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NETWORK BROKERAGE AND THE PERCEPTION OF LEADERSHIP

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Abstract

We renovate a classic experiment to define a research platform that provides data on network behavior and the causal effect of access to structural holes. Our hypothesis is that people are perceived to be leaders when they behave as network brokers, which is to say, when they coordinate information across structural holes. We focus on the perception of leadership to connect with the many field studies in which access to structural holes predicts success measures keyed to leadership. Our hypothesis is clearly supported. The broker-leader association we report is very similar in strength and form to broker-success associations reported in previous research. At the same time, it is also clear that people adapt to their randomly assigned network, re-shaping it to suit preferences that in some part emerge in team deliberations or outside the experiment. A modification to our hypothesis — at least for these small laboratory teams — is that monopoly brokerage is key to being cited as team leader. Leadership is ambiguous when multiple people are positioned to be brokers unless one person emerges by his or her network behavior as a monopoly broker. Our summary conclusion is that access to structural holes can be causal to the perception of leadership, a characteristic implicit in many success measures used to document the broker-success association.

A core result in contemporary network theory is the robust association between success and access to structural holes. Network brokers — the people whose networks span structural holes between groups — have information breadth, timing, and arbitrage advantages in detecting and developing good ideas into rewarding opportunities. The advantages are manifest in broker creativity, productivity, evaluation, compensation, and promotion to more senior job ranks. The broker-success association is reviewed elsewhere (Burt, Kilduff, and Tasselli, 2013; Burt, 2019a; Burt, 2021). It is energizing to have corroborating replication for a research association, and it is useful to know from accumulated research how the association is robust to, or contingent upon, alternative success predictors.

But there are two related problems with the available evidence: unobserved behavior and endogeneity. The behavior issue is that evidence of the broker-success association is not an association between network behavior and success. It is an association between network structure and success. The brokerage behavior presumed responsible for success is rarely observed. Obstfeld (2005) kicked off a generation of research with his call for attention to brokerage behavior, claiming that some broker behavior can be productive while other broker behaviors can be unproductive, even counterproductive. Ethnographic research is particularly useful for revealing possible behavioral links between structure and success (e.g., Lingo and O'Mahony, 2010; Kellogg 2014; Leonardi and Bailey, 2017; Rahman and Barley, 2017), but testing behavioral mechanisms responsible for the broker-success association requires representative behavioral evidence that is difficult to obtain in detail with probability surveys, and ostensibly impossible to obtain in scale with ethnographic research.

A lack of data on the network behavior resulting in success raises questions about cause and effect (Jackson, Rogers & Zenou, 2017:81-86, on network endogeneity). The evidence of broker-success association is largely from cross-sectional surveys, but causation must be symbiotic between network and success. Having a network that spans structural holes creates the information breadth, timing, and arbitrage advantages attributed to brokers and associated with success, but success attracts interest from new constituencies, which broadens a person's network across new structural holes. Armed with cross-sectional data, it is impossible to say whether evidence of a broker-success association is due to brokerage increasing success or success increasing brokerage.

Endogeneity can be addressed, if not resolved, with longitudinal data. For example, Kleinbaum (2012) uses six years of email data among 30 thousand managers to show that the people most likely to become network brokers emerge from unusual career histories (unusual business units, job functions, and geographic locations), then uses the data to distinguish the independent effect of rotating into corporate headquarters (Kleinbaum & Stuart 2014): Managers who have worked in corporate headquarters tend to have networks richer in structural holes, an association often attributed to connections created while at headquarters. Kleinbaum and Stuart show that a substantial portion of the headquarters effect is due to people being selected to work in headquarters because they already had networks rich in structural holes.

All good, but questions about endogeneity can still be raised. What puts a stake in the heart of endogeneity is evidence of the broker-success association when people are assigned at random to networks. That is our goal in this paper. We renovate a classic research platform to obtain data on network behavior and success when people are randomly assigned to networks.

We focus in this paper on the perception of leadership. Given a team of individuals with no assigned leader, who gets recognized as a leader? This is a general question for project teams relying in some part on self-governance, and one of many questions in the area of "emergent leadership" (Gerpott et al., 2019:717-719, offer succinct review of the literature). The question answer has become increasing ambiguous as job titles have become less relevant to how things get done. From the nineteenth century image of hierarchical bureaucracy emerged matrix management distinguishing "solid" line supervision from "dotted" line supervision, which evolved into more collaborative, flexible, shifting leadership (Pearce and Conger, 2003; Contractor et al., 2012). The organizational change is especially apparent in online communities wherein productive collaboration falters without a central person holding things together. Reflecting on how things get done online in virtual worlds, Au (2008: 45) opines: "almost invariably at the heart of the collaborative process is a strong avatar with wit and galvanizing energy, keeping up the team's cohesion and morale." Au follows with a quote from a leader in the virtual world of *Second Life* reflecting on her experience: "It was difficult balancing so many strong personalities . . . responding to drama, trying to find compromises when no one wanted to compromise, having to deal with the result of the compromises wherein everyone was unhappy and feeling cheated . . . at one point I was just logging in to be available for people to bitch at." That quote, and others like it (Teigland 2010:12), would not be out of place in the real world coming from the person managing a large project, especially a project that spans more than one functional or corporate organization (Fleming and Waguespack, 2007).

Beyond perceived leadership's relevance for understanding how things get done, we focus on the perception of leadership for two reasons more immediately relevant to this paper. First, perceived leadership as sociometric choice is a simple, replicable dependent variable readily available in our experiment setting and long familiar in social network analysis (e.g., Jennings, 1937, 1943). Of course, leadership involves many cognitive and behavioral dimensions, but being recognized as a leader is a key dimension that provides a good start here. Second, the perception of leadership is central to the accumulating evidence linking brokerage with success. Much of the evidence is from senior people evaluating subordinates for their leadership potential in the organization, expressing evaluations in response to research questions, in annual job evaluations, in compensation decisions, and in promotions to more senior rank. As access to structural holes is associated with measures of success, we expect access to structural holes to increase the odds that a person is perceived by colleagues to be a leader. Broker behavior is the exercise of leadership, which colleagues recognize, as manifest in so many success variables used to study the broker-success association. *Our hypothesis for this paper is that people are perceived to be leaders when they behave like network brokers, which is to say, when they coordinate information across structural holes.*

Our research strategy is to assign people at random to positions in the network of a self-governing team, then study behavior and opinion for evidence of who comes to be seen as team leader. To anchor our results in the literature, we go back to a classic experiment conducted at MIT shortly after World War II. Network structures in the original experiment were designed to test the intuition that coordination in a team is more effective when someone is centrally positioned to facilitate coordination. The structural intuition came from Bavelas (1948, 1950), the coordination experiment from Smith (1950), and the published results from Leavitt's doctoral dissertation (1949, 1951). A storm of work on the experiment ensued through the 1950s, tapering off in the 1970s (Shaw, 1964; Hummon, Doreian, and Freeman, 1990). For a sketch of the thinking in the MIT project for which Leavitt (1949) was an initial product, see Christie, Luce, and Macy (1952). For historical context and consequence, see Freeman, Roeder, and Mulholland (1979), Hummon et al. (1990, especially page 465 for the literature diverging into work on centrality measures versus work on group performance), Leavitt (1996), and Freeman (2004:66-71). Published results from the original experiment are the data Freeman (1977:40) uses to show the superiority of his betweenness measure of centrality over the network size (degree) and closeness measures used previously (detail in Freeman et al., 1979).

We update and extend the experiment with a more contemporary diverse subject pool, a computer interface, a more difficult coordination task, and with multiple people positioned to lead. The research platform provides rich, reliable data on team deliberations, and is readily scalable online. There are limitations. Our experiment evidence describes people doing a contrived task in a contrived environment with teammates of no future relevance. Therefore, our experiment evidence is not as substantively compelling as the accumulating field evidence of broker-success association among people in their actual work environments. Our experiment evidence does not test for reciprocal causation between network and the perception of leadership. We simply wish to see whether we can reject the null hypothesis of no network effect when people are randomly assigned to networks. Nor do our results show that access to structural holes is always causal. No experiment can do that. Our results show only that access to structural holes can be causal. Limitations acknowledged, our results have one sterling virtue with respect to causal order: they are clear, detailed demonstration that people who behave as network brokers are perceived to be leaders.

A final note on terminology. Leadership is both perception and position in our analysis. A person is perceived to be a leader to the extent that he or she is cited by teammates as team leader. A person is defined to be a leader by the network position to which he or she is assigned: The more opportunities a network provides to broker communication between teammates, the more the occupant is defined to be a leader. To keep the two meanings distinct in discussing our experiment, we limit our use of “leadership” to the dependent variable, perception of leadership, and use “broker” to refer to our causal network variable.

We begin with a brief recap of the original experiment, which sets expectations for our experiment. We then describe our experiment, empirical results, and conclusions.

BAVELAS-SMITH-LEAVITT EXPERIMENT

Figure 1 is a quick summary of the original experiment. Five subjects are assigned at random to positions in the four displayed communication networks. The networks are simplified in that connections are all or nothing (no variable-strength connections) and access to each structural hole is all or nothing (no shared access). Therefore, measures of access to structural holes are highly correlated: the number of contacts ("Ties" in Figure 1) equals a subject's number of non-redundant contacts (Burt, 1992), which is correlated -.92 with the level of network constraint on a subject (-.97 with log constraint), and correlated .95 with the number of holes to which a subject has monopoly access (ego-network betweenness, Freeman, 1977, which equals in these networks a simple count of the structural holes to which a subject has access, "Holes" in Figure 1).

Task

Each subject is given a card containing five of the six symbols displayed at the top of Figure 1. One symbol is on all five cards. The team coordination task is to determine, as quickly as possible, which symbol is on all five cards. Seated around a card table passing written notes under screen partitions (Leavitt, 1951:41; Christie et al., 1952:ii; Guetzkow and Simon, 1955:236), subjects communicate through connections displayed in Figure 1.

A trial is complete when all five teammates submit an answer. Completion does not depend on accuracy. After solving the task for the first trial, the team is presented with another, and another, until they complete 15 trials, or run out of time. Each trial task involves the same six symbols, but the particular symbol held in common during a trial varies from trial to trial. A total of five groups, each composed of five students, was run through each of the four networks in Figure 1, generating data on 15 trials for 100 students. At the end of the experiment, the subject completes a survey describing his experience.

Results

The results support Bavelas' structural intuition, and the hypothesis that network brokers are the people perceived to be leaders. Networks are arranged in Figure 1 in order of centralization: leadership is most obvious in the WHEEL (position C has access to six structural holes, the other four positions have access to none) and most distributed in the CIRCLE (everyone has access to one structural hole). Summary results from Leavitt (1949, 1951) are given in the table below the sociograms. Groups in the WHEEL network solve the problem more quickly (32.0 seconds versus 50.4 for the CIRCLE), involving fewer messages (43.0 messages per person versus 83.8 in the CIRCLE), but finish with a lower level of satisfaction (44.4 average survey response for people in the WHEEL on 100-point response to "How did you like your job in the group?" versus 65.6 for people in the CIRCLE).

——— Figure 1 About Here ———

More specifically, the boxes in Figure 1 contain network measures of access to structural holes. Position C in the WHEEL has the greatest access (4 disconnected contacts define 6 structural holes). Position C in the Y-NETWORK has the next highest access (3 disconnected contacts define 3 structural holes). Positions with two contacts have intermediate access, and positions with only one contact have no access (no access for positions A and E in the CHAIN, positions A, B, and E in the Y-NETWORK, and positions A, B, D, E in the WHEEL).

