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SOME EFFECTS OF CERTAIN COMMUNICATION PATTERNS ON GROUP PERFORMANCE [1]

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INTRODUCTION

COOPERATIVE action by a group of individuals having a common objective requires, as a necessary condition, a certain minimum of communication. This does not mean that all the individuals must be able to communicate with one another. It is enough, in some cases, if they are each touched by some part of a network of communication which also touches each of the others at some point. The ways in which the members of a group may be linked together by such a network of communication are numerous; very possibly only a few of the many ways have any usefulness in terms of effective performance. Which of all feasible patterns are "good" patterns from this point of view? Will different patterns give different results in the performance of group tasks?

In a free group, the kind of network that evolves may be determined by a multitude of variables. The job to be done by the group may be a determinant, or the particular abilities or social ranks of the group members, or other cultural factors may be involved.

Even in a group in which some parent organization defines the network of communication, as in most military or industrial situations, the networks themselves may differ along a variety of dimensions. There may be differences in number of connections, in the symmetry of the pattern of connections, in "channel capacity" (how much and what kind of information), and in many other ways.

It was the purpose of this investigation to explore experimentally the relationship between the behavior of small groups and the patterns of communication in which the groups operate. It was our further purpose to consider the psychological conditions that are imposed on group members by various communication patterns, and the effects of these conditions on the organization and the behavior of its members. We tried to do this for small groups of a constant size, using two-way written communication and a task that required the simple collection of information.

Some Characteristics of Communication Structures

The stimulus for this research lies primarily in the work of Bavelas (1), who considered the problem of defining some of the dimensions of group structures. In his study, the structures analyzed consist of cells connected to one another. If we make persons analogous to "cells" and communication channels analogous to "connections," we find that some of the dimensions that Bavelas defines are directly applicable to the description of communication patterns. Thus, one way in which communication patterns vary can be described by the sum of the neighbors that each individual member has, neighbors being defined as individuals to whom a member has communicative access. So, too, the concept of *centrality,* as defined by Bavelas, is of value in describing differences within and between structures. The most central position in a pattern is the position closest to all other positions. Distance is measured by number of communicative links which must be utilized to get, by the shortest route, from one position to another.

Bavelas also introduced a *sum of neighbors* measure—sum of neighbors being a summation, for the entire pattern, of the number of positions one link away from each position. Similarly, *sum of distances* is the summation, for all positions, of the shortest distances (in links) from every position to every other one.

Unfortunately, these dimensions we have mentioned do not in themselves uniquely define a pattern of communication. What defines a pattern is the *way* the cells are connected, regardless of how they are repre-

[1] The experiments reported here were conducted at the Massachusetts Institute of Technology. The stimulus for this research derives from the work and the thinking of Professor Alex Bavelas. A great deal of help was also contributed by members of Professor Bavelas' seminar in Advanced Experimental Psychology.

sented on paper. In essence, our criterion is this: if two patterns cannot be "bent" into the same shape without breaking a link, they are different patterns. A more precise definition of unique patterns would require the use of complex topological concepts.

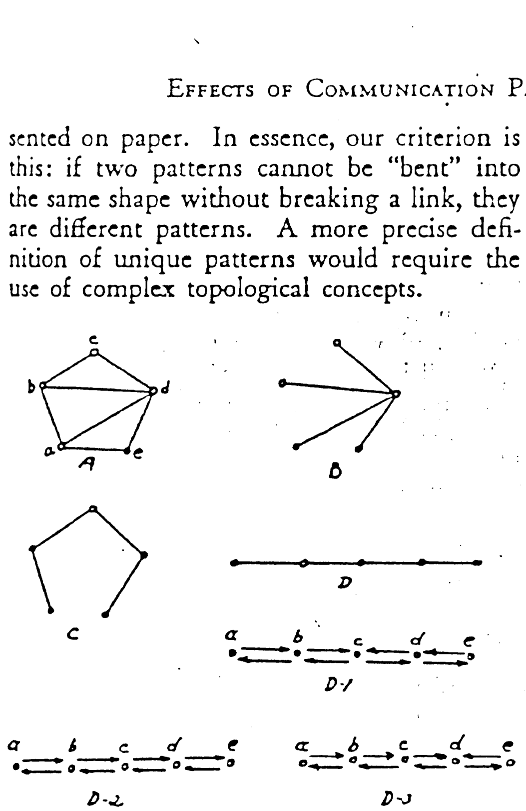

Fig. 1. Communication Patterns (See text)

Some Operational Characteristics of Communication Patterns

Consider the pattern depicted as A in Figure 1. If at each dot or cell (lettered *a*, *b*, etc.) we place a person; if each link (line between dots) represents a two-way channel for written communications; and if we assign to the five participants a task requiring that *every* member get an answer to a problem which can be solved only by pooling segments of information originally held separately by each member, then it is possible a priori to consider the ways in which the problem can be solved.

Pattern Flexibility. First we note that the subjects (*Ss*) need not always use all the channels potentially available to them in order to reach an adequate solution of the problem. Although pattern A (Fig. 1) contains potentially seven links or channels of communication, it can be solved as follows with three of the seven channels ignored.

Step 1: *a* and *e* each send their separate items of information to *b* and *d* respectively.

Step 2: *b* and *d* each send their separate items of information, along with those from *a* and *b* respectively, to *c*.

