and practical reality on the other. For example, to get some indication of learning effects in this kind of task we had to test teams repeatedly. Four experimental sessions could be scheduled in one week, even allowing for normal exceptions that always occur in human experiments due to students oversleeping, students forgetting an appointment, or cancellations because of other real or presumed emergencies and crises. From a considerable amount of previous experience with our student body, we felt sure that we could easily count on getting students back for one week of four sessions, but that more than that would involve us in administrative difficulties.

To run four consecutive sessions we had to use different problems, because

TABLE 1

REPLICATED 4 × 4 GRECO-LATIN SQUARES EXPERIMENTAL DESIGN USED IN THIS STUDY

Interchange Options	Groups	Communication Modes			
		V-V	V-T	T-V	T-T
Free	G_1	P_1,D_1	P_2,D_2	P_3,D_3	P_4,D_4
	G_2	P_2,D_3	P_1,D_4	P_4,D_1	P_3,D_2
	G_3	P_3,D_4	P_4,D_3	P_1,D_2	P_2,D_1
	G_4	P_4,D_2	P_3,D_1	P_2,D_4	P_1,D_3
Restricted	G_5	P_1,D_1	P_2,D_2	P_3,D_3	P_4,D_4
	G_6	P_2,D_3	P_1,D_4	P_4,D_1	P_3,D_2
	G_7	P_3,D_4	P_4,D_3	P_1,D_2	P_2,D_1
	G_8	P_4,D_2	P_3,D_1	P_2,D_4	P_1,D_3

Note.—(1) V = voice, T = typewriter. The first letter is the communication mode available to the seeker; the second the mode available to the source. (2) P_1 = geographic orientation problem; P_2 = information retrieval problem; P_3 = equipment assembly problem; P_4 = object identification problem. (3) D_1, D_2, D_3, D_4 are the first, second, third, and fourth days of test. (4) Each group, G, consisted of two teams and each team was made up of two men.

once a problem had been solved it could not be used again. Given the choice between (a) repeating tests with different combinations of modes versus (b) repeating tests with different interrupt options, we chose the former as being the more interesting. Finally, to ensure that neither problems nor modes of communication would be confounded with learning effects, we had to counterbalance these variables through the use of Greco-Latin squares.

Procedure

Before they appeared for their first experimental session, the two *S*s who were to make up a team were randomly assigned to a particular group in one of the two interchange conditions. When they arrived, one *S* was randomly assigned the role of seeker, the other automatically becoming the source. Both the team membership and the role designation for each *S* remained the same throughout the experiment.

Before the first experimental session the two members of each team were introduced and remained together while the general instructions were read to them and the apparatus was demonstrated. These general instructions stated that the purpose of the experiment was to study communication behavior. *S*s were told that to accomplish this purpose, tape recordings and other records would be collected during each of the four experimental sessions. *E* emphasized that all these records would remain confidential and would be used only for purposes of data analysis. All *S*s granted permission for such data to be collected and used in the way described. *S*s were also informed that the *E* would remain in the source's room to monitor the recording apparatus and to render aid in case of equipment failure. They were also told to ignore the presence of *E*, who would provide no assistance whatsoever in the solution of a problem.

The general instructions also emphasized that the solution to problems could be achieved only through the mutual cooperation of the two team members. Both members of the team were instructed to cooperate fully with each other and to be as helpful as possible in arriving at solutions. They were instructed to reach the correct solution as best they could, using any strategy they thought appropriate. *S*s were reminded that since all records would remain confidential, they should feel free to behave naturally. They were encouraged to do or say anything that would help them arrive at a solution to a problem. The instructions stressed that accuracy of the solution was more important than the time required to reach it. Finally, the seeker was told that he would initiate the first message in each problem. The seeker was also told that it was his responsibility to decide when the team had a satisfactory solution to a problem. He was to do this by signalling the source to tell *E* that they were through.

Having received this general set of instructions, each team spent 10 to 15 min. on the first day practicing with the two communication systems (microphone-speaker and typewriter), using control boxes appropriate to the interrupt

condition to which the team was assigned. The practice period ended when *E* decided that both team members were thoroughly familiar with the operation of the communication systems and their respective control boxes.

Next, *E* gave the team instructions for the specific problem to be solved that day. Then each *S* went to his designated laboratory room where he was given the information folio for his portion of the problem. At this point, *S*s were told which communication system each of them would use that day.

Prior to the start of each of the remaining three experimental sessions, the teams were again given a short rehearsal period in the operation of the control boxes and the particular communication system to be used that day. Instructions and information folios for each subsequent day's problem were given to the team in the manner described above.

Audio tape recordings were made of all voice communications. These tapes were later transcribed into typescript using linguistic notations to indicate such features as pauses of various duration, interruptions, and so on. This copy was then corrected by a secretary who checked it against the tape. The corrected copy was verified and corrected once again, this time by *E* also working jointly with the typescript and the tape. Thus, the final typewritten copy is as precise a record as possible of the voice communications in these modes. These procedures were necessary to capture accurately the many rapid, and extremely complex verbal exchanges that took place.

RESULTS

Time to Solution

Problem solution time was obtained by adding the times recorded by the timers for each of the two *S*s. The results of the analysis of variance on total solution times are shown in Table 2. This analysis is typical of those that were done on all the other kinds of data that will be reported in this article. Table 2 shows that modes, problems, job roles, and the interaction of job roles with problems all had significant effects on the time needed to solve problems.

Modes.—The mean solution times in each of the four communication modes are shown in Fig. 1. These data are averaged across problems, days, interchange conditions, and teams. Orthogonal comparisons among certain combinations of modes (Table 2) show that the largest single contribution to the variation among modes, accounting for 71% of that variance, arises from the difference between the unmixed typewriter (T-T) mode and the other three modes. The second largest contribution to the variation among modes, accounting for nearly the entire balance of that variance, arises from the difference between the unmixed voice (V-V) mode and the two mixed (V-T and T-V) modes. The two mixed modes do not differ significantly from each other. The average time required to reach a solution in the unmixed typewriter mode is almost exactly twice (49.9 min. vs 24.8 min.) that in the unmixed voice mode. These findings repli-