Access to structural holes predicts who is perceived to be team leader. Network brokers are more active in task coordination (number of messages a subject sends has a -.96 correlation with log constraint, Leavitt, 1951:45), more satisfied with their job in the team (-.98 correlation with log constraint, Leavitt, 1951:46), and more cited as the team leader.[1] With no one assigned to be in charge, subjects were asked at the end of the experiment: "Did your group have a leader? If so, who?" Subjects in the CIRCLE network, with its distributed leadership, are the most likely to cite no one as leader (12 of 25 subjects cited no one). All leader citations in the WHEEL network are to position C, after which, the tendency to be cited as a leader decreases in proportion to number of contacts (which in the original experiment indexes access to structural holes as illustrated in Figure 1, -.95 correlation with log constraint, Leavitt, 1949:38).

Freeman, Roeder, and Mulholland (1979) replicate the original experiment in setting and procedure, but use alternative network structures to create distinctions between a subject's number of contacts and his or her access to structural holes (Freeman et al., 1979:124). The leadership citations a subject receives increases with both number of contacts and access to structural holes, but more with the latter as indexed by a betweenness index of the structural holes to which a subject has monopoly access, from which the authors conclude (Freeman et al., 1979:129): "Betweenness, then, seems to be the key to understanding choice as a leader. Since it is based on potential to control for communication, this outcome makes good intuitive sense; it is reassuring to find that perceived leadership is related to what we have called 'control potential'."[2] In an earlier replication of the original experiment, Cohen, Bennis, and Wolkon (1961:428) offer a more management view of recognized leadership in the

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[1]Task accuracy is also cited as an outcome (Leavitt, 1951:49-50), but the supporting evidence is less clear than the evidence of activity, satisfaction, and leadership. A subject error occurs when a subject's final answer for a trial is wrong. Subject errors are more frequent in CIRCLE and CHAIN networks than in the Y and WHEEL networks (respectively 6.4 and 6.2 means versus 1.6 and 2.2 means), however, error counts vary widely for subjects in the same kind of network, so no statistical significance test is presented (Leavitt, 1949:33-35, 1951:43; cf., Freeman et al., 1979:132).

[2]Rogge (1953) runs a variation of the original experiment including personality measures. Subjects with a preference for leadership ("factor II") tend to exercise leadership during the experiment ("IR" behavior, $P < .02$) — unless they occupy a peripheral position in a WHEEL network ($P \sim .50$). In short, occupying a peripheral position suppresses leadership behavior for subjects who prefer to exercise leadership (Rogge, 1953:18).

WHEEL network: “The more a leader is clearly recognized and agreed upon (this was characteristic of no Circle group), the more likely will other members accept influence attempts by him: procedures, answers, etc. Less energy and time will be spent by other members in duplicating the functions off the leader: figuring out answers for themselves, checking on others (once the leader has approved information by passing it on), and trying to set up variations in problem-solving procedures according to their own idiosyncratic evaluations.” We note that these are precisely the qualities cited to explain why WHEEL network structures have difficulty with complex tasks (below), but they are advantages for the simple task in the original experiment.

Simple versus Complex

Coordination was deliberately simple in the original experiment. As described in a report on the MIT project that included the original experiment and variations on it (Christie et al., 1952:29): "Our aim in every case was to devise the task so that the intelligence or speed of reasoning of any individual in the group would not be a limiting factor in the performance of the group. A general feature of all the experimental tasks has been that an individual, substituted for the group, would have found the task trivial."

Simple coordination was a good idea for the initial studies, and continued to be used in many subsequent studies. The widely-cited Freeman et al. (1979) centrality study uses the simple task in the original study. But experiments with complex tasks soon followed the original (Burgess, 1968:325, lists early key studies using simple versus complex tasks). Marvin Shaw wrote several papers in which complexity was introduced by having subjects coordinate on logistic details that required simple math (e.g., Shaw, 1954). Sidney Smith, the person who designed the Figure 1 experiment run in 1948, subsequently ran a "noisy marble" version in 1950. Complexity is introduced by making more abstract the symbols on which subjects coordinate (see Christie et al., 1952:27, 131-164, 193-196). The task is to identify which of six marbles teammates have in common. The initial 15 trials are simple in that the six marbles obviously differ by solid color (red, blue, black, yellow, green, and white). The subsequent 15 trials are complex in that the marbles differed by (Christie et al., 1952:136-137): "cloudy, mottled, indistinct colors. They were still easy to distinguish if they could be directly compared, but it was very difficult to describe each one clearly and unambiguously." In other words, subjects in the complex trials of "noisy marble" had to coordinate on words to identify marbles in addition to determining which marbles each held.

Not surprisingly, coordination on complex tasks requires more time, involves more messages between subjects, more erroneous answers, and leaves subjects feeling less positive about the experience (succinctly shown in Shaw, 1954). Not anticipated was the fact that the CIRCLE network is more effective than the WHEEL for coordination on a complex task. Subjects in the CIRCLE network show faster learning and submit fewer wrong answers (Christie et al., 1952:139-141; Shaw, 1954). Christie et al. (1952:152-154) propose that the sharp difference between leader and follower in the WHEEL network — which is an advantage for simple coordination — is a disadvantage for complex coordination because followers are too passive in their confusion, and leaders too unaware of the confusion among followers. Teammate confusion is more apparent to teammates in the CIRCLE network, so they can deal with it. In corroboration, when the leader in the WHEEL network is given feedback at the end of each trial on the wrong answers submitted by teammates, their confusion was more evident to the leader, and WHEEL network performance improves visibly (Christie et al., 1952:141, 154).

RENOVATED EXPERIMENT

Our renovation of the original experiment adapts Smith's "noisy marble" complexity to a computer interface, and adds multiple network brokers competing for leadership, as is often found in project networks. Aside from people involved in pre-testing software and protocol, the final subjects are 385 men and women in 77 teams. Subjects are drawn from the subject pools of MIT's Behavioral Research Lab (25 teams) and Harvard

Business School's Computer Lab for Experimental Research (52 teams), which are composed of students from MIT, Harvard, and neighboring schools, along with individuals from the surrounding communities. Pre-testing showed that non-native English speakers found the learning task difficult to complete with native speakers, and older subjects often had difficulty with the chat-boxes and other features of the software, so we limit participation to native English speakers, and people between the ages of 18 and 55.

——— Figure 2 About Here ———

To provide a sense of the physical setting, Figure 2 contains the relevant floor plan of the MIT Behavioral Research Lab. The Harvard layout is larger, but similar. Subjects arrive by appointment to register with reception then sit in one of the computer cubicles. The subject is instructed not to talk with others in the room, that the experiment involves playing 15 rounds of a team coordination game with structured communication between players, the time limit is 75 minutes, and expect initial rounds to take more time as people learn to work as a team (an effort to manage initial frustration). When a subject consents to participate, and has clicked through a tutorial, he or she is added to a software "waiting room." When a sufficient number of subjects are in the waiting room, the software draws five people, assigns them at random to positions in a team network, and the experiment begins. Subjects are assigned to one network position, from which they play every trial. Communication is solely through the subject's computer interface. After a subject has participated once in the experiment, he or she is not allowed to participate again. Two or three teams were typically active simultaneously in the MIT Lab, three to ten teams in the Harvard Lab, so the subject typically did not know which four people in the room were his or her teammates.

Game Play

Figure 3 shows the subject's computer interface. The upper-left of the screen shows a set of five symbols assigned to the subject. This is the subject's "hand." The five symbols in each subject's hand come from a superset of the six symbols in Figure 4. There are six combinations of the Figure 4 symbols taken five at a time. One symbol is shared in five of the possible six combinations. That is sufficient for each subject on a team to receive a different hand, with one symbol shared by all team members. The coordination task is to identify their shared symbol. Identification in brackets is presented in Figure 4 to facilitate discussion, but you can see in Figure 3 that the symbols are presented to subjects without any short-cut identification. The symbols are so called "tangrams," which originated in China many hundreds of years ago, became popular in Europe in the 19th century, then spread again during World War I. Several thousand tangrams can be constructed from the seven generative shapes (see Wikipedia "tangram" for general background). Tangrams have been useful in teaching geometric concepts and studying language, the latter because people have to create language distinguishing the odd symbols in order to coordinate with one another about the symbols. The six in Figure 4 are taken from a well-known study of subjects creating language to coordinate tangram sequences (Clark and Wilkes-Gibbs, 1986:11). More often than not, teams correctly identify their shared symbol (percentages in brackets in Figure 4) — with the statistically significant exception of symbol E, which is identified correctly only half of the time.[3]

——— Figure 3 and Figure 4 About Here ———

To learn what other people have in their hands, subjects communicate by clicking on a teammate in the dialogue box at the top of the screen ("A" in Figure 3). Teammates listed in the dialogue box are the ones with whom a subject is allowed to communicate. The screen in Figure 3 is for player 2, who has access to all four teammates — indicated by options in the dialogue box for communication with player 1, 3, 4, or 5. As a subject communicates with teammates, a teammate-specific dialogue box at the bottom of the

[3]Across 964 trials, a logit model using assigned symbol to predict which teams correctly identify their shared symbol yields one statistically significant contingency. Correct is unlikely for teams assigned symbol E (-3.67 z-score test statistic, $P < .001$), and differences between the other symbols are negligible (4.54 chi-square, 4 d.f., $P \sim .34$).

screen accumulates exchanges ("B" in Figure 3). The messages sent and received during a trial can be reviewed by moving the dialogue-box slider up or down.

Subjects talk to one another about the tangrams in their hands until making a guess about what tangram they have in common. To submit his or her answer, the subject highlights one of the tangrams at the top of the screen and clicks the "submit answer" button below the tangrams ("C" in Figure 3). Dots at the top of the screen darken as teammates submit answers, so there is some social pressure on a subject to submit an answer as others have already done so ("D" in Figure 3). Subjects do not see teammate answers, but they see from the darkened dots how many have submitted answers. A trial ends when all five people have submitted their answer. Feedback is immediate. If everyone correctly guesses the shared tangram, "correct" shows on the screen. One or more incorrect guesses yields "incorrect." The screen clears, a new hand is dealt to each subject, and the next trial begins. Teams were given 75 minutes to finish 15 trials. The teams that completed 15 trials spent between 27 to 75 minutes in game play, around a mean of 58 minutes. Three teams ran out of time before completing 15 trials. One team had completed 14 trials but comments between subjects showed they decided to randomly guess in the 15th trial to meet the deadline. The next furthest team had only completed trial 10 when they ran out of time. The slowest team had only completed trial 6 when they ran out of time.

To enable waffling between alternative answers during game play, an option was provided for subjects to "reconsider" their submitted answer. When a subject submits an answer, the "submit answer" button on the screen ("C" in Figure 3) turns into "reconsider." If "reconsider" is clicked before all teammates submit answers, the number of darkened dots decreases by one and the trial stays open until the subject and all teammates submit an answer. The median and mode number of reconsiderations per trial is zero. At the same time, most subjects reconsidered their initial answer in one or more trials (309 of 385 subjects). Reconsiderations are correlated with the difficulty of a tangram. Teams assigned symbol E, the symbol in Figure 4 most difficult to identify, had an average of three reconsiderations per trial (versus an average to two for teams assigned one of the other five symbols in Figure 4).[4] The extreme case is a subject who reconsidered his initial answer 36 times in his first trial. He stumbled into the correct answer six times. His last nine submitted answers were incorrect.