Step 3: *c* organizes all the items of information, arrives at an answer, and sends the answer to *b* and then to *d*.

Step 4: *b* and *d* then send the answer to *a* and *e* respectively.

The use of these particular four channels yields pattern C (Fig. 1). The original seven-link pattern (A) can be used as a four-link pattern in various ways. For instance, each of the four *Ss* diagrammatically labelled *c*, *b*, *a*, and *e* might send his item of information to *d* who would organize the items, arrive at the answer, and send it back to each respectively. Use of these particular four channels would yield the pattern B in Figure 1. The problem could also be solved by the *Ss* using five, six, or all of the seven potential channels.

Operational Flexibility. Secondly, with the specification that a given number of links be used, any pattern can be operated in a variety of ways. Thus the pattern D (Fig. 1), which has no pattern flexibility, can be used as shown in D–1, with information funnelled in to C and the answer sent out from C. It is also possible to use it, as in D–2, with E as the key position; or as in D–3. These are operational differences that can be characterized in terms of the roles taken by the various positions. Thus in D–1, C is the decision-making position. In D–2, it is E or A. Some patterns can be operated with two or three decision-makers.

The Definition of Maximum Theoretical Efficiency

Before going further it may be helpful to state the task used in this research. To each *S*, labeled by color (see Fig. 2), was given a card on which there appeared a set of five (out of six possible) symbols. Each *S*'s card was different from all the others in that the symbol lacking, the sixth one, was a different symbol in each case.

Thus, in any set of five cards there was only one symbol in common. The problem was for every member to find the common symbol. To accomplish this each member was allowed to communicate, by means of written messages, with those other members of the group to whom he had an open channel (a link in our diagrams). Every separate written communication from one *S* (A) to another (B) was considered one message.

An S who had discovered the answer was allowed to pass the answer along.

Minimum Number of Communications. For any pattern of n Ss, the minimum number of communications, C, is given by $C=2(n-1)$.

Six Symbols Used: ○ △ ◇ □ + ✱						
Trial No.	Symbol Missing From: White	Red	Brown	Yellow	Blue	Common Symbol
1	△	◇	✱	○	□	+
2	◇	○	□	△	+	✱
3	+	✱	□	△	◇	○
4	□	◇	△	✱	+	○
5	○	✱	+	△	□	◇
6	△	○	□	✱	◇	+
7	□	+	○	◇	△	✱
8	◇	✱	□	+	○	△
9	✱	◇	□	△	○	+
10	+	○	□	✱	◇	△
11	○	+	△	◇	✱	□
12	✱	○	□	△	+	◇
13	△	○	◇	□	+	✱
14	□	◇	+	✱	△	○
15	+	○	□	◇	✱	△

FIG. 2. SYMBOL DISTRIBUTION BY TRIAL

Theoretically, then, with *number of messages as the sole criterion,* any pattern of n Ss is as efficient as any other n-sized pattern.

The Minimum Time Required for Solution. If we assume "standard" S's, all of whom work, think, and write at the same speed, it is possible to calculate the limit set by the communication pattern on the speed with which the problem can be solved. Toward this end, we can arbitrarily define a *time unit* as the time required to complete any message, from its inception by any S to its reception by any other.

For any n not a power of 2 and *with unrestricted linkage,* when $2^x<n<2^{x+1}$ and x is a power of 2, $x+1$ equals the minimum possible time units for solution of the problem. Thus, for a five-man group we have $2^x<5<2^{x+1}$ becoming $2^2<5<2^3$, and $x+1=3$ time units. *No* five-man pattern can be done in less than three time units, although several require more than three time units. When n is an even power of 2, the formula $2^x=n$ holds, and $x=$minimum time.[2]

It will be noted that, although some patterns require fewer time units than others, they may also require more message (m) units. This phenomenon, effectively the generalization that it requires increased messages to save time units, holds for all the patterns we have examined. It is, however, true that certain patterns requiring different times can be solved in the same number of message units.

Some Possible Effects of Various Patterns on the Performance of Individuals

There are two general kinds of reasons which dictate against our theoretically perfect performance from real people. The first of these is the obvious one that people are not standardized. There are also the forces set up by the patterns themselves to be considered. The problem becomes one of analyzing the forces operating on an individual in any particular position in a communication pattern and then predicting how the effects of these forces will be translated into behavior.

It is our belief that the primary source of differential forces will be *centrality.* Centrality will be the chief (though perhaps not the sole) determinant of behavioral differences because centrality reflects the extent to which one position is strategically located relative to other positions in the pattern.

Our selection of centrality derives from the belief that availability of information necessary for the solution of the problem will be of prime importance in affecting one's behavior. Centrality is a measure of one's closeness to

[2] This is an empirical generalization derived chiefly from an analysis of a four-man square pattern. In such a pattern, A and B, and C and D may swap information in one time unit. Then A and C, and B and D may swap in two time units to yield a complete solution. For an eight-man ladder pattern the same simultaneous swapping process yields a minimum time. For the intervening n's, at least "part" of a time unit is required, in addition to the minimum time for the four-man pattern. A detailed account of this analysis may be found in a paper, as yet unpublished, by J. P. Macy, Jr.

all other group members and, hence, is a measure of the availability of the information necessary for solving the problem.