TABLE 2

ANALYSIS OF VARIANCE OF SOLUTION TIME IN MINUTES

	Source	*SS*	*df*	*MS*	*F*
I.	Between Subjects (Su)	3,882.43	(31)		
	A. Between Teams (T)	2,273.77	15		
	1. Sequence (Se)	30.71	3	10.24	<1.00
	2. Interchange (I)	179.59	1	179.59	1.10
	3. Se × I	759.57	3	253.19	1.55
	4. $Error_{(b)}$	1,303.90	8	162.00	
	B. Between Subjects Within Teams	1,608.66	16		
	1. Job Role (JR)	1,009.24	1	1,009.24	21.90†
	2. T × JR	599.42	15		
	a. Se × JR	19.19	3	6.40	<1.00
	b. I × JR	115.18	1	115.18	2.50
	c. Se × I × JR	96.39	3	32.13	<1.00
	d. $Error_{(b)}$ × JR	368.66	8	46.08	
II.	Within Subjects (wSu)	13,169.89	(96)		
	A. Modes (M)	2,599.66	3	886.55	12.46*
	1. T-T vs V-V + V-T + T-V	1,851.33	1	1,851.33	26.60*
	2. V-V vs V-T + T-V	689.33	1	689.33	9.91†
	3. V-T vs T-V	59.11	1	59.11	<1.00
	B. Problems (P)	3,489.17	3	1,163.06	16.72*
	C. Days (D)	223.67	3	74.56	1.07
	D. M × I	469.21	3	156.40	2.25
	E. P × I	41.78	3	13.93	<1.00
	F. D × I	225.97	3	75.32	1.08
	G. M × JR	374.64	3	124.88	1.80
	H. P × JR	1,992.52	3	664.17	9.55*
	I. D × JR	140.32	3	46.77	<1.00
	J. M × I × JR	213.05	3	71.02	1.02
	K. P × I × JR	80.03	3	26.68	<1.00
	L. D × I × JR	47.12	3	15.71	<1.00
	M. Over-all Greco-Latin square error (= square uniqueness, S.U.)	3.79	6	0.63	<1.00
	N. S.U. × I	507.99	6	84.67	1.22
	O. S.U. × JR	221.26	6	36.88	<1.00
	P. S.U. × I × JR	35.63	6	5.94	<1.00
	Q. $Error_{(w)}$	2,504.08	36	69.56	
III.	Total	17,052.32	(127)		

*$p < 0.001$; †$0.001 < p < 0.005$.

cate almost precisely those of the first experiment (Chapanis, 1973; Chapanis, *et al.*, 1972) which showed that problems in the voice mode could be solved in about half the time required in the typewriting mode. Taken together, these findings confirm that voice communication is a rapid way of solving problems like those we have used. If only one of the two communicators has a voice channel, the time taken to solve problems is roughly midway between the times required in the unmixed voice (V-V) and unmixed typewriter (T-T) modes.

Problems.—Fig. 2 shows that the significant main effect of problems is due principally to the object-identification problem which was solved in slightly less than half the time required for each of the other three problems. The mean solution times for the geographic-orientation, information-retrieval, and equipment-assembly problems did not differ greatly. The data in Fig. 2 are averaged across

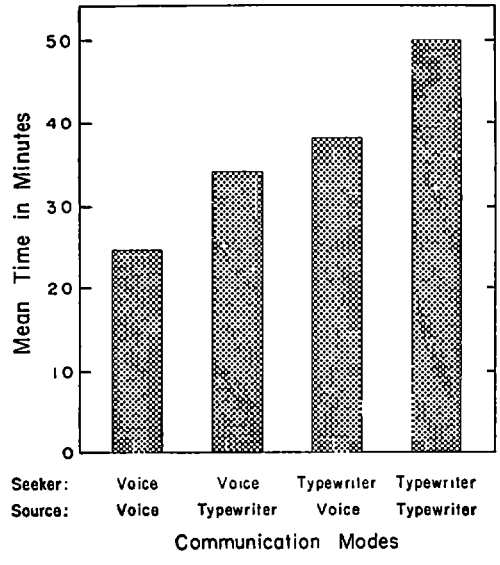

FIG. 1. Mean times to solve problems in the four modes of communication

modes of communication, interchange conditions, days, and teams. The problems themselves were not a variable of primary interest in this study. They were selected to sample different kinds of tasks and to serve as a vehicle for eliciting communication. That they did, or did not, require different times for solution is

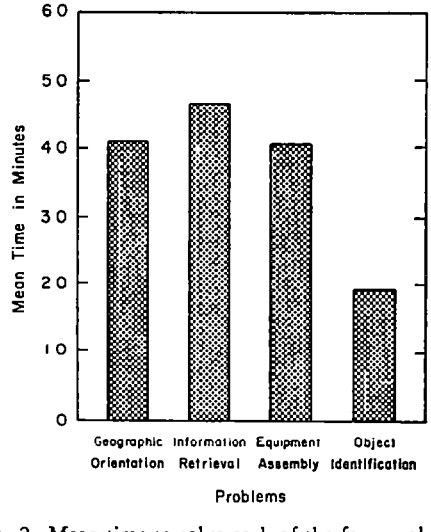

FIG. 2 Mean time to solve each of the four problems

of no great importance. However, this set of data, together with the interaction between job role and problem (discussed below), are useful in arguing for the generality of our findings (see the *Discussion* section).

Job roles.—The "open-channel" time for sources was, on the average, 37% greater than for the seekers (21.2 min. vs 15.6 min.). These data are averaged for all modes, problems, days, interrupt conditions, and teams. Once again we do not attach very much practical significance to these findings since the division of responsibilities between source and seeker was, to some extent, arbitrary. These data show that we placed a somewhat greater burden of communication on our source (our simulated computer) than on our seeker (our simulated computer user). This main effect should also be interpreted in the light of a somewhat more interesting interaction between job role and problem, discussed immediately below.

Problem times job role interaction.—The only significant interaction in Table 2 was that between problems and job roles, shown in Fig. 3. Both team members behaved similarly in solving the geographic-orientation and equipment-assembly problems, in that the source spent a slightly greater amount of time communicating during the solution of the problem. The results for the information-retrieval problem present an entirely different picture. In this case, the average source spent well over twice as much time communicating as did the

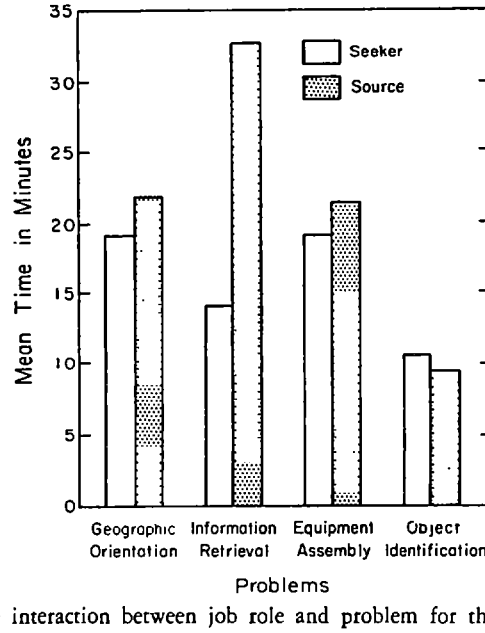

FIG. 3. The interaction between job role and problem for the total time required to solve problems

average seeker (32.8 min. vs 13.8 min.). This probably represents the time spent by the source in consulting his copy of the index of the *New York Times* and in communicating his findings to his partner. The seeker, by contrast, had primarily to decide whether contributions discovered by the source were relevant to his topic and, occasionally, to offer succinct suggestions and advice to his partner. Finally, in the object-identification problem, that general pattern was reversed in that the seeker spent somewhat more time communicating than his teammate did. The most important feature of this task was the precise description of the object that the seeker held in his hand. That required more communication than did the questions which the source directed to his partner.