Before leaving the lab, subjects were asked about team leadership and how they felt about participating in their team. As in the original experiment, we asked: “Did your group have a leader? If so, who?” Subjects typed a brief text and citation to a teammate perceived to be team leader. Subjects could cite themselves, and need not cite anyone if they saw no one as a leader. A few subjects cited two teammates as team leaders. To learn how a subject felt about participation in the experiment, each was asked: “How did you like your job in the group?” Subjects gave a rating from one to six, and had the option of typing a brief text. For teams that collapsed before completing the 15th trial, we use subject responses to the questions after the 10th or 5th trial, whichever was last completed by the subject.

Network Structure

Turning to the causal variable, Figure 5 displays the network structures imposed on teams. We use CLIQUE and WHEEL networks as a frame of reference. Our baseline is the CLIQUE in the lower-left of Figure 5 — a closed network in which everyone is connected to everyone else, which is a closed-network version of the CIRCLE network in the original experiment. With so many voices asking questions and expressing opinion, we expect coordination to be difficult for subjects in CLIQUE networks. At the

[4]The difference is 2.90 reconsiderations in a team assigned symbol E versus an average of 1.69 in teams assigned one of the other five symbols. Across 964 trials, a Poisson regression model using assigned symbol to predict a team’s number of reconsiderations during a trial yields one statistically significant contingency. Reconsiderations are more frequent within teams assigned symbol E (6.45 z-score test statistic, $P < .001$), and differences between the other symbols are negligible (6.59 chi-square, 4 d.f., $P \sim .16$).

other extreme, and based on the fast performance of the WHEEL and Y networks in the original experiment, we expect coordination to be efficient in the Figure 5 WHEEL network, which is exactly the WHEEL network in the original experiment. Information aggregates in the person at the hub of the WHEEL, a person defined to be a monopoly broker in that he or she is the one voice coordinating and distributing information to teammates (this point is explored in more detail by Reagans et al., 2020).

——— Figure 5 About Here ———

While we expect higher performance from teams with a WHEEL structure, it would not be a complete surprise to see CLIQUE networks deliver higher performance. Tangrams are the unknown factor. To the extent that coordinating on tangrams is complex in ways comparable to the above-discussed “noisy marble” variation on the original experiment, or Shaw’s (1954) variation using a computational task, the concentrated leadership in a WHEEL network could obscure teammate confusion from the central leader such that CLIQUE networks deliver the higher performance as illustrated by Shaw (1954). This is not to say that tangrams are a stimulus equivalent to the swirling colors in “noisy marble,” or Shaw’s computational task. Each is more complex in certain ways than the others. The point is that all three stimuli — tangrams, noisy marbles, and computational tasks — are more complex than the familiar symbols displayed in Figure 1 on which teammates coordinated in the original experiment.

Between the extremes of CLIQUE and WHEEL networks, we include two variations in which multiple people are positioned to lead. The Disconnected Brokers (DB) network defines two people as team leaders, and prohibits communication between them. Subjects in the leader positions (position 2 in Figure 5) are 3-hole brokers in that they are both connected to three teammates disconnected from one another. The teammates disconnected from one another (position 3 in Figure 5) are 1-hole brokers in that the disconnect between the two leaders is their one opportunity for brokerage. In the original experiment, subjects assigned to position C in the Y network operated as coordination hubs in the network (Figure 1). The ego-network around each of the two leaders in a DB network is identical to the ego-network around position C in the original Y network. The difference is that there are two of them in a DB network. The empirical question is whether having two such network brokers enhances coordination or creates confusion (Podolny and Baron, 1997, on network brokers in matrix organizations).

The Connected Brokers (CB) network is the same as the DB network except the two leaders can communicate with one another. The two leaders (position 4 in Figure 5) are still 3-hole brokers in that they have access to three disconnections between their three contacts, but the social situation is different in two ways: Networks are more closed around the two leaders because they are in one another's network (network constraint increases from .33 for position 2 in DB networks to .68 for position 4 in CB networks). Second, the teammates disconnected from one another that were 1-hole brokers in DB networks are now reduced to 3-person cliques composed of one position 6 teammate plus the two connected brokers, so a CB network more clearly concentrates brokerage in the two leaders. The empirical questions here are whether communication between the two leaders enhances or erodes coordination, and

what happens to the subordinates reduced from being secondary brokers in the DB network to being members of a triad with two better connected colleagues in the CB network (cf., Mehra et al., 2005:235-236, on "distributed-coordinated" leadership).

Team Collapse and Subject Frustration

The original experiment involved 100 subjects, in 20 teams of five, completing 15 trials. Every subject completed all 15 trials, and was then asked (bracket inserted): "How many more problems [trials] do you think it would take before you would get 'fed up'?" The median response was 25, and the extreme patience of some subjects brought the mean up to 36.9 (Leavitt, 1949:40). In contrast, we began with 385 subjects, in 77 teams of five, scheduled to complete 15 trials. Almost half of the teams collapsed — 32 of 77 teams — before completing all 15 trials. By "collapse" we mean that the team members agreed to stop before completing 15 trials, or one or more individuals stopped communicating with teammates. We have 964 trials of completed game play (of the 1,155 that would have resulted if each team had completed all 15 trials).

Our use of tangrams rather than the familiar, everyday symbols used in the original experiment increased the difficulty of coordination, and being limited to the permitted channels of communication must have made the difficult coordination frustrating, even irritating. We suppose that every subject sometimes wished he or she could leave the experiment. Two context factors likely facilitated exit. The first is population change. The original experiment was run in 1948 — just after the traumatic events of World War II during which the military was more a part of civilian life than it is now. We suspect that people today are less compliant to authority than they were in 1948, especially with respect to frustrating online activity (e.g., Zhou and Fishbach, 2016). The lab itself is another contributing factor. The original experiment was run with subjects sitting around a card table (Leavitt, 1951:41; Christie et al., 1952:ii; Guetzkow and Simon, 1955:236, for pictures of the lab context). The subjects could not see or talk to one another during the experiment, but they had seen one another's faces, were similarly young men enrolled at MIT, participating as a team alone in a room, watched by an older male running the experiment. In contrast, our subjects are more socially diverse (male and female students plus civilians from the surrounding neighborhood), and participate from a computer cubicle in a room full of cubicles, typically not knowing who else in the room is a teammate (Figure 1).[5] In short, our subjects participated more anonymously, with little sense of responsibility to the team (a variable to measure, and manipulate, in

[5]Of 77 teams, 74 were run with multiple teams in the lab. Only three were run as the one team in the lab. Subjects in the later three teams likely knew that the other people in the room were teammates. Two of the three solo teams collapsed, so — acknowledging the limits of a sample of three teams — being aware that the other people in the lab were teammates seems not to create much sense of responsibility to the team.

future). The population context made exit more reasonable than in 1948, and the lab context facilitated exit.

Context factors common to all our subjects might account for more team collapse in our experiment, but they do not distinguish teams prone to collapse. One distinguishing factor is when teams collapsed. No teams collapsed in the first four trials. Four percent of teams collapsed in the trials between five and nine. The odds jump up to 17% after completing trial 10, then drop back down to 4% in trials 11 to 14. The nonrandom concentration of team collapses after the 10th trial indicates a subjective sense in many subjects that 10 is enough. When analyzing trial-to-trial behavior, we include a control for teams in their 10th trial.

——— Table 1 About Here ———

More direct evidence comes from sentiment data. While a majority of subjects expressed neutral or positive sentiments about the game, a sizeable minority were frustrated or irritated. Example sentiments in Table 1 illustrate the frustration and irritation associated with teams that collapsed before completing 15 trials. Columns distinguish three categories of teams: those that completed 15 trials (45 teams), those that quit as a team in that all five subjects quit together (13 teams), versus teams in which certain individuals stopped communicating, leaving their teammates to continue into the next trial with less than five people (19 teams).[6] Rows of the table distinguish the sentiment subjects expressed in response to being asked: “How did you like your job in the group?” Subjects are grouped by their evaluation of the experience on a six-point scale (1-2 negative, 3-4 neutral, 5-6 positive), moved up or down a row if their qualitative evaluation text did not match their quantitative rating.

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[6]The 19 teams are 4 in which one teammate kept playing after the other four had quit, 2 in which two teammates kept playing after the other three had quit, 7 in which three teammates kept playing after the other two had quit, and 6 in which four teammates tried to continue with one person nonresponsive. Only completed trials are retained in the analysis.

Positive and negative sentiments are expressed by subjects in all three team outcomes, and assigned network is independent of both sentiment and collapse (4.89 chi-square for the four assigned networks being independent of the columns in Table 1, 6 d.f., P ~ .56; 7.33 chi-square for the networks being independent of the rows in Table 1, 6 d.f., P ~ .29). Positive sentiments are concentrated in the teams that complete all 15 trials, and negative sentiments are concentrated in the teams containing subjects that stopped communicating. Loglinear test statistics (in parentheses in Table 1) show that subjects in teams that completed all 15 trials are the most likely to feel positive about their job in the team (8.09 test statistic, P < .001), and unlikely to feel negative (-5.53 test statistic, P < .001). Subjects in teams that quit before completing the experiment are most likely to express negative sentiments (2.82 and 2.80 test statistics, P < .01). We use the rows and columns of Table 1 to control for teams prone to collapse.

RESULTS

The hypothesis is strongly supported. People randomly assigned to broker positions are more likely to be perceived as team leader – especially if they have a monopoly on brokerage. Figure 6 shows people assigned to the hub position in a WHEEL network are almost always cited as team leader. Less cited are people assigned to one of the two 3-hole broker positions, and almost never cited are people assigned to one of three 1-hole broker positions or a closed network.

——— Figure 6 and Table 2 About Here ———

Differences between mean citations plotted in Figure 6 can be seen in the distribution of frequencies in Table 2, but the further point in Table 2 is that only five of 24 frequencies in Table 2 are significantly different from what would be expected if citations were independent of brokerage: Monopoly brokers are likely to be cited as team leader (four or five citations, respective test statistics of 2.80 and 4.49 in first row of Table 2), and unlikely to be never cited (-3.33 test statistic in first row). The only other statistically significant associations are that people assigned to closed networks, or assigned to one of the multiple 1-hole broker positions, are unlikely to ever be cited as a leader (respective test statistics of 4.41 and 3.45 in first column of Table 2).

Perceived Lack of Leadership

Given evidence strongly supporting the hypothesis, we turn to component and nuanced effects in the evidence. For example, the first three columns of Table 3 show that leader citations do not come equally from teams. A substantial minority of subjects cite no one as team leader (45%). A few said “no” to the image of a single leader, but qualified the response by saying that everyone was equally a leader (“Team” column). Sample responses are: “We all were equals,” “It was a group effort,” and “Everyone contributed evenly, I think.” Most people who said there was no team leadership simply said “no” (96 of 118 subjects), but some offered a sentiment: “LOL, no,” “No, it was a disaster,” or “No, we were very disorganized.” Some people were confused, responding “don’t know” to the question.