Availability of information should affect behavior, in turn, by determining one's role in the group. An individual who can rapidly collect information should see himself and be seen by others in a different way from an individual to whom vital information is not accessible. Such roles should be different in the extent to which they permit independence of action, in the responsibility they entail, and in the monotony they impose. Finally, differences in independence, in responsibility, and in monotony should affect the speed, the accuracy, the aggressiveness, and the flexibility of behavior.

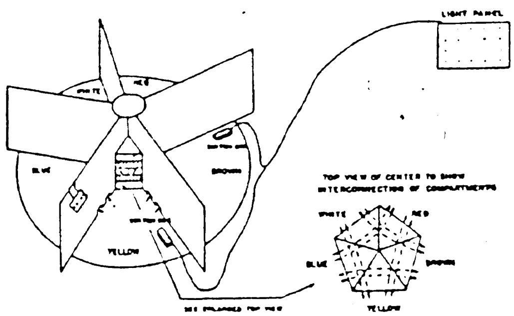

FIG. 3. APPARATUS

METHOD

The Problem to be Solved

We have already described the task to be given our *Ss*—a task of discovering the single common symbol from among several symbols. When *all five* men indicated that they knew the common symbol, a trial was ended. Another set of cards, with another common symbol, was then given to the *Ss*, and another trial was begun.

Each group of *Ss* was given 15 consecutive trials. The composition of the standard sets of cards, used for all groups, is indicated in Figure 2, which indicates the symbol *not* on each person's card for each trial. By referring this missing symbol to the set of six symbols at the top, the reader may reconstruct the symbols actually on each man's card. The common symbol (the right answer) is also shown in Figure 2.

The Apparatus

The *Ss* were seated around a circular table (Fig. 3) so that each was separated from the next by a vertical partition from the center to six inches beyond the table's edge. The partitions had slots permitting subjects to push written message cards to the men on either side of them.

To allow for communication to the other men in the group, a five-layered pentagonal box was built and placed at the center of the table. The box was placed so that the partitions just touched each of the five points of the pentagon. Each of the five resulting wedge-shaped work-spaces was then painted a different color. The *Ss* were supplied with blank message cards whose colors matched that of their work spaces. Any message sent from a booth had to be on a card of the booth's color. On the left wall of each partition, 16 large symbol cards, representing 16 trials, were hung in loose-leaf fashion. The cards were placed in order with numbered backs to *S*. At the starting signal, *S* could pull down the first card and go to work.

In addition, each work space was provided with a board on which were mounted six switches. Above each switch appeared one of the six symbols. When *S* got an answer to the problem, he was to throw the proper switch, which would turn on an appropriate light on a master board of 30 lights in the observer's room. When five lights (whether or not they were under the correct symbol), representing five different *Ss*, were lit, the observer called a halt to the trial. The observer could tell by a glance at the light panel whether (a) five different *Ss* had thrown their switches, (b) whether all five had decided on the same answer, and (c) whether the answer decided on was right or wrong. The same detailed instructions were given to all *Ss*.

A preliminary series of four problems, in which each *S* was given all the information required for solution, was used. This was done to note the extent of differences among *Ss* in the time required to solve such problems.

The Procedure

One hundred male undergraduates of M.I.T.,[3] drawn from various classes at the Institute, served as *Ss* for these experiments. These 100 were split up into 20 groups of five men each. These 20 groups were then further subdivided so that five groups could be tested on each of four experimental patterns.

Each group was given 15 consecutive trials on *one* pattern, a process which required one session of about fifty minutes. These *Ss* were *not used again*. The order in which we used our patterns was also randomized. Just in case the color or geographical position of one's work-space might affect one's behavior, we shifted positions for each

[3] Data on female graduate students are being gathered at M.I.T. by Smith and Bavelas, and the indications are that their behavior differs in some ways from the behavior of our male *Ss*.

new group. After a group had completed its 15 trials, and before members were permitted to talk with one another, each member was asked to fill out a questionnaire.

FIG. 4. THE EXPERIMENTAL PATTERNS

The Patterns Selected

The four five-man patterns selected for this research are shown in Figure 4.

These four patterns represented extremes in centrality (as in the circle vs. the wheel), as well as considerable differences in other characteristics (Table 1).

served only as a transmitter of information and of answers. In at least one case, C transmitted answers first to A and B and only then to D. Organization for the Y evolved a little more slowly than for the wheel, but, once achieved, it was just as stable.

In the *chain* information was usually funnelled in from both ends to C, whence the answer was sent out in both directions. There were several cases, however, in which B or D reached an answer decision and passed it to C. The organization was slower in emerging than the Y's or the wheel's, but consistent once reached.

The *circle* showed no consistent operational organization. Most commonly messages were just sent in both directions until any *S* received an answer or worked one out.

TABLE 1

CHARACTERISTICS OF THE EXPERIMENTAL PATTERNS

PATTERN	NO. OF LINKS	MOST CENTRAL POSITION	SUM OF NEIGHBORS	SUM OF DISTANCES	MIN. TIME UNITS	MIN. MESSAGES
CHAIN	4	C(6.7)	8	40	5(8*m*)	8(5*t*)
Y	4	C(7.2)	8	36	4(8*m*)	8(4*t*)
WHEEL	4	C(8.0)	8	32	5(8*m*)	8(5*t*)
CIRCLE	5	All(5.0)	10	30	3(14*m*)	8(5*t*)

RESULTS

The data which have been accumulated are broken down in the pages that follow into (a) a comparison of total patterns and (b) a comparison of positions within patterns.