Non-significant effects.—There were no other significant main effects nor were there any other significant interactions. That in itself is an interesting finding. We had, frankly, expected to find a difference between the interchange conditions and perhaps a significant interaction between interchange conditions and modes. Neither expectation was fulfilled. There was, however, the suggestion of an interaction between interrupt conditions and modes. In the two mixed modes of communication and in the unmixed typewriter mode, problems were solved faster when *S*s were able to interrupt freely. By contrast, the solution time in the unmixed voice mode was about 40% greater (28.9 min. vs 20.7 min.) in the free interrupt condition than in the restricted interrupt condition. It is as though having the freedom to interrupt in typewriter communication speeds up the attainment of a solution because one can sometimes cut short a lengthy and obvious message that is coming through slowly on a typewriter. The voice mode, by contrast, is already so fast, with such rapid interchanges of communication, that interruptions actually seem to disturb and to slow up the achievement of a solution. We emphasize that however provocative these findings may be, they were not statistically significant ($p \cong 0.10$). They are only suggestive of effects that might perhaps be revealed with more sensitive experiments.

We had also expected to find a difference on successive days. No such effect was apparent. Teams did not become significantly faster, or slower, as they acquired experience with these systems. This finding, plus other related ones, is considered more fully in the *Discussion* section.

Number of Messages

For our purposes, a message began when a subject began to talk or to type, and ended either when he had finished and relinquished control of the communication channel to his partner, or when he was interrupted. By our definition, therefore, a message may be a word, a group of words, a complete sentence or question, or several sentences or questions. The analysis of variance on the total number of messages exchanged was an abbreviated version of the one in Table 2, in that job roles and all interactions involving job roles were eliminated. Because

of the way we defined a message, the number of messages communicated by the seeker could not differ by more than one from the number communicated by the source. Several statistically significant sources of variation turned up in this analysis (see Table 3).

TABLE 3

p VALUES OF ALL STATISTICALLY SIGNIFICANT SOURCES OF VARIATION FOR ALL DEPENDENT MEASURES

Source	Time	No. Messages	No. Words	Message Length	Messages per Minute	Words per Minute
Communication modes (M)	<0.001	<0.001	<0.001	0.007	<0.001	<0.001
T-T vs V-V + V-T + T-V	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
V-V vs V-T + T-V	0.004	<0.001	<0.001		<0.001	<0.001
V-T vs T-V						
Interchange conditions (I)		<0.001		0.005	0.004	
Days (D)				<0.001		
Job Roles (JR)	0.002		0.02	0.03	0.02	
Problems (P)	<0.001	0.002	0.007	0.04		<0.001
M × I		0.003			0.04	
M × JR			<0.001	<0.001		<0.001
I × D						
I × JR					0.05	
I × P						
D × JR						0.02
JR × P	<0.001		0.025	<0.001		<0.001
M × I × JR				0.01		
D × I × JR						
P × I × JR						
Sequence (Se)		<0.001				
Se × I		0.006				

Modes.—Fig. 4 shows that about 2½ times as many messages were communicated in the unmixed voice as in the unmixed typewriter mode and that the two mixed modes fell between those two extremes. Orthogonal comparisons confirm that the unmixed typewriter mode differed significantly from all the others and that the unmixed voice mode differed significantly from the two mixed modes.

Interchange conditions.—Fewer messages were communicated under conditions of restricted interchange than under conditions of free interchange (35.9 vs 56.4). These data are averaged across communication modes, days, problems, and teams.

Mode × interchange condition interaction.—Fig. 5 shows a marked interaction between modes and interrupt conditions. Under conditions of restricted interchange, the mean numbers of messages exchanged were nearly constant among the several modes of communication. When *S*s had the freedom to interrupt, the number of messages communicated in the V-V mode was greatly increased. Free interchange also resulted in increases in the numbers of messages communicated in the other three modes, but the increases are modest. It is as

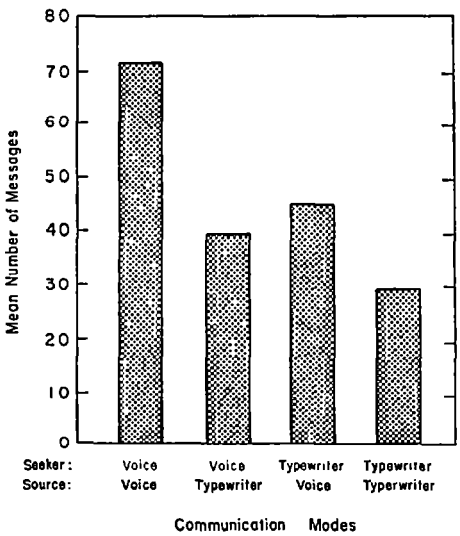

FIG. 4. Mean number of messages exchanged in the four modes of communication

though the use of a typewriter by one or both *S*s inhibited the number of messages that were exchanged even when *S*s could interrupt if they wanted to do so. Since *S*s in our first experiment (Chapanis, 1973; Chapanis, *et al.*, 1972) also had the freedom to interrupt, the data in the open bars for the V-V and T-T modes in Fig. 5 are consistent with what was found in our earlier study although the differences here are not as great as those reported earlier (102.0 and

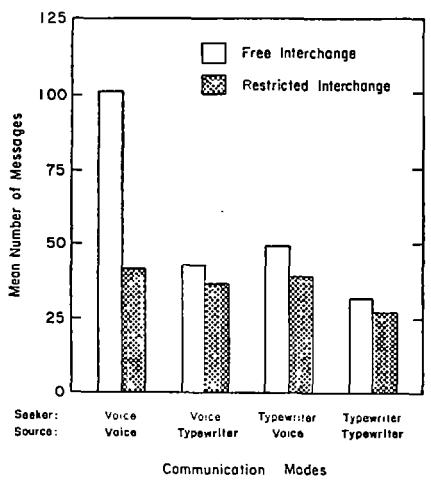

FIG. 5. The interaction between mode of communication and interchange condition for the mean number of messages exchanged

31.2, respectively, in this experiment, as compared with 163.8 and 29.4, respectively, in the first experiment). In this connection, it is important to keep in mind the substantial differences between this experiment and the first one, for example, in the numbers and kinds of problems used, in the kinds of *S*s tested, and in the number of times *S*s were tested. Mixed modes of communication had not been tested previously.

Problems.—There were, finally, some significant differences among the mean numbers of messages communicated in the solution of the several problems. Approximately half as many messages were exchanged in the solution of the object-identification problem (26.1) as in the solution of each of the other three problems (50.5 for the geographic-orientation problem, 54.2 for the information-retrieval problem, and 53.8 for the equipment-assembly problem). In fact, the number of messages exchanged in the solution of the several problems is almost perfectly correlated with the time required to solve them (Fig. 2).