Test statistics in the first two columns of Table 3 show that “no” and “don’t know” responses are not associated with any of the four network structures defined in the experiment, and the two columns combined as “no leadership” for Model A in Table 4, show no association with network constraint, which measures an individual subject’s lack of access to structural holes in the team network (-.40 logit test statistic, P ~ .69). We also estimated the Table 4 models with standard errors adjusted for autocorrelation between responses by subjects on the same team (Stata “cluster” option). All effects statistically significant in Table 4 are about the same significance after adjustment for autocorrelation so we present the simpler models without adjustment.[7]

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[7]Network constraint measures the extent to which a person is “constrained” by being embedded in a closed network: $\Sigma_j (p_{ij} + \Sigma_k p_{ik}p_{kj})^2$, $j \neq i \neq k$, where i is the person for whom constraint is being computed, summation is across i’s contacts j, and p_{ij} is the proportional strength of i’s relationship to contact j ($p_{ij} = (z_{ij}+z_{ji}) / \Sigma_j (z_{ij}+z_{ji})$), $i \neq j$, where z_{ij} is the strength of

——— Table 3 and Table 4 About Here ———

Two conditions are associated with a perceived lack of leadership: negative sentiment and team collapse. Associations with these two conditions are consistent across the three network metrics in Table 4. People who are positive about their job on the team (top row of Table 1), are unlikely to say their team had no leadership (-3.08 test statistic in Model A in Table 4, P < .01; -3.08 and -3.23 for Models B and C). Team collapse is associated with people saying the team had no leadership, but not collapse per se. If the team withdraws from the experiment as a team ("Team Quit All" in Table 4), there is no tendency to report a lack of leadership. It is when a subset of the team withdraws, leaving teammates to struggle on, that collapse is attributed to a lack of leadership ("Team Quit Part" in Table 4, 3.18 test statistic, P ~ .001; 3.26 and 3.49 for Models B and C). This is not a result of colleagues resenting teammates who quit. Of the 95 subjects in teams that collapsed because some teammates stopped communicating (right-most column in Table 1), 42 stopped communicating, and the other 53 tried to continue into the next round. Both kinds of subjects are equally likely to cite a lack of leadership in the team (57% of the former, 58% of the latter).

CLIQUE and WHEEL networks generate the extremes in perceived leadership; clear leadership in WHEEL networks, and ambiguous leadership in CLIQUES. The two strongest associations in Table 3 are the tendency for leaders to be cited in WHEEL networks (3.49 loglinear test statistic, P < .001) and the tendency for no leaders to be cited in CLIQUE networks (-3.53 test statistic, P < .001) — in part because the team as a

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relationship from i to j). The index was designed to describe networks of several contacts. Scores can exceed one if ego has only two strongly-connected contacts (Burt, 1992: 58-59), so we round to 1.0 constraint scores greater than one. We multiply constraint scores by 100 to discuss points of constraint. A constraint score of 100 indicates that a person's contacts are all strongly connected with one another (no access to structural holes). Constraint decreases toward zero with the extent to which a person has many contacts (size), increases with the extent to which the person's network is closed by strong *direct* connections between contacts (density), and increases with the extent to which the person's network is closed by a partner through whom contacts have strong *indirect* connections (hierarchy).

whole is viewed as leader (2.07 test statistic, P ~ 04, for “Team” cited as leader in Table 3), though citing a leader is the modal response within a CLIQUE (41% of subjects in CLIQUE networks cite a leader). A similar frame of reference emerged in the original experiment, with 92% of people in WHEEL networks citing a leader, versus 52% of people in CIRCLE networks (Leavitt, 1949: 38, with intermediate percentages of 80% and 68% respectively in the Y and CHAIN networks).

Who Is Perceived to be Team Leader?

Categorical network positions in Figure 6 are replaced by a continuous network metric in Figure 7. Network positions are distributed on the horizontal axes by access to structural holes. The metric is network constraint. The most extreme brokers appear to the left with most access to structural holes (low network constraint, illustrated by the sociogram of a person’s network below the left side of the horizontal axis). To the right are subjects embedded in a closed network that provides little or no access to structural holes (illustrated by the sociogram at the bottom right of the horizontal axis).

Vertical axes in Figure 7 measure the percent of votes a person received as team leader.[8] The nonlinear, downward sloping curves in Figure 7 show the expected association. To the left in each Figure 7 graph, the most readily recognized leaders are

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[8]We report two measures in Figure 6: the number of leader citations a person received and the percent of citations. The two measures show the same pattern in Figure 6 and are highly correlated (.88 in Appendix), but they have different virtues in supporting our hypothesis. The count measure is attractively concrete and intuitive, so we use counts to introduce our evidence in Figure 6 and Table 2. The percent measure is useful for two reasons in controlling for team differences in the amount of voting: (1) We made it perhaps too easy for subjects to say there was no leadership. We had subjects saying there was no leadership even when it seems obvious from the data that there was a leader (e.g., 10 subjects said there was no leadership in a WHEEL network). (2) In recording an open-ended response to the question about perceived leadership, we opened the door to subjects citing more than one teammate. The typical two-person citation is oneself and a teammate. The end results is that we have uneven numbers of citations within teams, so we model perceived leadership by how much of the available vote a subject received. It is attractive to have the familiar metric of OLS regression coefficients in the analysis of percent citations, but it worth noting that we found the same pattern of statistically significant and negligible effects when we ran the analysis with Poisson regressions predicting citation counts (as might be expected from the similar correlations with other variables in the Appendix for citation counts and percent citations).

positioned as the hub in a WHEEL network: 92% cited as leaders in the original study (Figure 7A), and 99% cited as leaders here (Figure 7B). To the right in each Figure 7 graph, the individuals least often cited as leaders are in small, closed networks — 0%, 0%, and 3% respectively cited as leaders in the pendant positions of the WHEEL, CHAIN, and Y networks in the original study, 0% cited here as leaders in the pendant positions of a WHEEL network (position 7 in Figure 5), and 3% cited as leaders in 3-person clique networks (position 6 in Figure 5). Between the extremes, Model D in Table 4 shows that the visually apparent broker-leadership association in Figure 7B is statistically significant (-5.24 t-test, P << .001).

——— Figure 7 About Here ———

Monopoly brokerage stands out for its association with perceived leadership. The hub in a WHEEL network is most often recognized for leadership, in the original study and here. The hub has a monopoly on access to structural holes within the team. The next most recognized is the 3-hole broker in a Y network, which again has monopoly access to its three structural holes. Adding a second 3-hole broker to the team lowers and splits the leadership vote (Disconnected Brokers, DB, network). The vote is lower in that fewer people cast a vote because more say there was no leadership. An average of 4.18 teammates vote for a leader in a WHEEL network. That average drops to 2.54 in a DB network (a statistically significant drop in citations, -2.53 loglinear test statistic in Table 3, P ~ .03). With respect to splitting the DB vote, the sum of cites to one or the other 3-hole broker in a DB network is about the same as cites to 3-hole brokers in the original study (68% of votes to 3-hole broker in a Y network versus 66% of votes to one or the other 3-hole broker in a DB network), but neither leader in a DB network is as clearly perceived to be leader as was the case in the Y network — average cites to Position 2 are 33% of the team vote (plotted in Figure 7B).

Leaders in Connected Broker (CB) networks stand out as an exception to the monopoly rule. The CB network only differs from DB in allowing the two central brokers to communicate (position 4 versus 2 in Figure 5). Allowing that communication increases the tendency for teammates to cite a leader (Table 3), and triggers a statistically significant increase in the percent of teammates citing one of the two central brokers as the team leader (3.53 t-test for "Position 4" effect in Model D in Table 4, P < .001).[9]

The third characteristic of perceived leaders is activity. The number of messages a subject exchanges with teammates is associated in Table 4 with votes received for team leadership (5.20 t-test in Model D, P < .001). Number or accuracy of answers is a separate dimension. In Model D, there is a slightly negative association with submitting multiple answers (which means reconsiderations), but it disappears in Models E and F. There is no leadership association with number of wrong answers submitted. The other controls in Table 4 are also irrelevant to being cited as team leader, in Model D as well as in the subsequent two models: Feeling good about your job in the team, being part of a team that collapsed, participating in the lab at MIT versus Harvard.[10]

Behavioral versus Defined Networks

The networks in Figure 5 limit communication between certain teammates, but every position — except the pendants in a WHEEL (position 7) — allows choice in when and how often to communicate with allowed contacts. For example, subjects in position 6 (subordinates in a CB network) can communicate with either of the two connected brokers, which is their defined network in Figure 5. Here is the network behavior that

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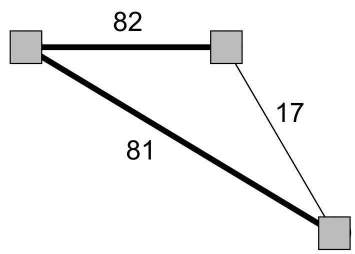
[9]The network-leadership association does not depend on the Position 4 control. The -5.24 t-test for network constraint in Model D is a still strong -4.58 when we remove the Position 4 control from the model. The network-leadership association is similarly strong in Models E and F if the Position 4 control is removed. We also tested for the higher-than-expected leadership citations to subjects in CLIQUE networks by adding a Position 5 control. The added control is statistically negligible in all three models D, E, and F (respective t-tests of 0.54, 1.86, and -.06).

[10]Message activity is correlated with the network constraint measures in Table 3 (-.60, -.63, and -.60), so we checked for multicollinearity affecting the network effects in Table 4. If we drop the messages variable from the models, we get the same results for constraint predicting the perceived lack of leadership (-.88, -.49, and 2.39 respective test statistics for network constraint in Models A, B, and C), and the same results predicting citations as team leader (-10.53, -12.13, and -18.74 respective t-tests for network constraint in Models D, E, and F).

developed for one of the subjects in position 6, showing the number of messages sent between the two connected brokers (above) and with the subordinate (below):



There are more messages with the broker to the left than with the broker to the right. This illustrates difference between the network defined by the experiment and the behavioral network that develops. Guetzkow and Simon (1955:243-245; cf. Cohen et al., 1961:426-427) use messaging to determine when a team has a stable adaptation to its defined network. We use messaging to capture the behavioral network that develops within a team. Since the behavioral network is the one experienced by subjects, network predictions from a team's behavioral network should be more accurate than predictions from the possible network defined by the experiment (when the two predictions are different).

The 385 subjects sent a total of 74,861 messages to teammates. Network constraint computed from binary relations in the Figure 5 networks we term "defined" network constraint. Constraint computed from the number of messages exchanged between teammates we term "behavioral" network constraint. We also ran the computation for messages weighted by number of characters to see whether message length mattered. Message length varied from 7 to 78 characters around a mean of 30 characters per message. Constraint computed in terms of characters is correlated .99 with constraint computed in terms of messages, so we rely on the simple count of messages.

Consider Figure 8. The insert table shows number of messages sent to teammates in an example team, and line weight in the sociogram indicates relative frequency. Across 15 trials, for example, the subject in position 5A sent 89 messages to the subject in position 5B. This team was defined to be a CLIQUE network, so everyone was allowed to communicate with everyone else, but actual communication is not equally likely between pairs of teammates. Messages are concentrated with the subject in position 5A. The way teammates behaved in the network makes the team look less like a CLIQUE and more like a WHEEL network (cf. Figure 5A in Guetzkow and Simon, 1955). Defined network constraint on position 5A in Figure 7 is 77 points, but behavioral network constraint defined by the volume of messages actually exchanged between teammates is a much lower 42 points.

——— Figure 8 About Here ———

The Figure 8 sociogram is an extreme example. Subjects assigned to CLIQUE networks each worked under 77 points of constraint according to the network defined by the experiment. The histogram in Figure 8 shows a distribution of behavioral network constraint for teams defined to be CLIQUE networks. Position 5A in the Figure 8 example sociogram is located to the extreme left in the distribution.