A. Differences among Patterns

It was possible to reconstruct a picture of the operational methods actually used by means of: (a) direct observations, (b) post-experimental analysis of messages, and (c) post-experimental talks with *Ss*.

The *wheel* operated in the same way in all five cases. The peripheral men funnelled information to the center where an answer decision was made and the answer sent out. This organization had usually evolved by the fourth or fifth trial and remained in use throughout.

The Y operated so as to give the most central position, C (see Fig. 4 and Table 1), complete decision-making authority. The next-most-central position, D (see Fig. 4),

In every case, all available links were used at some time during the course of each trial.

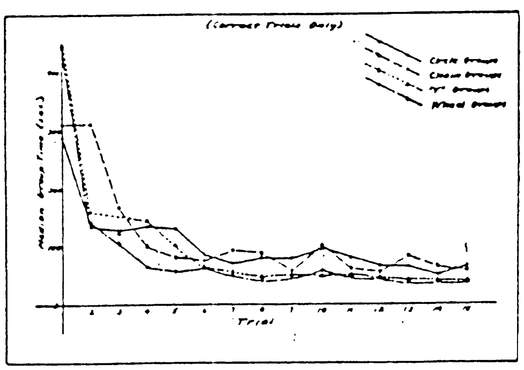

FIG. 5. MEDIAN GROUP-TIMES PER TRIAL

Direct Measures of Differences among Patterns

Time. The curves in Figure 5 are for *correct* trials only, that is, for trials in which all five switches represented the correct common symbols. In most cases, the median shown are for distributions of five groups, but in no case do they represent less than three groups.

The variability of the distributions represented by these medians is considerable. In the fifteenth trial, the distribution for the circle has a range of 50–96 seconds; for the chain, 28–220 seconds; for the Y, 24–52 seconds; and for the wheel, 21–46 seconds. Moreover, much of the time that went to make up each trial was a constant consisting of writing and passing time. Any differences attributable to pattern would be a small fraction of this large constant and would be easily obscured by accidents of misplacing or dropping of messages.

Despite all these factors, one measure of speed did give statistically significant differences. A measure of the *fastest single trial* of each group indicates that the wheel was considerably faster (at its fastest) than the circle (Table 2).

TABLE 2

FASTEST SINGLE CORRECT TRIAL

	CIRCLE	CHAIN	Y	WHEEL	DIFF.	p*
MEAN	50.4	53.2	35.4	32.0	Ci–W	<.01
MEDIAN	55.0	57.0	32.0	36.0	Ch–W	<.10
RANGE	44–59	19–87	22–53	20–41	Ci–Y	<.05
					Ch–Y	<.20

* Significance of differences between means were measured throughout by t-tests. The p-values are based on distributions of t which include both tails of the distribution (see Freeman [2]). Where differences are between proportions, p is derived from the usual measure of significance of differences between proportions. Ci-W means the circle-wheel difference, and so on.

Messages. The medians in Figure 6 represent a count of the number of messages sent by each group during a given (correct) trial. It seems clear that the circle pattern used more messages to solve the problem than the others.

Errors. An error was defined as the throwing of any incorrect switch by an S during a trial. Errors that were *not* corrected before the end of a trial are labelled "final errors"; the others are referred to as "corrected errors."

It should be pointed out that the error figures for the *wheel* in Table 3 are distorted by the peculiar behavior of one of the five

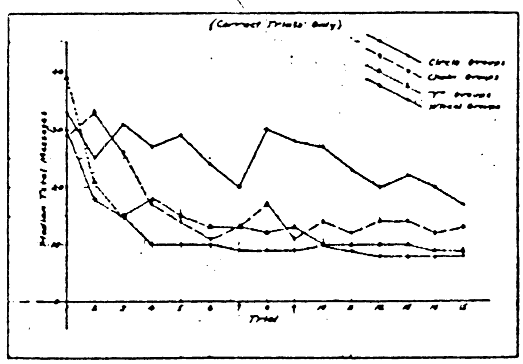

FIG. 6. MEDIAN MESSAGES PER TRIAL

wheel groups. The center man in this group took the messages which he received to be *answers* rather than simple information, and, in addition to throwing his own switch, passed the information on *as an answer.* This difficulty was cleared up after a few trials, and the figures for the last eight trials are probably more representative than the figures for the full 15 trials.

In addition to the differences in errors, there are differences in the proportion of total errors that were corrected. Although

TABLE 3

ERRORS

PATTERN	TOTAL ERRORS (15 TRIALS)		TOTAL ERRORS (LAST 8 TRIALS)		FINAL ERRORS		MEAN NO. OF TRIALS WITH AT LEAST ONE FINAL ERROR
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE	
CIRCLE	16.6	9–33	7.6	1–18	6.4	2–14	3.4
CHAIN	9.8	3–19	2.8	0–11	6.2	1–19	1.8
Y	2.6	1–8	0	0	1.6	0–5	.8
WHEEL	9.8	0–34	0.6	0–2	2.2	0–7	1.2

p VALUES Ci–Y <.02

more errors were made in the circle pattern than any other, a greater proportion of them (61 per cent) were corrected than in any other pattern. Too, the frequency of unanimous five-man final errors is lower, both absolutely and percentage-wise, for the circle than for the chain.