Number of Words

Counting words is conceptually easy but practically very difficult. Most word counts in psycholinguistic research are done on immaculate prose, i.e., on prose that is grammatically correct. Our communications were natural and unrestricted with all of the irregularities and grammatical errors that one finds in such communications. Our definition of what constituted a word was extremely liberal for two reasons: First, most vocal utterances and typewritten sequences of symbols convey some information. Second, if we are ever to have truly conversational computers, they must be capable of dealing with the kinds of natural language expressions that people use in their ordinary communications. The rules we observed in making our word counts are those established in our earlier experiment. Some of the principal ones were:

1. Mispronounced words in the voice mode and misspelled words in the typewriter mode were counted as words.

2. Partial and incomplete words were counted as words. For example, "'em," "d'ya," "'cause," and "wh'" were all counted as single words.

3. Colloquial, slang, and idiosyncratic words were counted as words even if they cannot be found in a dictionary. For example, "yup," "nope," "daggone," "jobbers," and "dumb-dumb" were all counted as single words.

4. Contractions, both grammatical and ungrammatical, were counted as words. For example, "I'll," "can't," "don't," "gonna," "gotcha," "whatta," and "gimme" were each counted as single words.

5. Combined numerals were counted as single words. So, for example, "4805 21st Street" was counted as three words, "4805," "21st," and "Street."

6. Interjections, such as "hmmm," "ugh," and "whew," were each counted as words.

7. Hyphenated words, whether correctly hyphenated or not, were counted as single words. For example, "half-wit," and "twenty-three," were counted as single words.

8. Special characters were counted as words. So, for example, "50%" was counted as two words, "50" and "%."

The analysis of variance of the total number of words exchanged in the solution of problems yielded five significant terms (see Table 3): among modes of communication, between job roles, among problems, the interaction of modes of communication with job roles, and the interaction of problems with job roles.

Modes.—The data for the several modes of communication resemble very closely the pattern shown in Fig. 4 with an appropriate change in ordinate, of course. The mean number of words communicated in the several modes were: V-V, 1165; V-T, 644; T-V, 781; and T-T, 325. These findings, together with those in Fig. 4, are especially impressive when considered in the light of the data in Fig. 1. Fig. 1 shows that the unmixed voice mode is the fastest. Yet this extremely fast mode of communication is an extremely wordy one, both in the number of messages and in the number of words exchanged. By contrast, the unmixed typewriter mode is a verbally parsimonious but much slower mode of communication. The mixed modes of communication fall between these two extremes in all respects: in time, in number of messages, and in words exchanged.

Job roles.—Although, as we have already pointed out, it was not meaningful to compute the significance of the difference between job roles in number of messages exchanged, there was a difference in verbal output between the job roles. On the average, the source used more words than the seeker (838 vs 620). In fact, these data parallel very closely the mean "open-channel" times for source and seeker given earlier.

Problems.—The number of words exchanged in the solution of the four problems resembles the data in Fig. 2 for times, and the data for the number of messages exchanged (discussed earlier but not illustrated in this paper). On the average, 642 words were used in the solution of the geographic-orientation, 1,012 in the information-retrieval, 754 in the equipment-assembly, and 508 in the object-identification problem.

Mode $\times$ *job-role interaction.*—The strong influence of the communication channel is shown once again in the interaction between modes and job roles (Fig. 6). The results for the two mixed modes amplify the findings given above in showing that far more words are transmitted over the voice channel, regardless of whether the source or the seeker used that channel. In the mixed voice-typewriter mode, the seeker had the voice channel and produced 3 times as many words (978 vs 310) as his partner. Correspondingly, in the mixed typewriter-voice mode, the source had the voice channel and produced nearly 5½ times as many words (1317 vs 246) as his partner. These findings are even more impressive when one compares the mean number of words for *S* assigned the voice channel in each of the two mixed modes with the mean value for his respective role counterpart in the unmixed voice-voice mode. That is, compare the two open bars (those for the seeker) in the voice-voice and voice-typewriter modes. Then compare the two stippled bars (those for the source) in the voice-voice and

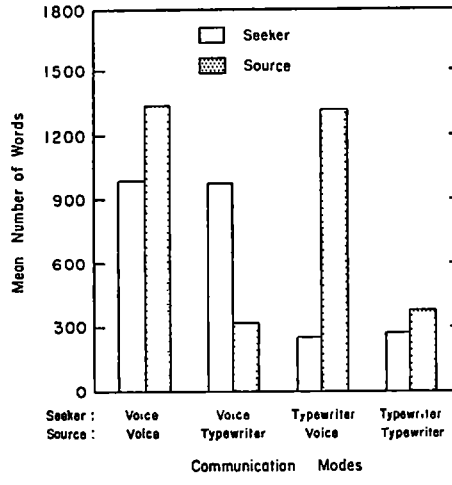

FIG. 6. The interaction between job role and mode of communication for the mean number of words communicated per *S*

typewriter-voice modes. Similar comparisons should be made between the data for the seekers in the typewriter-voice and typewriter-typewriter modes, and the sources in the voice-typewriter and typewriter-typewriter modes. There was a remarkable stability in the average number of words produced by sources and seekers, respectively, when they used the voice channel or the typewriter channel. This stability was completely unaffected by large changes in the partner's performance.

Problem × job role interaction.—The interaction between problem and job role (Fig. 7) resembles roughly the data in Fig. 4 for times. In the geographic-orientation and object-identification problems, source and seeker exchanged very nearly equal numbers of words, although there was a tendency for the seeker to use somewhat more words than the source. In the information-retrieval and equipment-assembly problems, by contrast, the source used far more words than the seeker. As we have already observed, the burden of communication was placed on the source in the information-retrieval problem because it was he who had the *New York Times Index* and had to communicate his findings to his partner. In the equipment-assembly problem, it was the source who had the drawings and the instructions for assembling the equipment. His partner had only parts to work with.

Non-significant effects.—Once again it is instructive to note the sources of variation that were not significant in this analysis. Prominent among these were interchange conditions and days. *S*s used almost equal numbers of words under the free and restricted interchange conditions. Finally, there was no evidence that *S*s became more or less loquacious on successive days of the experiment.

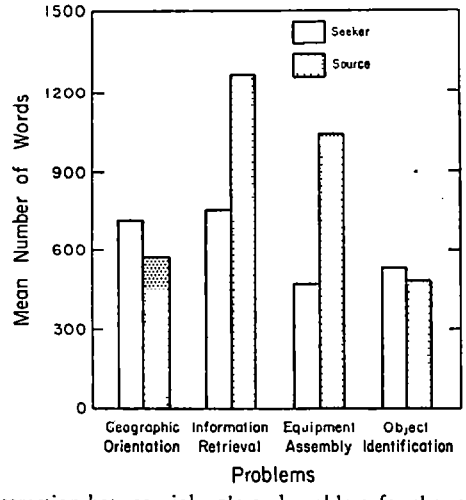

FIG. 7. The interaction between job role and problem for the mean number of words communicated per *S*

Message Length

Message length, or the average number of words per message, is one of several derived measures that can be computed from our data. This one was obtained by dividing the number of messages each *S* used into the number of words he used. The quotients so computed for all *S*s were entered into an analysis of variance similar to that shown in Table 2. Eight significant sources of variation were found (see Table 3): among modes of communication, between interchange conditions, between job roles, the interaction of modes with job roles, the triple interaction of modes with interchange conditions with job roles, among problems, the interaction of problems with job roles, and among days.