Triads defined to be closed allow variation in behavioral constraint. Table 5 displays mean defined and behavioral network constraint for each of the seven positions in defined networks. Means are almost identical for defined and behavioral networks (1.00 correlation), but variation around the means is associated with closed triads. Defined and behavioral constraint differ little in WHEEL networks (smallest standard deviations for positions 1 and 7). There is a little more variation in behavioral constraint in DB networks (positions 2 and 3). The bulk of the variation between behavioral and defined constraint is in the networks of closed triads, CLIQUE and CB networks (positions 4, 5, and 6). Variation in behavioral constraint is particularly interesting between subjects in the connected broker positions of CB networks, which show unexpectedly high leadership citations to subjects in those positions (Figure 7B and positive effect of Position 4 control variable in Model D, Table 4). Figure 9 shows the distribution of behavioral network constraint for the 34 subjects in position 4. The two subjects in the displayed example team network span the range of behavioral constraint scores. The subject in position 4A in the Figure 9 example sociogram has taken over as a hub (low constraint) while the potential other broker, in position 4B, is relegated to a subordinate position (high constraint).

——— Table 5 and Figure 9 About Here ———

To the extent that our hypothesis is true — network brokers are perceived to be leaders — then subjects who behave like network brokers should be perceived to be leaders. In the Figure 9 sociogram, for example, the subjects in positions 4A and 4B are defined equally by the experiment to be brokers, but the person in position 4A acts more like a network broker (low behavioral constraint of 50.9 points on position 4A versus high behavioral constraint of 97.1 points on position 4B). As predicted by our hypothesis, the person in position 4A is more cited as team leader. Everyone in the team cites 4A as team leader ("4A" cites in parentheses in Figure 9 sociogram). Network brokers emerge as leaders even in the confusion of a CLIQUE network. Back in Figure 8, the subject in position 5A emerged as a hub, converting the defined CLIQUE network into something closer to a WHEEL network. The ambiguity of CLIQUE leadership is apparent: one person says there was no team leadership, one person says everyone was leader, and one person does not know whether there was a team leader. Two people on the team cite a team leader. They both cite the hub in the emergent WHEEL network, the subject in position 5A. Systematic evidence is in Table 4. When defined network constraint in Model D is replaced with behavioral network constraint in Model E, the slope of the predicted network-leadership association is steeper (-23.16 coefficient becomes -30.62), data conform to the association more closely (-5.24 t-test becomes -6.74), and there is a modest increase in explained variance (.33 R^2 increases to .36).[11]

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[11]There is a caveat to the supportive result: To the extent that network behavior varies between people assigned to the same network treatment, the causality of network effects is more open to question. For example, person 5A in the Figure 8 example sociogram clearly

Relative Network Constraint

Frame of reference is another consideration. In the accumulating field evidence of brokerage associated with success, colleagues within and beyond one's familiars are the frame of reference. Conflicting interests are abundant and multiple people seek the same limited resources. In the artificial world of the experiment, four teammates are the frame of reference. Consider the Figure 9 subject in position 4A at 50 points of constraint, the Figure 8 subject in position 5A at 42 points of constraint, and a Figure 5 subject in position 2 at 33 points of constraint. From the perspective of an observer outside the teams, position 2 is subject to lower constraint than the constraint on position 4A, so a clearer perception of leadership is expected for position 2. But within the team as a frame of reference, the people in position 4A, position 5A, and position 2 are all the closest thing to a network broker in their team — so perhaps they are all likely to be perceived as team leaders. This is another version of the monopoly characteristic of network brokers being perceived as leaders. A person can be perceived as team leader because he or she is the only person on the team with access to structural holes, or because he or she is the closest thing the team has to a network broker.

——— Figure 10 About Here ———

To test this idea, we compute the "relative network constraint" on a subject by dividing a subject's behavioral network constraint by the average behavioral constraint on teammates. For example, the subject in position 4A in the Figure 9 example sociogram works under 50.9 points of behavioral network constraint. The average score for his four teammates is 111.9, so relative constraint on position 4A is 50.9/111.9, or .45. Relative constraint scores for the teammates are .97, 1.30, 1.34, and 1.05

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behaves as a network broker in the team despite everyone being able to communicate directly with one another. What characteristics of subject 5A explain why he behaved as he did? Did he enter the lab from a team meeting in which he led discussion? Is he a social leader among his friends? Why do his teammates let him take over the team? It is substantively interesting to see how individuals adapt their defined network, and to see how teammates respond in citing certain colleagues as team leader. We return to this point as a final note in our conclusions.

respectively for positions 4B, 6A, 6B, and 6C. In short, the subject in position 4A is the closest thing the team had to a network broker, and is unanimously cited as team leader.

Relative network constraint further supports our hypothesis. When behavioral network constraint in Model E is replaced with relative network constraint in Model F, the data fit the network-leadership association more closely (-6.74 t-test for log network constraint in Model E becomes -13.91 in Model F), there is a notable increase in explained variance (.36 R^2 for Model E increases to .52 for Model F), and citations to leaders in CB networks are no longer unexpectedly high (3.96 t-test in Model E drops to a negligible 1.39 in Model F). Relative network constraint also reduces the importance of message activity, allowing us to focus on network brokerage as the key to perceived leadership. Sending and receiving numerous messages is a strong predictor of being recognized as team leader when defined or behavioral network constraint are used as the network predictor (5.20 t-test in Model D, 3.99 t-test in Model E). When relative network constraint is the predictor, the impact of extensive messaging is much less relevant to being cited as team leader (2.31 t-test in Model F).[12] In sum, the initial jagged network-leadership association in Figure 7B is now the relatively smooth association in Figure 10 (which looks very similar to field evidence on the broker-success association, e.g., compare Figure 10 to a success-brokerage graph in an earlier issue of this journal, Burt, 2019b:38).

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[12]The strong effect of relative network constraint in Model C indicates a tendency for the more constrained members in a team to perceive no leader, perhaps wishing that someone would give them a more active role (3.46 logit test statistic, $P < .001$). We do not pursue this in the text for three reasons: (1) Defined and behavioral network constraint have no association with a perceived lack of leadership (Models A and B) so we are suspicious of the dramatic change in Model C. (2) Number of messages sent and received is a close correlate of network constraint (Appendix), and is a negligible predictor in Models A and B, but emerges with relative network constraint as a predictor in Model C, so we suspect multicollinearity. When we estimate the network effect in Model C with number of messages excluded, we still get a statistically significant network association with perceived lack of leadership, but the 3.46 test statistic for the effect in Model C decreases to 2.39 ($P \sim .03$). We put this issue aside for future research.

Message Behavior

Broker connections have logistic implications for messaging behavior, so is it the case that messaging like a network broker can have its own effect on the perception of leadership? The behavior we have in mind is not the above-analyzed network structure of who messages whom. Rather, we have in mind messaging as an activity. For example, the broker in a WHEEL network exchanges messages with four teammates, so she can be expected (relative to someone in a pendant position) to deal with more messages, which means she has less time to write each message, so her messages are likely to be shorter. A person assigned to one of the pendant positions has only one contact, so they have time to write more fulsome messages. As expected, subjects assigned to position 1 receive more messages than subjects assigned to position 7 (respective means of 27 versus five messages), send more (20 versus seven messages), and their messages are shorter (respective means of 22 characters versus 38 characters).

Answering the question about message behavior requires a control for learning because behavior changes as teammates learn how to work with one another faster with less effort (Argote, 1999, for general review; Thompson, 2001, for the iconic Liberty Ship example). Learning has been a stable feature of the original experiment and replications, but it has been handled in various ways. Learning was evident in graphs of behavior in the original experiment (Leavitt, 1951:42-43; Christie et al., 1952:141), held constant in some replications (Shaw, 1954:213), strategically set aside in some replications (Freeman et al., 1979:113), and a focus in some replications. For example, Guetzkow and Simon (1955) extend the number of trials to 20 and include discussion periods between trials to facilitate team learning and demonstrate their point that teams perform similarly once they learn how to operate with the network structure they have. Cohen, Bennis, and Wolkon (1961) extend the number of trials to 60 to show that learning continues past the 15th trial in the original experiment. Offering students in his introductory sociology class the option of doing an assigned term paper or participating in his experiment, Burgess (1968) extends the number of trials to 900 to show that network differences disappear as teams become extremely experienced. For the purposes of this paper, we use team learning as a control variable (Reagans, Volvovsky, and Burt, 2020, discuss patterns of learning).

Figure 11 displays learning curves of change in message behavior during the experiment. The summary indicator is teams completing their work more quickly. The bold line through solid dots in Figure 11 shows teams averaging 11.39 minutes to complete their first trial. With the completion of each trial over the next eight, teams gain about a minute per trial (-1.02 slope), completing the 15th trial in an average of 1.68 minutes. The quicker completion of work across trials is based on fewer and shorter messages. The lines through hollow dots in Figure 11 show teams in their first trials average 29.34 messages, 34.05 characters in length. Both lines decrease to an average of 7.52 messages in the 15th trial, averaging 26.46 characters in length.

——— Figure 11 and Table 6 About Here ———

The final change displayed in Figure 11 is a shift away from function words. There is a general distinction in language between function versus content words. Function words indicate relations between content words in a sentence. Example function words are pronouns (<u>he</u> is a new victim), prepositions (go <u>to</u> the store), articles (a, the), and auxiliary verbs (verbs that indicate the tense, mood, or voice of other verbs, e.g., I <u>would have</u> gone). Function words are often described as the glue that holds a sentence together. Content words are sentence elements with clear meaning that are held together by function words. The Figure 11 line through hollow squares shows that teams average 52.09% function words in the messages they send during their first trial (which is comparable to text in tweets and the New York Times). The line decreases by half across trials to an average of 23.61% function words in the messages sent during trial 15. These percentages were obtained by combining in a single text all the messages an individual sent during a trial, then using software to count function words in the messages and divide by the number of words (Pennebaker et al., 2015). As described elsewhere (Reagans, Volvovsky, and Burt, 2020), faster teamwork with fewer, shorter messages is based on teammates shifting from a conversational mix of function and content words, to messages focused on team-created jargon as content words that enable teammates to quickly and reliably identify the tangrams on which they coordinate.

In Table 6, we add three message predictors to the brokerage prediction in Figure 10 and Model F, Table 4. We measure the extent to which an individual sends more messages than teammates (messages sent by an individual during a trial divided by the average sent by his or her teammates during the trial), and the relative extent to which an individual sends longer messages than teammates (average number of characters in messages sent by an individual during a trial divided by the average for teammates during the trial). The third measure of message behavior is the extent to which an individual uses more function words than teammates (average number of function words in an individual's messages during a trial divided by the average number used by his or her teammates during the trial). The other predictors in Table 4 that are negligible in Model F are also negligible here.[13]

Message behavior has the expected associations with the perception of leadership. Model G in Table 6 uses predictors averaged across all trials. The people who send more and shorter messages that contain fewer function words are more likely to be

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[13]Since volume of messages is included here, there are seven predictors in Table 4 that are not in Table 6. Adding all seven to Table 6 does not improve prediction (0.71 $F_{(7,373)}$ for Model H, 0.44 $F_{(7,373)}$ for Model J, 0.74 $F_{(7,293)}$ for Model L, each giving more than a .6 probability to the null hypothesis). Particularly important is the irrelevance of the dummy variable distinguishing subjects assigned to position 4, the leadership position in a Connected Brokers (CB) network, which is associated with frequent leader citations (Figure 7B, Models D and E in Table 4). Replicating Table 5's Model F there is no statistically significant recognition of position 4 subjects as leaders in Table 6 (t-tests of 0.05, 0.35, and 0.44 for Models H, J, and L respectively, each giving more than a .6 probability to the null hypothesis).

recognized as team leaders at the end of the experiment. Given dramatic changes in message behavior as a team gains experience, we ran the prediction limited to trials at the beginning and end of the experiment. The first four trials cluster together in that message length is increasing while other message characteristics decrease (phase 1 in Figure 11). Model I uses predictors computed from messages sent during the first four trials: People who send more messages that contain fewer function words are more likely to be recognized at team leaders at the end of the experiment. The last six trials hold together in that learning curve slopes are low relative to slopes across the preceding trials, with the exception of messages becoming shorter across even these final trials (phase 3 in Figure 11). Model K uses predictors computed from messages sent during the last six trials: People who send more and shorter messages in the final trials are more likely to be recognized as team leaders.