Questionnaire Results

1. *"Did your group have a leader? If so, who?"*

Only 13 of 25 people who worked in the circle named a leader, and those named were scattered among all the positions in the circle. For all patterns, the total frequency of people named increased in the order *circle, chain, Y, wheel.* Similarly, the unanimity of opinion increased in the same order so that, for the wheel pattern, all 23 members who recognized any leader agreed that position C was that leader.

2. *"Describe briefly the organization of your group."*

The word "organization" in this question was ambiguous. Some of the *S*s understood the word to mean pattern of communication, while others equated it with their own duties or with status difference.

These differences in interpretation were not random, however. Sixteen people in the wheel groups fully reproduced the wheel structure in answer to this question, while only one circle member reproduced the circle pattern.

3. *"How did you like your job in the group?"*

In this question *S*s were asked to place a check on a rating scale marked "disliked it" at one end and "liked it" at the other. For purposes of analysis, the scale was translated into numerical scores from 0 at the dislike end to 100. Each rating was estimated only to the closest decile.

Again, we find the order circle, chain, Y, wheel, with circle members enjoying their jobs significantly more than the wheel members.

4. *"See if you can recall how you felt about the job as you went along. Draw the curve below."*

The *S*s were asked to sketch a curve into a space provided for it. We measured the height of these curves on a six-point scale at trials 1, 5, 10, and 15. These heights were averaged for each group, and the averages of the group averages were plotted.

Although the differences between groups are not statistically significant, trends of increasing satisfaction in the circle and decreasing satisfaction in the wheel seem to corroborate the findings in the question on satisfaction with one's job. Except for a modest Y-chain reversal, the order is, as usual, from circle to wheel.

5. *"Was there anything, at any time, that kept your group from performing at its best? If so, what?"*

The answers to this question were categorized as far as possible into several classes.

None of the circle members feels that "nothing" was wrong with his group; a fact that is suggestive of an attitude different from that held by members of the other patterns. So, too, is the finding that insufficient knowledge of the pattern does not appear as an obstacle to the circle member but is mentioned at least five times in each of the other patterns.

6. *"Do you think your group could improve its efficiency? If so, how?"*

Circle members place great emphasis on *organizing* their groups, on working out a "system" (mentioned 17 times). Members of the other patterns, if they felt that any improvement at all was possible, emphasized a great variety of possibilities.

7. *"Rate your group on the scale below."*

For purposes of analysis, these ratings (along a straight line) were transposed into numbers from 0, for "poor," to 100.

The same progression of differences that we have already encountered, the progression *circle, chain, Y, wheel,* holds for this question. Once again the circle group thinks less well of itself (Mean=56) than do the other patterns ($M_{ch}=60$; $M_{y}=70$; $M_{w}=71$).

Message Analysis

The messages sent by all *S*s were collected at the end of each experimental run and their contents coded and categorized. Some of these categories overlapped with others, and hence some messages were counted in more than one category.

The now familiar progression, *circle, chain, Y, wheel,* continues into this area. Circle members send many more informational messages than members of the other patterns ($M_{ci}=283$; $M_{w}=101$). Circle members also send more answers ($M_{ci}=91$; $M_{w}=65$).

The same tendency remains in proportion to total errors as well as absolutely. The circle has a mean of 4.8 recognition-of-error messages for a mean of 16.6 errors; the chain has a mean of 1 recognition-of-error messages for a mean of 9.8 errors.

We were concerned, before beginning these experiments, lest *S*s find short cuts for solving the problem, thus making certain comparisons among patterns difficult. One such short cut we have called "elimination." Instead of taking time to write their five symbols, many *Ss*, after discovering that only six symbols existed in all, wrote just the missing symbol, thus saving considerable time. This method was used by at least one member in two of the circle groups, in all the chain groups, in three of the Y groups, and in four of the wheel groups. In *both* the circle cases, the method was used by *all five members* during final trials. In the chain, though present in every group, elimination was used only once by all five members, twice by three members, and twice by just one member. In the Y, the method was adopted once by four members (the fifth man was *not* the center) and twice by two members. There was at least one case (in the wheel) in which a member who suggested the use of elimination was ordered by another member not to use it.

The questions raised here are two. Is the idea of elimination more likely to occur in some patterns than in others? Is an innovation like elimination likely to be more readily accepted in some patterns than in others? To neither of these questions do we have an adequate answer.

B. A Positional Analysis of the Data

Observation of the experimental patterns indicates that every position in the circle is indistinguishable from every other one. No one has more neighbors, is more central, or is closer to anyone than anyone else. In the wheel, the four peripheral positions are alike, and so on. Despite our inability to differentiate these positions from one another, we have set up the data in the following sections as if all positions in each pattern were actually different from one another.

Direct Observations

Messages. The most central positions, it will be seen from Table 4, send the greatest number of messages; the least central ones send the fewest.

Errors. The analysis of total errors made in each position showed nothing of significance.

Questionnaire Results by Position

1. *"How much did you enjoy your job?"*

The most central positions in other patterns enjoy their jobs more than any circle position. Peripheral positions, on the other hand, enjoy the job less than any circle position (Table 5).