Modes.—The effect of modes on message length is unlike any of the previous effects reported for communication modes (see Fig. 8). It made surprisingly little difference whether both team members used a voice channel or whether only one of them did. Messages were about equally long in all forms of communication except in the unmixed typewriter mode. When both members of the team used typewriters, messages were markedly shorter. This finding has to be considered in the context of a significant mode by job-role interaction (see Fig. 9).

Interchange option and job role.—The kind of interchange option available has a marked effect on message length. Messages sent under conditions of restricted interchange are almost twice as long as those sent under conditions of free interchange (48 vs 25 words). Job role has a somewhat smaller effect on message length. On the average, the source used messages that were about 25% longer than those sent by the seeker (40 vs 32 words).

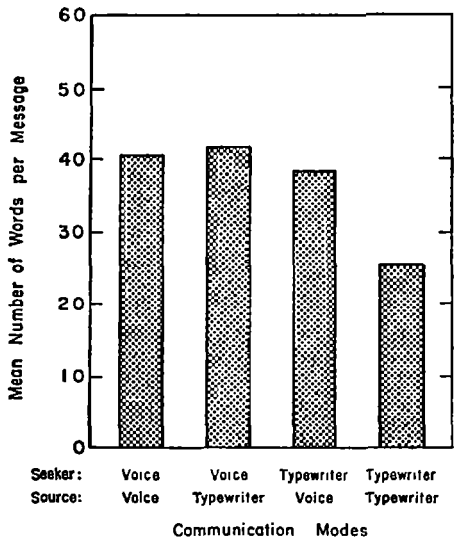

FIG. 8. Average message lengths in the four modes of communication

Mode × *job-role interaction.*—Fig. 9 shows that the man who had the voice channel always produced longer messages than the man who had the typewriter channel. In the mixed modes of communication, messages spoken by the source in the T-V mode were longer than those spoken by the seeker in the V-T

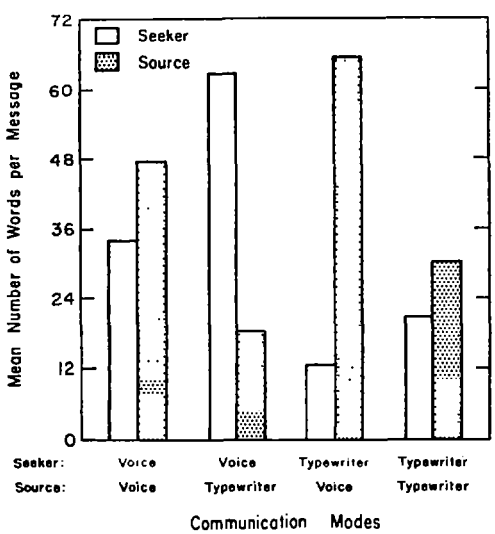

FIG. 9. The interaction between job role and communication mode for mean message lengths

mode. This is in agreement with the finding already reported that the source tended to use somewhat longer messages than the seeker, a finding that is also clearly evident in the V-V and T-T conditions. Perhaps the most interesting finding shown in Fig. 9, however, is that in the two mixed modes, the person with the voice channel used messages that were much longer than either the source or seeker did when they both used voice channels. Correspondingly, the person with the typewriter channel in the two mixed modes typed out messages that were shorter than those typed out by either the source or seeker when they both used typewriter channels. It was as though using the voice and typewriter channels in the same mode heightened the normal contrast that holds between these two channels. At the same time, the increase in message length for the person who used the voice channel almost exactly balanced out the decrease in message length for the person who used the typewriter channel because, as Fig. 8 shows, average message lengths were very nearly equal for the V-V, V-T, and T-V conditions.

Mode $\times$ *job-role* $\times$ *interchange-condition interaction.*—The interpretation of the effects in Fig. 9 is still further complicated by a significant triple interaction between communication modes, job roles, and interchange conditions (see Fig. 10). We have already noted that under conditions of restricted interchange, messages tended to be almost exactly twice as long as those under conditions of free interchange. Fig. 10 shows that this roughly 2 to 1 ratio did not hold for all combinations of job roles and communication modes. *S*s who used the voice channel produced messages that were, on the average, 2.1 times longer under conditions of restricted interchange than under conditions of free interchange. For the typists, by contrast, messages were only 1.5 times as long under conditions of restricted interchange than under conditions of free interchange. All this can be summed up in another way: Messages were much more nearly equal in length under conditions of free interchange than they were under conditions of restricted interchange. So, for example, the variance of the eight bars in the left-hand graph of Fig. 10 is about 4 times the variance of those in the right-hand graph.

In this connection it is worth pointing out that the same triple interaction was not significant for the numbers of words exchanged. A plot of that triple interaction resembles superficially the data in Fig. 10 in that each pair of bars (that is, the data for seekers and sources) have about the same relative heights as in Fig. 10. In the case of the mean number of words transmitted, however, the eight bars under conditions of free interchange have very nearly the same variance as the eight under the restricted interchange condition. This may be summed up by saying that *S*s used very nearly equal numbers of words under conditions of free and restricted interchange. The two interchange conditions differentiated themselves primarily in terms of average message lengths.

Problems.—The effect of problem on mean message length (see Fig. 11) is also unlike any of the other effects reported for problems. In all the data re-

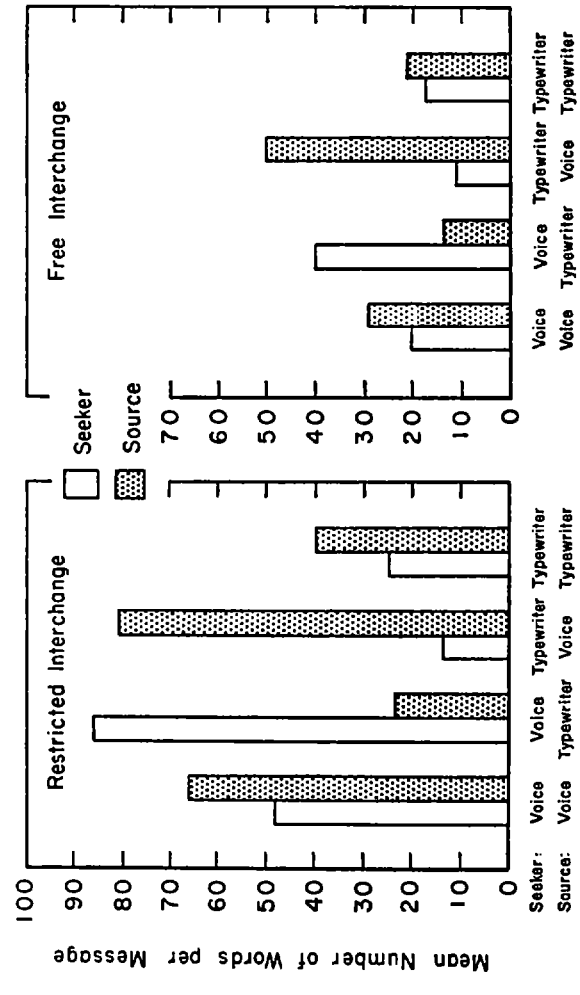

FIG. 10. The triple interaction of job role, interchange condition, and communication mode for mean message lengths