Network structure dominates message behavior. Variables measuring message number, length, and function words add nothing to the broker measure in predicting who emerges as recognized leader. The initial trials are an exception (Model J), where teammates are struggling with numerous and long messages to learn how to work together. But averaged across all trials (Model H), and during the final trials (Model L), the primary predictor of who gets recognized as team leader is the relative extent to which a person operates as a network broker within the team.[14]

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[14]We went a step deeper looking for a link between leadership and message behavior. The results do not change our conclusion from Table 6, so we do not discuss them in the text, but the lack of results at the deeper level warrants mention for related research. Prior work with word-count profiles shows that people coordinate on function words (measured by a "Language Style Match" index, Gonzales, Hancock, and Pennebaker, 2010). The index has been reported to covary with successful negotiation (Bayram and Ta, 2018), along with social attachment and cohesion in student teams (Gonzales et al., 2010; Ireland et al., 2011; Kovacs and Kleinbaum, 2020). Given the drift in Figure 11 away from function words as teammates become more experienced with one another, we wondered whether teammates align in their use of retained function words, and whether network brokers lead the transition to communication using fewer function words. There is no evidence of either. The below graph shows function word use within teams. The line through solid dots shows word use by the teammate who uses the lowest percent function words during a trial. The line through hollow dots shows the same thing for the

CONCLUSIONS

Our purpose in this paper has been to introduce a renovation of a classic experiment in order to study the network behavior responsible for a core empirical result in contemporary network analysis — access to structural holes is associated with success. The theory is that structural holes are opportunities to broker information across groups separated by the holes, which gives people with access to structural holes information

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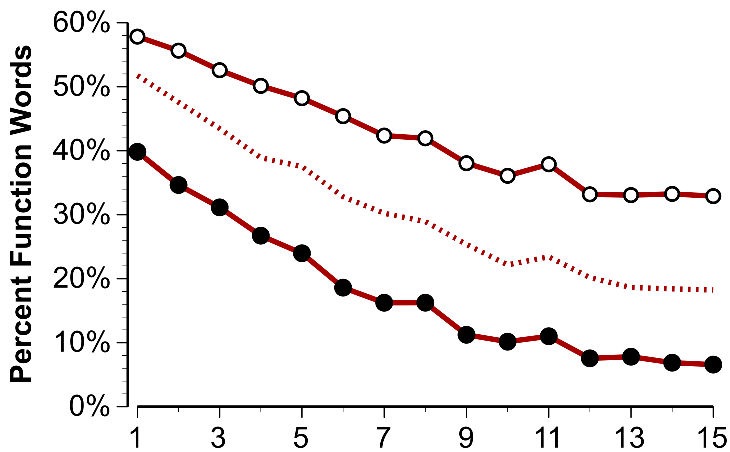

teammate who uses the highest percent function words during a trial (i.e., these are components that combine to the Figure 11 solid line with hollow squares). The dashed line with no dots is the average percent function word use by the other three teammates during a trial. We use the graph to make three points: (1) As in Figure 11, all lines show decreasing use of function words as teammates become experienced with one another. (2) Teams become less, not more, aligned on function words. Alignment would be indicated by the solid lines converging with one another in later trials. Instead they diverge. The gap between the two solid lines is correlated .80 with trial. Similarly, in analogy to the "Language Style Match" index, Euclidean distances between teammates on a twelve-dimension profile of function word use increases with trial (.70 correlation). (3) Lines in the above graph have no association with network brokers leading or holding back the drift away from function words. Behavioral network constraint is correlated .006 with the number of trials in which a subject uses function words less than any teammate (line through solid dots) and .014 correlated with the number of trials in which a subject uses function words more than any teammate (line through hollow dots). Adding to Table 6 the number of trials in which a subject is ahead of teammates in making least use of function words adds nothing to the predictions (-.34, -.12, and -.94 t-tests for Models H, J, and L; giving the null hypothesis more than a .35 probability). In fact, it is rare for a subject to be continuously at the extremes of function word use. When one teammate makes least use of function words in this trial, a different teammate is likely to make least use in the next trial. We surmise that the decreasing use of function words is due to indifference, not intention; it is a by-product of teammates focusing on the content words needed to coordinate with one another (Reagans and Burt, 2020).

advantages of breadth, timing, and arbitrage, so such people — network brokers — are more likely to detect and develop good ideas into rewarding achievements. Empirical support for the brokerage-success prediction has emerged in diverse areas of human endeavor, particularly in business.

Our goal is today more important than ever because the mounting evidence of a brokerage-success association typically suffers from two weaknesses: (1) the evidence is often cross-sectional, so causal order between brokerage and success is uncertain, and (2) the evidence shows success associated with network structure, not network behavior. The broker behavior presumed responsible for success is typically unobserved. The renovated experiment we present addresses both weaknesses, first by assigning people at random to networks in which they have variable access to structural holes, and second by providing rich data on the behavior by which network brokers emerge successful.

We focused in this paper on the perception of leadership as a network outcome. Our three reasons are that (1) the question of emergent leadership is central to how things get done in network organizations, (2) perceived leadership measured by sociometric choice is a simple, replicable measure readily available in our experiment setting and long familiar in social network analysis, and (3) the perception of leadership is central to many of the success measures used in the accumulating evidence of the broker-success association. As access to structural holes is associated with measures of success, we expect access to structural holes to increase the odds that a person is perceived by colleagues to be a leader. *Our hypothesis has been that people are perceived to be leaders when they behave as network brokers, which is to say, when they coordinate information across structural holes.*

The hypothesis is supported. Access to structural holes can be causal to the perception of leadership. In fact, the broker-leader association in Figure 10 looks very similar to the summary broker-success association displayed earlier in this journal based on several thousand observations from Asia, the E.U. and the U.S. (Burt 2019b:38). The one modification to our hypothesis is that (at least in these small teams of five people) having a monopoly on brokerage is key to being cited as team leader. Leadership is ambiguous when multiple people are positioned to be brokers in a team — unless one person emerges by his or her network behavior as a monopoly broker.

It is also clear that people adapt to their randomly assigned network, re-shaping it to suit preferences that in some part emerge in team deliberations, and in some part originate outside the experiment. Subjects are severely constrained to defined structure in the WHEEL and Disconnected Brokers (DB) networks, but in the CLIQUE and Connected Brokers (CB) networks — where subjects have more choice in how often and with whom they communicate — leader citations go to the individual who emerges most resembling a network broker in the behavioral network of messaging (Table 4, with example emergent leaders in Figures 8 and 9). The implication for network experiments is that random assignment to network positions does not guarantee an exogenous network effect. The more a subject has choice in how often and with whom exchanges occur in the defined network (e.g., CLIQUE and CB networks here), the more endogenous the behavioral network can be. We find that people randomly assigned to a broker position are more likely to be perceived as team leaders (Figure 7b, Model D in Table 4) — but the association is clearer and stronger when we incorporate observed network behavior into the prediction (Figure 10, Model F in Table 4). The cost of that stronger prediction is that the behavioral network is less clearly exogenous. The puzzle now is to devise network experiments by which we can disentangle the clearly exogenous effect on perceived leadership from the stronger prediction with networks less clearly exogenous.

APPENDIX

Computations in the below table are across 385 subjects. “No Leadership” is 1 if subject said there was no team leader (first two columns in Table 3). “Leader Cites” is the number of people who cite the subject as team leader, and “% Leader Cites” is the percentage of team cites that go to the subject. “Defined Constraint” is log 100 times network constraint defined by the experiment design (Figure 5). “Behavioral Constraint” is log 100 times network constraint defined by relations measured by number of messages between subjects (e.g., Figures 8 and 9). “Relative Constraint” is the log ratio of behavioral constraint on subject over average constraint on the subject’s teammates. “Position 4” is 1 if subject was assigned to one of the leader positions in a Connected Brokers (CB) network (Figure 5). “Subject Messages” is the total number of messages the subject exchanged with teammates (measured in 10s). “Subject Answers” is the number of answers the subject submitted in all trials (final answer plus reconsidered answers), and “Wrong Answers” is number of wrong final answers the subject submitted in all trials. “Subject Positive” equals 1 if the subject reported at the end of the experiment that he or she enjoyed his or her job during the experiment (top row in Table 1). “Team Quit All” is 1 if whole team quit early together, and “Team Quit Part” is 1 if a subset of the team quit early (second and third columns in Table 1). “MIT” is 1 if the subject was in an experiment run at the MIT lab. The last three variables measure message behavior averaged across all trials (Model H, Table 6): “Relative Volume” is the number of messages sent by an individual during a trial divided by the average sent by his or her teammates during the trial, “Relative Length” is the average number of characters in messages sent by an individual during a trial divided by the average for teammates during the trial, and “Relative Function Words” is the average number of function words in an individual’s messages during a trial divided by the average number used by his or her teammates during the trial.

	Means	S.D.	Correlations															
No Leadership	.38	.49	1.00															
Leader Cites	.61	1.19	-.31	1.00														
% Leader Cites	18.44	33.28	-.28	.88	1.00													
Defined Constraint	4.19	.41	-.05	-.47	-.46	1.00												
Behavioral Constraint	4.21	.41	-.02	-.52	-.52	.98	1.00											
Relative Constraint	-.03	.35	.14	-.77	-.71	.68	.71	1.00										
Subject in Position 4	.09	.28	-.08	.25	.20	.02	.02	-.22	1.00									
Subject Messages	38.67	18.76	-.02	.47	.51	-.60	-.63	-.60	.18	1.00								
Subject Answers	17.08	8.28	-.05	-.08	-.09	.04	.08	.05	.06	-.07	1.00							
Wrong Answers	2.80	2.48	.20	-.09	-.04	.02	.05	.01	-.08	-.08	.09	1.00						
Subject Positive	.54	.50	-.27	.18	.11	-.06	-.08	-.08	.07	.18	.02	-.40	1.00					
Team Quit All	.17	.38	.10	-.04	-.02	-.02	-.01	02	-.04	.01	-.19	.13	-.24	1.00				
Team Quit Part	.25	.43	.23	-.08	-.03	-.07	-.07	.01	-.01	-.08	-.17	.27	-.28	-.26	1.00			
MIT	.32	.47	.06	-.03	.02	-.03	-.01	.01	-.18	.11	02	.12	-.01	-.02	.05	1.00		
Relative Volume	1.11	1.03	-.11	.47	.50	-.39	-.42	-.62	.13	.40	-.12	.07	.02	-.04	.10	-.02	1.00	
Relative Length	1.22	1.61	.01	.05	.11	-.09	-.09	-.14	-.04	.02	-.12	.07	-.08	-.05	.19	-.03	.46	1.00
Relative Function Words	1.30	1.96	-.11	.27	.32	-.16	-.20	-.35	.11	.18	-.12	.09	.01	-.04	.07	-.04	.84	.46

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Table 1.
How Did You Like Your Job in the Group?