TABLE 4

NUMBER OF MESSAGES SENT BY EACH POSITION

		A	B	C	D	E	DIFF.	*p*
CIRCLE	MEAN	78.4	90.0	83.6	86.2	81.0	A–B	<.30
	RANGE	64–101	63–102	60–98	60–122	72–90		
CHAIN	MEAN	24.8	70.8	82.4	71.8	27.6	C–E	<.01
	RANGE	20–34	43–112	45–113	42–101	22–43		
Y	MEAN	28.0	23.8	79.8	63.8	25.6	A–C D–C D–E	<.01 <.20 <.01
	RANGE	20–44	21–28	65–104	43–78	21–37		
WHEEL	MEAN	29.4	26.2	102.8	26.6	30.2	C–E	<.01
	RANGE	19–48	17–40	78–138	17–39	22–43		

2. *"See if you can recall how you felt about the job as you went along. Draw the curve below."*

The data for this question are gathered after all most-peripheral and all most-central positions are combined. Peripheral positions were: positions A and E, in the chain; position E in the Y; and positions A, B, D, and E in the wheel. Central positions were all C positions with the exception of C in the circle. The data thus combined highlight the trend toward higher satisfaction with increasing centrality. The central positions progress from a mean of 2.1 at trial 1 to a mean of 3.9 at trial 15. Peripheral positions decline from 3.9 to 2.3.

Message Analysis by Position

One of the things that immediately stands out from an examination of the messages is an apparent peculiarity in the *informational message* category. Although the most central man in the chain sends more informational messages (52) than the other positions in that pattern, the same is not true of the most central men in the Y and the wheel. In the Y, it is position D, the next-most-central position, that sends most; while in the wheel all positions are about equal. This peculiarity becomes quite understandable if we take into account (a) the kind of organization used in each pattern and (b) the fact that these figures represent the entire 15 trials, some of which occurred before the group got itself stably organized. In the wheel, the Y, and the chain, the center man really needed to send *no* informational messages, only answers; but in the *early* trials, before his role was clarified, he apparently sent enough to bring his total up to or higher than the level of the rest.

It can also be noted that the number of *organizational messages* (messages which seek to establish some plan of action for future trials) is negatively correlated with positional centrality. The most peripheral men send the greatest numbers of organizational messages, the most central men least.

TABLE 5

ENJOYMENT OF THE JOB

		A	B	C	D	E	DIFF.	p
CIRCLE	MEAN RANGE	58.0 0–100	64.0 0–100	70.0 20–100	65.0 40–100	71.0 25–100	A–E	<.70
CHAIN	MEAN RANGE	45.0 25–55	82.5 50–100	78.0 50–100	70.0 40–100	24.0 0–70	C–E C–AE	<.02 <.01
Y	MEAN RANGE	46.0 0–100	49.0 25–100	95.0 75–100	71.0 30–100	31.0 0–75	C–A C–AB D–E	<.02 <.01 <.10
WHEEL	MEAN RANGE	37.5 0–50	20.0 0–40	97.0 85–100	25.0 0–75	42.5 0–100	B–C C–E ABED–C	<.01 <.02 <.01

DISCUSSION

Patternwise, the picture formed by the results is of differences almost always in the order *circle, chain, Y, wheel.*

We may grossly characterize the kinds of differences that occur in this way: the circle, one extreme, is active, leaderless, unorganized, erratic, and yet is enjoyed by its members. The wheel, at the other extreme, is less active, has a distinct leader, is well and stably organized, is less erratic, and yet is unsatisfying to most of its members.

There are two questions raised by these behavioral differences. First, what was wrong with our a priori time-unit analysis? The results measured in clock time do not at all match the time-unit figures. And second, to what extent are behavioral differences matched by centrality differences?

The Time Unit

It was hypothesized earlier that the time taken to solve a problem should be limited at the lower end by the structure of the pattern of communication. If pattern does set such a limitation on speed, the limitation is not in the direction we would have predicted. Our analysis (Table 1), based on a theoretical time unit, led us falsely to expect greatest speed from the circle pattern.

There are three outstanding reasons for the failure of the time-unit analysis to predict clock time. First, the time unit, itself, was too gross a measure. We defined the time unit as the time required for the transmission of one message from its inception to its reception. In actuality, different kinds of messages required very different clock times for transmission. *Ss* could send two messages simultaneously. They could also lay out and write several messages before sending any.

A second reason for the failure of the time-unit analysis was the assumption that *Ss* would gravitate to the theoretically "best".

operating organization. Only the wheel groups used the theoretically "best" method (the minimum time method) consistently.

Finally, it should be pointed out that differences in speed between patterns were subject to major fluctuations for reasons of differences in writing speed, dexterity in passing messages, and other extraneous factors.

The Relation of the Centrality Measure to Behavior

Our second and more important question is: Are the behavioral differences among patterns and among positions related consistently to the centrality index? An examination of Table 1 indicates that the centrality index shows the same progression, *circle, chain, Y, wheel,* as do most of the behavioral differences. On a positional basis, centrality also differentiates members of a pattern in the same order that their behavior does.

Because such a relationship does exist between behavior and centrality, a more detailed consideration of the centrality concept is in order.

The central region of a structure is defined by Bavelas as "the class of all cells with the smallest p to be found in the structure." The quantity, p, in turn, is defined as the largest distance between one cell and any other cell in the structure. Distance is measured in link units. Thus the distance from A to B in the chain is one link; from A to C the distance is two links. The most central position in a pattern is the position that is closest to all other positions. Quantitatively, an index of the centrality of position A in any pattern can be found by (a) summing the shortest distances from *each* position to every other one and (b) dividing this summation by the total of the shortest distances from position A to every other position.