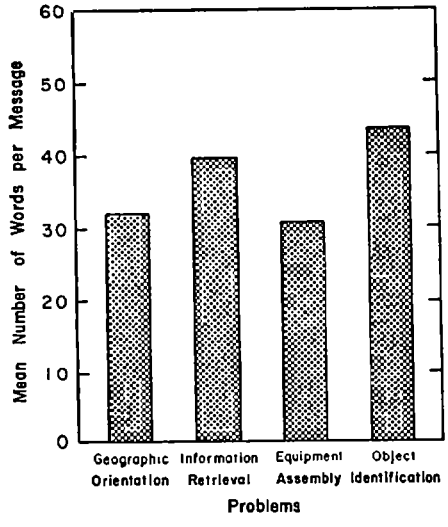

FIG. 11. Mean message lengths during the solution of the four problems

ported so far, the object-identification problem was the consistently deviant one. It was solved faster, with the fewest messages, and with the fewest words. Fig. 11 shows that the object-identification problem is again deviant, but in another way. Messages exchanged in the solution of the object-identification problem were longer than were messages exchanged in the solution of all the other problems.

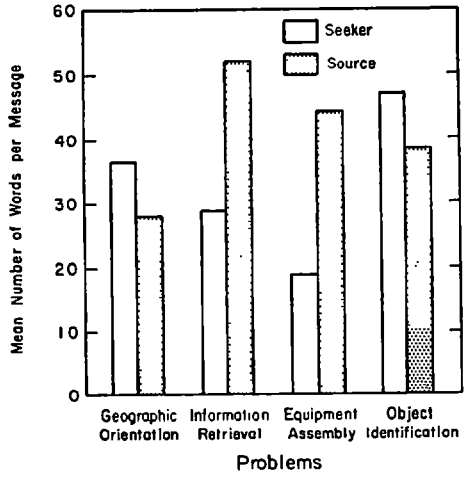

FIG. 12. The interaction of job role and problem for mean message lengths

Problem × job-role interaction.—Fig. 12 shows a marked interaction between problems and job roles. Seekers used longer messages than their partners in the geographic-orientation problem and the object-identification problem. That situation was reversed for the other two problems

Days.—Average message length is the only dependent variable to show a significant effect of days. Message lengths were about equal on the first two days but increased markedly in length on the remaining two days (Day 1 = 29; Day 2 = 29; Day 3 = 42; Day 4 = 47 words).

Messages per Minute

Another derived measure we computed from our data was the number of messages transmitted per unit time. This was done by dividing into the number of messages exchanged by each *S* the length of time his channel was open. This measure is not, unfortunately, a clean one. We know from the data of our first experiment (Chapanis, *et al.*, 1972) that in an experiment like this, *S*s spend a considerable amount of time in activities other than communicating, for example, in making notes, handling parts, and consulting their respective information folios. Our measure of time in this experiment is not a measure of communication time, but of "open channel" or "channel use time." For that reason, our measure of words per minute underestimates true communication rates. Further, comparisons involving this measure are valid only to the extent that *S*s spent equal fractions of their open channel times in communicating. Despite these limitations, some of our findings are so strong that they are at least suggestive of the kinds of communication rates that would undoubtedly be found under more precisely measured conditions.

The analysis of variance of messages per minute gave five significant effects (see Table 3): among communication modes, between interchange conditions, between job roles, the interaction of interchange conditions and job roles, and the interaction of modes with interchange conditions.

Modes.—In the unmixed voice mode *S*s communicated messages five times as fast (3.0 messages per min.) as they did in the unmixed typewriter mode (0.6 messages per min.). Rates of transmission in the two mixed modes (V-T = 1.2, T-V = 1.3 messages per min.) were intermediate between those in the unmixed modes. It is interesting to note from Fig. 8 that message lengths, i.e., numbers of words per message, were much more homogeneous than were the rates at which messages were communicated. To anticipate, then, we should expect to find differences among rates at which words were communicated in the several communication modes. Such was indeed the case (see below).

Interchange conditions and job roles.—Messages were transmitted nearly twice as fast under conditions of free interchange (2.3 messages per min.) as under conditions of restricted interchange (1.3 messages per min.). Recall, however, that messages sent under conditions of restricted interchange were al-

most twice as long as those sent under conditions of free interchange. As a result of these two effects, the number of words communicated per minute (discussed below) is almost identical for the two interchange conditions.

Seekers communicated at markedly higher rates (2.2 messages per min.) than did their partners (1.4 messages per min.). Recall once again that messages sent by the source were longer than those sent by the seeker. As a result, the numbers of words communicated per minute (discussed below) do not differ for source and seeker.

The main effects of interchange condition and job role are evident in Fig. 13 which shows the interaction between them. Sources and seekers transmitted messages at very nearly the same rates under restricted interchange conditions. Both team members exchanged messages faster under conditions of free interchange, but the most pronounced effect was for the seekers who, under free interchange conditions, communicated messages at more than twice the rate of seekers who worked under restricted interchange conditions.

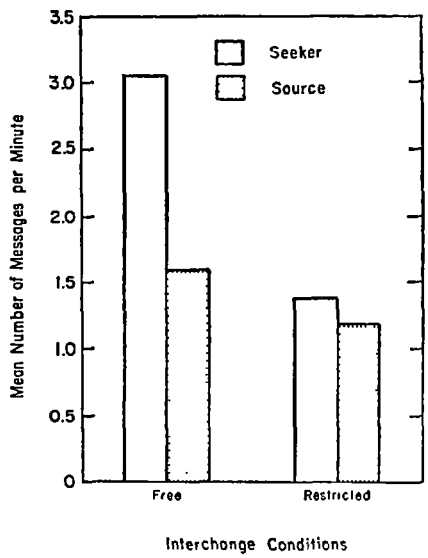

FIG. 13. The interaction of job role and interchange condition for the number of messages communicated per minute

Mode × *interchange-condition interaction.*—The main effect of modes is evident in Fig. 14 which shows the interaction between modes and interchange conditions. The difference between the rates at which messages are communicated under conditions of free interchange and under conditions of restricted interchange is most pronounced for the unmixed voice mode, least pronounced for the unmixed typewriter mode, and intermediate for the two mixed modes.