Team Completes All 15 Trials	Team Quit All in Same Trial	Part of Team Quit Before Others
161 POSITIVE (8.09)	18 POSITIVE (-3.33)	28 POSITIVE (-3.26)
It was good.	Its exciting.	It was fun.
I liked it.	It was good.	I LIKED IT.
It was fun.	Enjoyed it.	Its super fun.
Loveeed it.	It was good trying to get faster.	I liked it very much.
Worked GREAT for me.	Good.	Yes.
45 NEUTRAL (-1.14)	23 NEUTRAL (0.57)	33 NEUTRAL (0.44)
Fine.	Ok.	Was tough but manageable.
Its fine.	It was ok but frustrating.	Fine. It was boring.
Just fine.	Could have been better.	I was fine with it.
It worked.	It was interesting but annoying.	It was a bit frustrating.
I am okay with it.	Not bad but frustrating.	I think I did a good job.
19 NEGATIVE (-5.53)	24 NEGATIVE (2.82)	34 NEGATIVE (2.80)
I don't like not having all-access.	Its frustrating.	Didn't like it; player 4 annoying.
Not very much.	I'm frustrated by my group.	I hated my job & all my colleagues.
Slightly frustrating.	I felt the need to push the pace.	Not very much.
I appear to be a court jester.	Not so much.	It was rather confusing.
Quite frustrating and a bit boring.	I didn't like it much.	I really didn't have a role to play.

NOTE — These are illustrative responses associated with the row emotion category and the column team survival category. Integer is the number of subjects in each cell. Loglinear z-score test statistic in parentheses shows which emotional responses occur more/less often than would be expected if emotional response were independent of the columns (76.09 chi-square, 4 d.f., $P < .001$).

Table 2. Broker Effect by Number of Citations

	Citations Received as Team Leader						
	0	**1**	**2**	**3**	**4**	**5**	**Total**
Monopoly Broker (position 1)	**0** **[0%]** **(-3.33)*****	1 [6%] (-1.75)	1 [6%] (-1.09)	2 [12%] (1.27)	**4** **[23%]** **(2.80)****	**9** **[53%]** **(4.49)*****	17 [100%]
One of Multiple 3-Hole Brokers (positions 2, 4)	33 [42%] (-.71)	15 [19%] (-.36)	19 [24%] (1.56)	5 [7%] (0.20)	4 [5%] (0.14)	2 [3%] (-.47)	78 [100%]
One of Multiple 1-Hole Brokers (position 3)	**55** **[83%]** **(3.45)*****	7 [11%] (1.08)	4 [6%] (0.71)	0 [0%] (-1.05)	0 [0%] (-.85)	0 [0%] (-.59)	66 [100%]
Not a Broker (positions 5, 6, 7)	**187** **[84%]** **(4.41)*****	25 [11%] (1.91)	7 [3%] (-.48)	4 [2%] (0.33)	1 [0%] (-1.17)	0 [0%] (-1.69)*	224 [100%]
Total	275 [71%]	48 [13%]	31 [8%]	11 [3%]	9 [2%]	11 [3%]	385 [100%]

NOTE — Rows distinguish subjects by assigned position in their experiment network (Figure 5). Cells contain frequency with which subject in row received column number of citations as team leader. Row percent is in brackets. Loglinear z-score test statistic in parentheses shows which level of citations occur more/less often than would be expected if column citations were independent of the rows (272.89 chi-square, 15 d.f., P < .001). * P ≤ .05 ** P ≤ .01 *** P ≤ .001

Table 3.
Did Your Group Have a Leader?

	No	Don't Know	Team	Yes	Total
CLIQUE	41 [39%] (0.56)	9 [9%] (-.84)	**12** **[11%]** **(2.07)***	**43** **[41%]** **(-3.53)*****	105 [100%]
WHEEL	9 [11%] (-.67)	6 [7%] (1.50)	0 [0%] (-1.70)	**70** **[82%]** **(3.49)*****	85 [100%]
DB Network	47 [43%] (1.71)	9 [8%] (-.54)	7 [6%] (0.72)	**47** **[43%]** **(-2.53)***	110 [100%]
CB Network	21 [25%] (-.89)	6 [7%] (-.76)	6 [7%] (1.13)	52 [61%] (-.14)	85 [100%]
Total	118 [31%]	30 [8%]	25 [6%]	212 [55%]	385 [100%]

NOTE — Rows distinguish subjects by their assigned experiment network (Figure 5). Columns distinguish subjects by response to title question. Integer is number of subjects. Row percent is in brackets. Loglinear z-score test statistic in parentheses shows which responses occur more/less often than would be expected if column response were independent of the rows (48.43 chi-square, 9 d.f., $P < .001$). Example responses: "No" ("LOL, no" "No, it was a disaster." "No, we were very disorganized." 96 subjects simply said "No."). "Don't Know" ("Don't know" "I have no idea." "Not sure." "I don't think so."). "Team" ("Yes, all of us." "We all were equals." "It was a group effort." "Everyone contributed evenly, I think.") * $P \le .05$ ** $P \le .01$ *** $P \le .001$

Table 4. Leadership Is About Active Monopoly Brokerage

	No Leadership			Percent Leader Citations		
	A	B	C	D	E	F
Defined Constraint	-.14 .35 (-.40)	—	—	**-23.16 4.42 (-5.24)*** **	—	—
Behavioral Constraint	—	.04 .36 (0.12)	—	—	**-30.62 4.54 (-6.74)*** **	—
Relative Constraint	—	—	**2.06 .59 (3.46)*** **	—	—	**-60.36 4.34 (-13.91)*** **
Subject in Position 4	-.51 .45 (-1.12)	-.56 .46 (-1.21)	-.25 .47 (-.54)	**18.66 5.28 (3.53)*** **	**20.51 5.18 (3.96)*** **	6.09 4.40 (1.39)
Subject Messages	.004 .01 (0.47)	.01 .01 (0.77)	**.03 .01 (3.14)** **	**.53 .10 (5.20)*** **	**.41 .10 (3.99)*** **	**.19 .08 (2.31)* **
Subject Answers	.002 .01 (0.13)	.002 .01 (0.16)	.001 .01 (0.09)	**-.36 .18 (-1.97)* **	-.33 .18 (-1.83)	-.26 .15 (-1.68)
Wrong Answers	.05 .05 (1.03)	.05 .05 (1.01)	.06 .05 (1.28)	.56 .65 (0.86)	.69 .64 (1.08)	.05 .55 (0.10)
Subject Positive	**-.79 .26 (-3.08)** **	**-.79 .26 (-3.08)** **	**-.85 .26 (-3.23)*** **	1.09 3.33 (0.33)	.85 3.25 (0.26)	1.53 2.80 (0.55)
Team Quit All	.57 .33 (1.76)	.59 .33 (1.80)	.59 .33 (1.78)	-4.94 4.34 (-1.14)	-5.19 4.24 (-1.22)	-1.79 3.64 (-.49)
Team Quit Part	**.94 .29 (3.18)*** **	**.97 .30 (3.26)*** **	**1.05 .30 (3.49)*** **	-4.58 3.92 (-1.17)	-5.83 3.84 (-1.52)	-2.06 3.25 (-.63)
MIT	.12 .24 (0.51)	.11 .24 (0.46)	.06 .25 (0.23)	.18 3.13 (0.06)	1.01 3.07 (0.33)	1.73 2.63 (0.66)
Intercept	-.17	-1.05	-11.13	99.46	135.06	290.27
R^2 or Pseudo R^2	.09	.09	.12	.33	.36	.52

NOTE — Standard errors and test statistics below coefficients (N = 385). Descriptive statistics and variable descriptions are in Appendix. First three columns are logistic regressions predicting which subjects did not perceive a team leader (first two columns of Table 3). Last three columns are OLS regressions predicting the percentage of cites the subject received. * P ≤ .05 ** P ≤ .01 *** P ≤ .001

Table 5.
Defined and Behavioral Network Constraint

ID	Position	Subjects	Mean Defined	Mean Behavioral	S.D. Behavioral
1	**6-hole broker**	17	25.0	26.1	0.86
2	**3-hole broker**	44	33.0	34.5	1.38
3	**1-hole broker**	66	50.0	51.4	3.86
4	**3-hole broker**	34	68.0	70.2	12.27
5	**5-person clique**	105	77.0	80.2	9.49
6	**3-person clique**	51	112.5	111.9	11.84
7	**pendent**	68	100.0	100	0.00
	Total	385	73.0	74.5	27.37

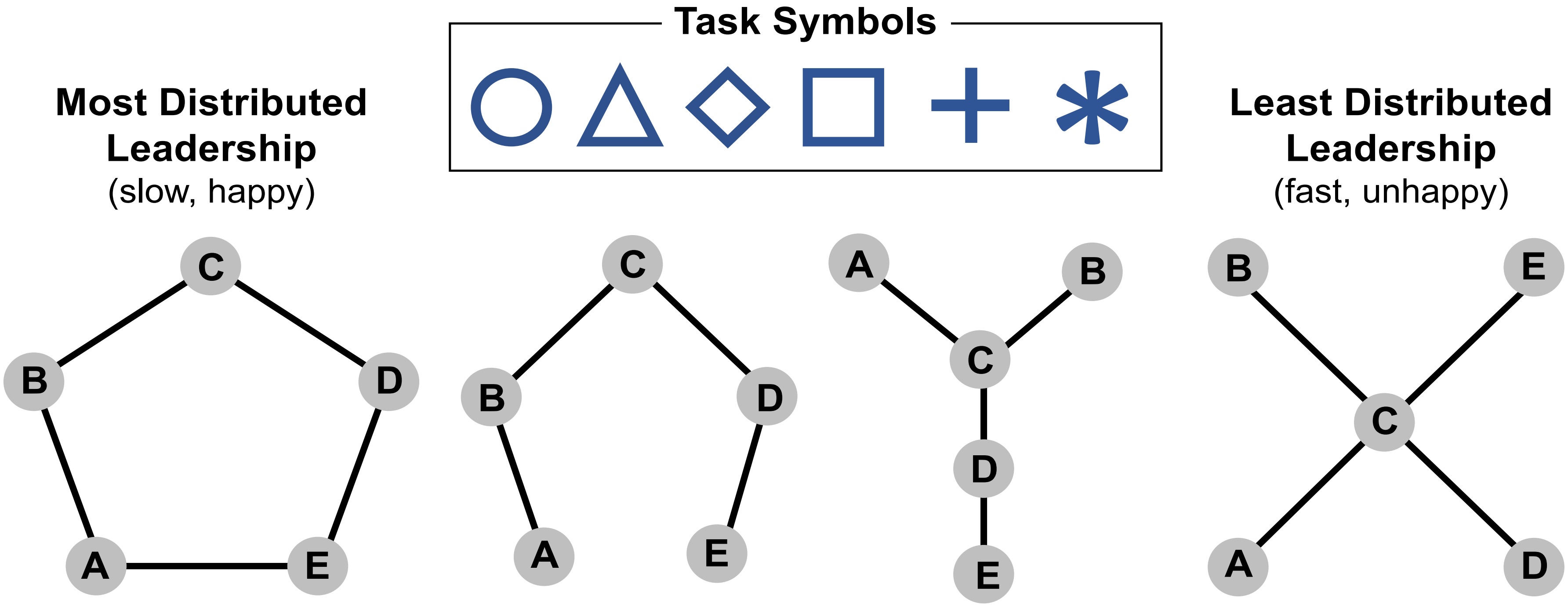
NOTE — Positions are defined in Figure 5. Constraint in 3-person cliques shows the constraint overrun that occurs in small, dense networks. Raw results are reported here, but overrun scores are truncated to 100 in the analysis to be comparable to other networks providing no access to structural holes (see footnote 7).