Centrality, then, is a function of the size of a pattern as well as of its structure. Thus, in a five-man circle, the centrality of each man is 5.0. In a six-man circle, the centrality of each man jumps to 6.0. The two most peripheral men in a five-man chain each have a centrality of 4.0. But in a seven-man chain, the two most peripheral men have centralities of 5.3.

In Figure 7 are given the centralities of each position in each of our four test patterns. The sum of centralities is also given. Both total centrality and distribution of centralities fall in the order *circle, chain, Y, wheel.*

These centrality figures correlate with the behavior we have observed. But it seems unreasonable to assume that the correlation would hold for larger n's. Certainly we would not expect *more* message activity or *more* satisfaction from peripheral positions in a chain of a larger n than from a five-man chain.

To obviate this difficulty, a measure we have called "relative peripherality" may be established. The relative peripherality of

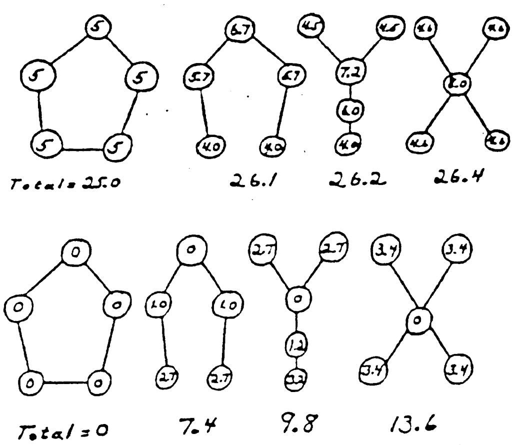

FIG. 7. CENTRALITY INDICES (above) AND PERIPHERALITY INDICES (below)

any position in a pattern is the difference between the centrality of that position and the centrality of the most central position in that pattern. Thus, for the two end men in a five-man chain, the peripherality index is 2.7 (the difference between their centralities of 4.0 and the centrality of the most central position, 6.7). For a total pattern, the peripherality index may be taken by summating all the peripherality indices in the pattern (Fig. 7).

Examination of the data will show that observed differences in behavior correlate positively with these peripherality measures. *By total pattern,* messages, satisfaction, and errors (except for the wheel) vary consistently with total peripherality index. Similarly, by position, messages and satisfaction vary with peripherality. Errors, however, show no clear relationship with peripherality of position, a finding which is discussed in detail later in this section.

Recognition of a leader also seems to be a function of peripherality, but in a somewhat different way. A review of our leadership findings will show that leadership becomes more clear-cut as the differences in peripherality *within a pattern become greater.* Recognition of a leader seems to be determined by the extent of the difference in centrality between the most central and next-most-central man.

There arises next the question: What is the mechanism by which the peripherality of a pattern or a position affects the behavior of persons occupying that pattern or position?

A reconstruction of the experimental situation leads us to this analysis of the peripherality-behavior relationship:

First, let us assume standard *Ss*, motivated to try to solve our experimental problem as quickly as possible. Let them be "intelligent" *Ss* who do not send the same information more than once to any neighbor. Let them also be *Ss* who, given several neighbors, will send, with equal probability, their first message to any one of those neighbors.

Given such standard *Ss*, certain specific positions will probably get an answer to the problem before other positions. In the chain, position C will be most likely to get the answer first, but, in the circle, all positions have an equal opportunity.

To illustrate, consider the chain pattern (see Fig. 4): During time unit 1, A may send only to B. B may send either to C or to A. C may send either to B or to D. D may send either to C or to E. E may send only to D. No matter where B, C, and D send their messages, B and D will have, at the end of one time unit, A's and E's information. During the second time unit, if B and/or D had sent to C the first time, they will now send to A and E. If they sent to A and E the first time, they will send to C, and C will have the answer. Even if B and D do not send to C until the third time unit, C will either get the answer before or simultaneously with B and D. In *no* case can any other position beat C to the answer. In the wheel, C cannot even be tied in getting an answer. He will *always* get it first.

Our second concern is with *Ss*' perceptions of these answer-getting potentials. We suggest that these random differences in answer-getting potentials rapidly structure members' perceptions of their own roles in the group. These differences affect one's independence from, or dependence on, the other members of the group. In the wheel, for example, a peripheral *S* perceives, at first, only that he gets the answer and information from C and can send only to C. C perceives that he gets information from everyone and must send the answer to everyone. The recognition of roles is easy. The peripheral men are dependent on C. C is autonomous and controls the organization.

In the circle, an *S*'s perception must be very different. He gets information from both sides; sometimes he gets the answer, sometimes he sends it. He has two channels of communication. He is exclusively dependent on no one. His role is not clearly different from anyone else's.

Thirdly, having closed the gap between structural pattern and *Ss*' perceptions of their roles in the group, the problem reduces to one purely psychological. The question becomes: How do differences in one's perception of one's own dependence or independence bring about specific behavior differences of the sort we have observed?

Differences in satisfaction level are relatively easy to relate to independence. In our culture, in which needs for autonomy, recognition, and achievement are strong, it is to be expected that positions which limit independence of action (peripheral positions) would be unsatisfying.