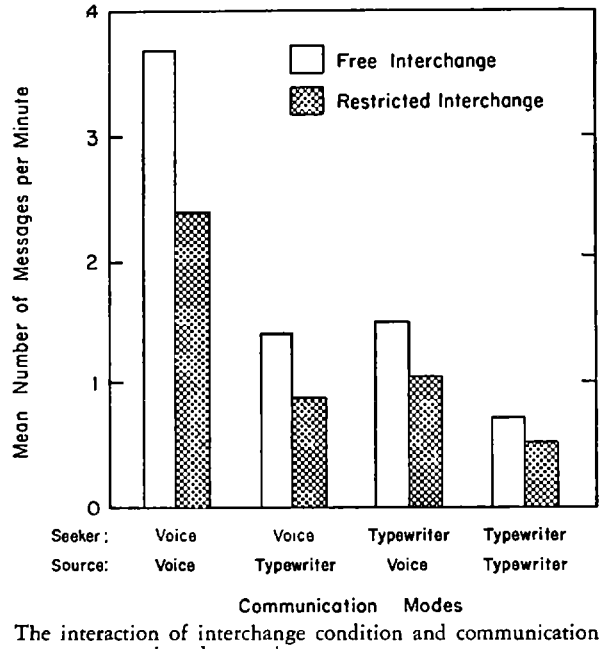

FIG. 14. The interaction of interchange condition and communication mode for the number of messages communicated per minute

Words per Minute

The last measure we report here is another derived measure obtained by dividing into the number of words communicated by *S* the total time that his channel was open. As in the case of messages per minute, this is not a pure measure and for the same reasons. The communication rates are underestimates because *S*s did things other than communicate while their respective channels were open. Further, as we have noted earlier, the validity of any comparison rests on the assumption that *S*s spent about equal proportions of time communicating under the several conditions being compared. Despite their limitations, these data show some effects that we believe are worthy of comment. As Table 3 shows, significant sources of variation were: modes, problems, the interaction of modes with job roles, the interaction of job roles with days, and the interaction of job roles with problems.

Modes.—As might have been anticipated, words were communicated much faster in the unmixed voice mode (105.5 words per min.) than in the unmixed typewriter mode (14.2 words per min.). The two mixed modes fell between these two extremes and had similar values (49.8 for the V-T, and 46.7 for the T-V modes). The orthogonal comparisons show that the unmixed typewriter mode differs from the other three, that the unmixed voice mode differs significantly from the two mixed modes, and that the two mixed modes do not differ

significantly. These findings should be interpreted in the light of the significant mode times job-role interaction discussed immediately below.

Mode × *job-role interaction.*—The mode times job-role interaction (Fig. 15) reinforces even more strongly the differences among the several modes of communication. *S*s with the typewriter channel communicated at very nearly a constant rate of 14.5 words per minute, irrespective of whether *S* was source or seeker. *S*s with the voice channel, irrespective of job role, communicated at a rate (on the average, 93.5 words per min.) about 6.5 times that of *S*s who used the typewriter channel. There is considerably more variability among the communication rates for the voice channel than for the typewriter channel in the several mode-job role combinations, to be sure, but the striking contrast throughout is between the average level for the voice channel and that for the typewriter channel, irrespective of job role.

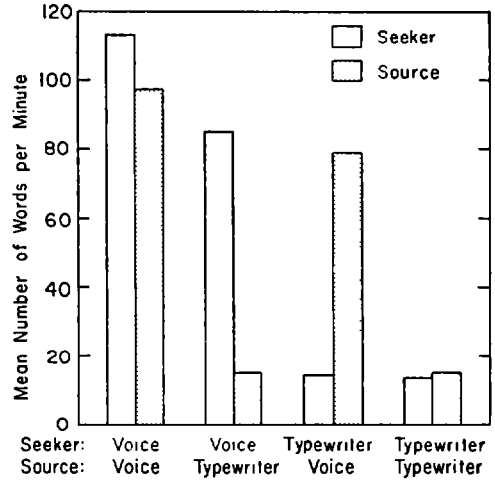

FIG. 15. The interaction of job role and communication mode for the number of words communicated per minute

Problems.—Communication rates in the solution of the object-identification problem were higher (68.7 words per min.) than in the solution of the other three problems (43.3 for the geographic-orientation, 57.3 for the information-retrieval, and 46.8 for the equipment-assembly problems). Note that these communication rates are almost perfectly correlated with message lengths in the solution of the four problems (see Fig. 11). These rates must also be interpreted in the light of the significant problem times job-role interaction discussed below.

Problem × *job-role interaction.*—Fig. 16 shows that communication rates were very nearly equal for the two team members in the solution of the object-identification problem. In the equipment-assembly problem the source commu-

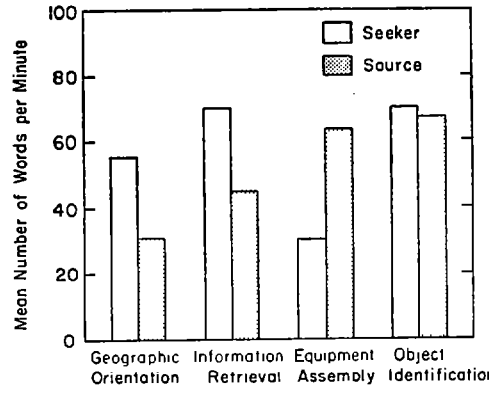

FIG. 16. The interaction of problem and job role for the number of words communicated per minute

nicated much faster than the seeker, and in the geographic-orientation and information-retrieval problems the reverse was true.

Day × *job-role interaction.*—This interaction, although significant, is not illustrated here because the results appear to be idiosyncratic. They show that on the first day the source communicated faster than the seeker. On the second and third days this pattern was reversed, that is, the seeker communicated faster than the source. On the fourth day, the pattern reversed again and resembled more nearly that of the first day. We have no rational explanation for these results and are inclined to attribute them to a rare Type I error.

DISCUSSION

The richness of the findings in this experiment far exceeded our original expectations. At the same time, many effects that we had expected to be significant were not. The latter are in some instances just as interesting as the former. It is also important to note that most of our statistically significant effects were large ones, that is to say, the effects were practically significant as well as statistically significant. Without attempting to define precisely the meaning of "practically significant," we do point out that for the most part, we are dealing with numerically large differences, that is, with factors of two or more.

Communication Modes

Communication mode was the most uniformly significant main effect in this experiment. It affected every single dependent measure used. The general pattern of the findings is one of large and consistent differences between the voice and typewriter channels of communication: Communication by voice is much more rapid and wordy than is communication by typewriter. Problems in the unmixed voice mode of communication were solved in about half the time as in the unmixed typewriter mode. At the same time, *S*s in the unmixed voice

mode used two and a half times as many messages and nearly four times as many words as they did in the unmixed typewriter mode. As a result, rates of communication, measured both by the number of messages and by the number of words exchanged per minute, were about 6 times greater in the V-V mode than in the T-T mode. In every one of these instances, the mixed modes of communication fell between the two unmixed modes, in time to solution, number of messages exchanged, number of words exchanged, messages per minute, and words per minute.

The only dependent measure that deviated from the general pattern discussed above is message length. Mean message lengths were about the same for the unmixed voice mode and the two mixed modes of communication. Messages in the unmixed typewriter mode, however, were significantly shorter than in the other three modes. These findings have to be considered in the light of the interaction of modes with job roles. That interaction shows clearly that the person with the voice channel, whether he be source or seeker, and whether he was in a mixed or unmixed mode, used much longer messages than the person with the typewriter channel.