A fairly direct relationship between centrality (and, hence, independence) and the speed with which a group gets organized is also perceptible. In the wheel, unless *Ss* act "unintelligently," an organization, with C as center, is forced on the wheel groups by the structural pattern. In the circle, no such differences in role and, hence, in organization are forced on the group.

Message-activity can also be related to centrality by means of the independence-of-action concept. A peripheral person in any pattern can send messages to only one other position. Only one informational message is called for. Extra messages would be repetitious. Central positions, however, are free to send more than one non-repetitious informational message until an organization evolves. Once the most central man perceives that he is most central, he need send *no* informational messages. But so long as the most central man does not perceive his own position, it is intelligent to send informational messages to whomever he feels may require some information. It is in keeping with this analysis that the circle should yield maximum messages and the wheel minimum messages.

If the behavior of one of the wheel groups can be discounted, then an explanation, in terms of peripherality, is also possible for both differences in tendencies to correct errors and total error differences.

If peripherality determines one's independence of action, it seems very likely that positions most limited in independence should begin to perceive themselves as subordinates whose sole function is to send information and await an answer. That they should then uncritically accept whatever answer they receive is perfectly in keeping with their subordinate, relatively unresponsible positions—hence, very little correction of errors in the patterns in which there are great differences in peripherality.

Total errors, it will be recalled, were correlated with total peripherality indices but showed no clear relationship with the relative peripherality of particular positions. A consideration of our definition of error may shed some light on this apparent anomaly.

The "errors" that we recorded were signals from the *S* that indicated a wrong answer. But these wrong answers derived from a variety of sources. First, *S*s might wrongly interpret the correct information they received. They might also make errors in throwing switches; and they might also *correctly* interpret *wrong* information. In all three cases, "errors" were recorded.

We submit that this broad definition of error should yield a total pattern relationship with peripherality, but no positional relationship. Our reasoning can be illustrated by an example. Suppose that the central man in the wheel wrongly interprets information sent to him and, hence, throws an incorrect switch. This is a "real" error. He then funnels out the wrong answer to the other members. At least three of these intelligently conclude that the answer sent them is correct and also throw the wrong switches. We then have three "false" errors consequent to our single "real" one. When several independent answer decisions are made (as in the circle), we should expect several real errors, multiplication of these by a factor of about 3, and a larger total of errors. This process should lead to a correlation between total pattern behavior and peripherality but not to a correlation between positional behavior and peripherality. The process simply multiplies real errors more or less constantly for a whole pattern but obscures positional differences because the "real" and the "false" errors are indistinguishable in our data.

We submit, further, that pattern differences in real errors, if such there be, may be attributable to "over-information"; too much information to too many members which, under pressure, leads to errors. Central positions or positions which are no less central than others in the pattern should be the ones to yield the greatest number of real errors, while peripheral positions, which require no such rapid collation of information, should be the false error sources. Such an hypothesis would be in keeping with our total pattern findings and might also clarify our positional findings. Only an experiment designed to differentiate real from false errors can answer this question.

It is in keeping with this peripherality-independence analysis, also, that we should find the recognition of a single leader occurring most frequently in the wheel and Y groups. It is also to be expected that we should find circle members emphasizing need for organization and planning and seldom giving a complete picture of their pattern. Perhaps, too, it is reasonable to expect that the whole group should be considered good in the highly organized wheel (and not so good in the unorganized circle) even though one's own job is considered poor.

In summary, then, it is our feeling that centrality determines behavior by limiting independence of action, thus producing differences in activity, accuracy, satisfaction, leadership, recognition of pattern, and other behavioral characteristics.

SUMMARY AND CONCLUSIONS

Within the limits set by the experimental conditions—group size, type of problem, source of *Ss*—these conclusions seem warranted:

1. The communication patterns within which our groups worked affected their behavior. The major behavioral differences attributable to communication patterns were differences in accuracy, total activity, satisfaction of group members, emergence of a leader, and organization of the group. There may also be differences among patterns in speed of problem solving, self-correcting tendencies, and durability of the group as a group.

2. The positions which individuals occupied in a communication pattern affected their behavior while occupying those positions. One's position in the group affected the chances of becoming a leader of the group, one's satisfaction with one's job and with the group, the quantity of one's activity, and the extent to which one contributed to the group's functional organization.

3. The characteristic of communication patterns that was most clearly correlated with behavioral differences was *centrality*. Total pattern differences in behavior seemed to be correlated with a measure of centrality we have labelled the *peripherality index*. Positional differences in behavior seemed to be correlated with the positional peripherality indices of the various positions within patterns.

4. It is tentatively suggested that centrality affects behavior via the limits that centrality imposes upon independent action. Independence of action, relative to other members of the group is, in turn, held to be the primary determinant of the definition of who shall take the leadership role, total activity, satisfaction with one's lot, and other specific behaviors.

More precisely, it is felt that where centrality and, hence, independence are evenly distributed, there will be no leader, many errors, high activity, slow organization, and high satisfaction. Whatever frustration occurs will occur as a result of the inadequacy of the group, not the inadequacy of the environment.

Where one position is low in centrality relative to other members of the group, that position will be a follower position, dependent on the leader, accepting his dictates, falling into a role that allows little opportunity for prestige, activity, or self-expression.

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