There were two other significant interactions involving modes and job roles, that for number of words and for words per minute. Once again, these interactions merely strengthen the contrast between the voice and the typewriter channels. The person with the voice channel, whether he be source or seeker, and whether he was in a mixed or unmixed mode, used more words and communicated them much faster than the person with the typewriter channel.

Collectively, these results confirm the results of our first experiment (Chapanis, 1973; Chapanis, *et al.*, 1972). To be sure, there were some substantial differences between the two experiments: in the number and kinds of modes, problems, conditions of interchange, and subjects. Still, the two sets of experiments agree in showing that the oral modes (that is, those using spoken words) are much faster but wordier than hard-copy modes (that is, those using typewritten or handwritten messages).

There was, however, an intriguing difference between the results of the two experiments. If we take only those conditions in this experiment that match those of the first experiment, that is, consider only the data for the geographic-orientation and equipment-assembly problems, the free interchange condition, and the unmixed voice and unmixed typewriter modes, the absolute values of the data in this experiment differ substantially from those of the first experiment. For example, problems in this experiment were solved nearly 20% faster than were comparable problems in the first experiment. At the same time, *S*s in this experiment used about 15% fewer messages and 15% fewer words than did those in the first experiment.

We are inclined to attribute these differences in absolute values to the differences between *S*s tested in the two experiments. The first experiment used

high school boys; this one, highly selected college students. It would be interesting to see if these differences would hold up in an experiment deliberately designed to test different levels of ability on the part of *Ss*. Despite the differences between the outcomes of the two experiments, it is reassuring to see that the mode that is faster for the college students is also faster for the high-school boys and that the faster mode is the wordier one for both groups.

For reasons elaborated earlier, the two rate measures in this experiment, words per minute and messages per minute, are not pure measures. They cannot be compared with similar measures obtained in the first experiment which yielded much better estimates of communication rates. Even so, the general pattern of the communication rates among the several modes in this experiment is the same as that in the first experiment. The numbers are different, to be sure, but communication rates in the unmixed voice mode are much greater than those in the unmixed typewriter mode, a finding that is in agreement with that of the first experiment.

Finally, the results of the first experiment showed no significant differences between the mean message lengths communicated in the several modes. If we take only those data in this experiment that are roughly comparable to those of the first experiment (i.e., data for only the geographic-orientation and equipment-assembly problems and for only the free interchange condition), mean message lengths in the unmixed voice and unmixed typewriter modes are almost identical (18.0 vs 17.0 words per message, respectively).

Interchange Conditions

Our two interchange conditions produced some complex effects that add up to a consistent picture. First, consider the dependent variables that showed no effects. Allowing communicators the freedom to interrupt at any time or denying them that freedom had no effect on the time taken to solve problems. Nor did the interchange option produce a significant difference between the mean number of words used to solve problems or the rates at which words were communicated. When communicators had the freedom to interrupt, they exchanged more messages, messages were much shorter, and messages were exchanged at a greater frequency. Conversely, when communicators did not have the freedom to interrupt, they exchanged fewer messages, messages were much longer, and messages were exchanged at a slower rate.

These significant main effects are also substantiated by the interactions. First, the interaction for modes by interchange options shows that under conditions of free interchange, *Ss* were much more variable in the number of messages exchanged in the different modes. Conversely, when *Ss* did not have the freedom to interrupt, the numbers of messages exchanged in the several modes were much more nearly uniform.

Next, the triple interaction of modes, interchange options and job roles

for message length, taken in conjunction with the significant main effect for interchange conditions on the same dependent measure, shows that under conditions of free interchange, not only did *Ss* use shorter messages but message lengths were more uniform for the various combinations of modes and job roles.

Finally, the significant double interactions of modes and interchange options and of interchange options and job roles for messages per minute, taken in conjunction with the significant main effects for the same dependent measure, show that under conditions of free interchange, *Ss* exchanged messages at a faster rate, and that rates of message interchange under these conditions were more variable in the several modes and for the two job roles.

Taken collectively, these results suggest that the freedom to interrupt has no appreciable effect on the time taken to solve problems, on the total number of words exchanged, or on the rate at which words are exchanged. What does happen is that communicators "package" their words differently according to whether they can, or cannot, interrupt. When communicators have the freedom to interrupt, they exchange more messages, messages are shorter, and messages are exchanged faster. These mean effects are accompanied by changes in variance. That is, not only are more messages exchanged and exchanged faster under conditions of free interchange, but the variability of these two dependent measures increases among the several modes and, in the case of messages per minute, for job roles as well. Similarly, under conditions of free interchange, messages are not only shorter on the average, but the variance of message lengths is much smaller for the various combinations of modes and job roles.

Days

Ss in this experiment solved problems on four successive days so that the main effect of days is, in essence, a practice or learning effect. Days had a significant effect on only one dependent measure, message length, and there was only one significant interaction involving days, the double interaction of days and job roles for words per minute. These results are, in one sense, gratifying, and, in another sense, mystifying.

The results are gratifying because they suggest that the principal effects in which we were interested, those among the several modes and the two interchange conditions, are consistent over time. They are mystifying because it is so rare to find in any human experiment no change in performance, or learning, over time. On the face of it, it seems reasonable that people should improve their ability to solve problems collectively while communicating through restricted channels of communication. It may very well be that four days are not enough to reveal such learning as does occur in tasks of this kind.

Problems and Job Roles

Problems yielded significant effects on five dependent measures, job roles on four, and the interaction of problems and job roles on four. Without elaborat-

ing in detail, these findings mean simply that our problems were different, that the jobs assigned to the two communicators were different, and that the jobs of the communicators were partly dependent on the problem being solved. Neither problems nor job roles were main effects of primary interest in this experiment. The significance of these main effects means that we appear to have been testing different tasks and functions. That in turn makes us feel more secure about the main effects of primary interest, namely, communication modes and interchange conditions. Stated in another way, differences among the latter two main effects appear to be valid for a variety of problems and human functions.

Sequence

Sequence, and the interaction of sequences with interchange conditions, were also variables of minor interest in this experiment. These two sources of variation were significant on only one of the six dependent measures, number of messages exchanged. An examination of the raw data shows that these results were due entirely to the behavior of two of our 16 teams. In the free interchange condition the two teams that used the voice-voice mode in solving their first problem produced a total of 171 and 175 messages, respectively. By contrast, the remaining six teams that also solved a problem in the voice-voice mode but that had solved a problem in another mode first, produced on the average only 78 messages. This difference is even more striking when the data of the two deviant teams are compared with all those in the restricted interchange condition.

In short, communicators who used the voice-voice mode first under conditions of free interchange produced a disproportionately large number of messages as compared with all the other teams that either solved problems in the voice-voice mode but after having had experience with some other communication mode first, or that solved problems under the restricted interchange condition. That is neither a terribly exciting nor, in our opinion, interesting result. Of much greater importance is that sequences, and the interaction of sequence with interchange conditions, had so little effect. That makes us feel much more comfortable about the generality and the validity of our principal main effects.

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