Table 6.
Prediction from Brokerage and Message Behavior

	All Trials		Early Trials		Final Trials	
	G	H	I	J	K	L
Relative Network Constraint	—	**-59.65** **4.70 (-12.69)*** **	—	**-42.72** **6.41 (-6.66)*** **	—	**-61.82** **4.27 (-14.47)*** **
Relative Number of Messages Sent	**26.93** **2.56 (10.54)*** **	2.98 2.85 (1.04)	**43.60** **3.12 (13.99)*** **	**18.73** **4.76 (3.94)*** **	**16.78** **1.98 (8.47)*** **	2.80 1.80 (1.55)
Relative Length of Messages Sent	**-2.73** **1.01 (-2.71)** **	-.76 .85 (-.89)	**7.63** **3.82 (1.99)* **	4.81 3.65 (1.32)	**-2.40** **.41 (-5.89)*** **	-.53 .34 (-1.56)
Relative Percent Function Words	**-5.50** **1.35 (-4.09)*** **	.41 1.22 (0.33)	**-7.94** **1.94 (-4.10)*** **	**-3.89** **1.93 (-2.01)* **	.74 .89 (0.83)	.86 .68 (1.25
Intercept	-1.00	13.35	-26.88	-3.65	2.33	12.95
R^2 Subjects	.30 385	.51 385	.47 385	.52 385	.23 315	.55 315

NOTE — These are OLS regressions predicting the percentage of leader citations a subject received. "Relative Network Constraint" is entered as a log score. Standard errors and test statistics are below coefficients (N = 385). Descriptive statistics and variable descriptions are in the Appendix. Predictors are computed for the indicated trials. Trials 1 through 4 are "early" and trials 10 through 15 are "final" (see Figure 11).

* P ≤ .05 ** P ≤ .01 *** P ≤ .001



CIRCLE (50.4 seconds)				
	Ties	Holes	Mes.	Sat.
A	2	1	78.4	58.0
B	2	1	90.0	64.0
C	2	1	83.6	70.0
D	2	1	86.2	65.0
E	2	1	81.0	71.0
Avg	2.0	1.0	83.8	65.6

CHAIN (53.2 seconds)				
	Ties	Holes	Mes.	Sat.
A	1	0	24.8	45.0
B	2	1	70.8	82.5
C	2	1	82.4	78.0
D	2	1	71.8	70.0
E	1	0	27.6	24.0
Avg	1.6	0.6	55.5	59.9

Y-NET (35.0 seconds)				
	Ties	Holes	Mes.	Sat.
A	1	0	28.0	46.0
B	1	0	23.8	49.0
C	3	3	79.8	95.0
D	2	1	63.8	71.0
E	1	0	25.6	31.0
Avg	1.6	0.8	44.0	61.2

WHEEL (32.0 seconds)				
	Ties	Holes	Mes.	Sat.
A	1	0	29.4	37.5
B	1	0	26.2	20.0
C	4	6	102.8	97.0
D	1	0	26.6	25.0
E	1	0	30.2	42.5
Avg	1.6	1.2	43.0	44.4

Figure 1. The Bavelas-Smith-Leavitt Experiment.

NOTE — The WHEEL is a traditional bureaucracy with C the leader. The other three networks distribute leadership (all five people in CIRCLE; B, C, and D in CHAIN; C and D in Y-NET). More distributed leadership is associated with slower task completion (Leavitt, 1951: 43, mean shortest time), more messages (Leavitt, 1951:45, mean messages sent), and higher satisfaction with one's job in the team (Leavitt, 1951:46, on 100-point scale).

Figure 2. Laboratory

Subjects arrive by appointment to register with reception then sit in one of the computer cubicles. The subject is instructed not to talk with others in the room, that the experiment involves playing 15 rounds of a team coordination game with structured communication between players, the time limit is 75 minutes, and expect initial rounds to take more time as people learn to work as a team (an effort to manage initial frustration). When a subject consents to participate, and has clicked through a tutorial, he or she is added to a software "waiting room." When a sufficient number of subjects are in the waiting room, the software draws five people, assigns them at random to positions in a team network, and the experiment begins.

MIT Behavioral Research Lab

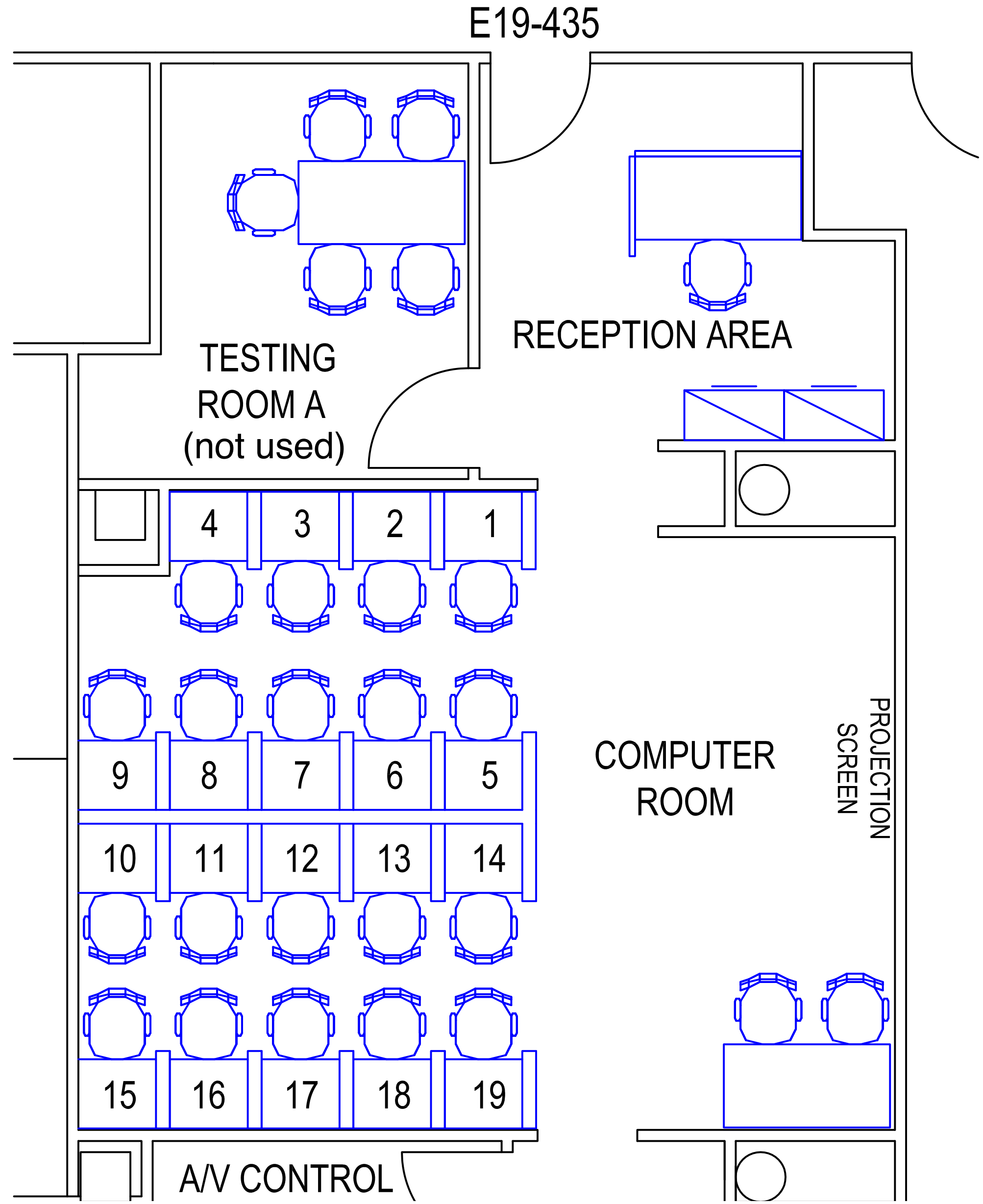
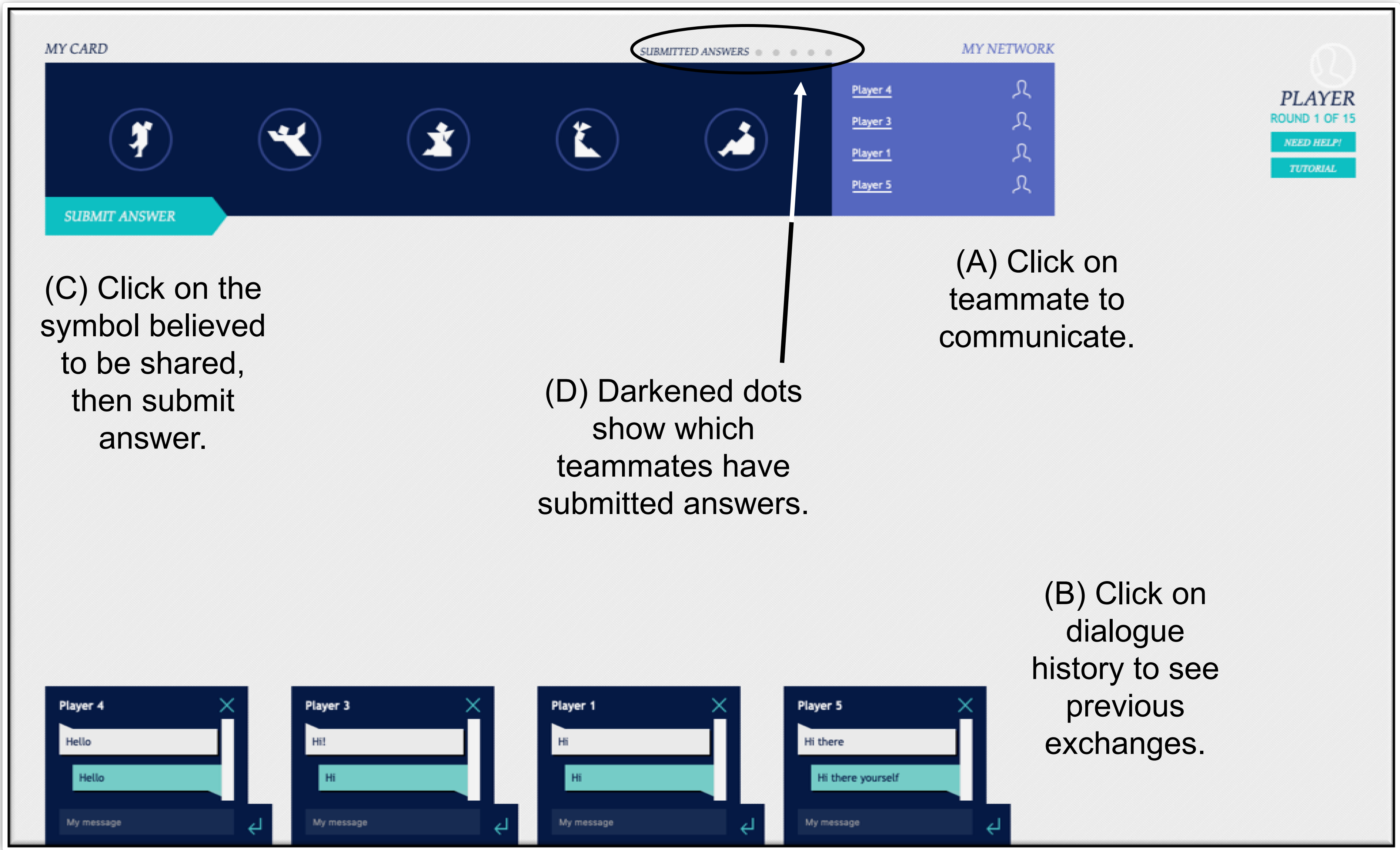


Figure 3. Example Game Screen.



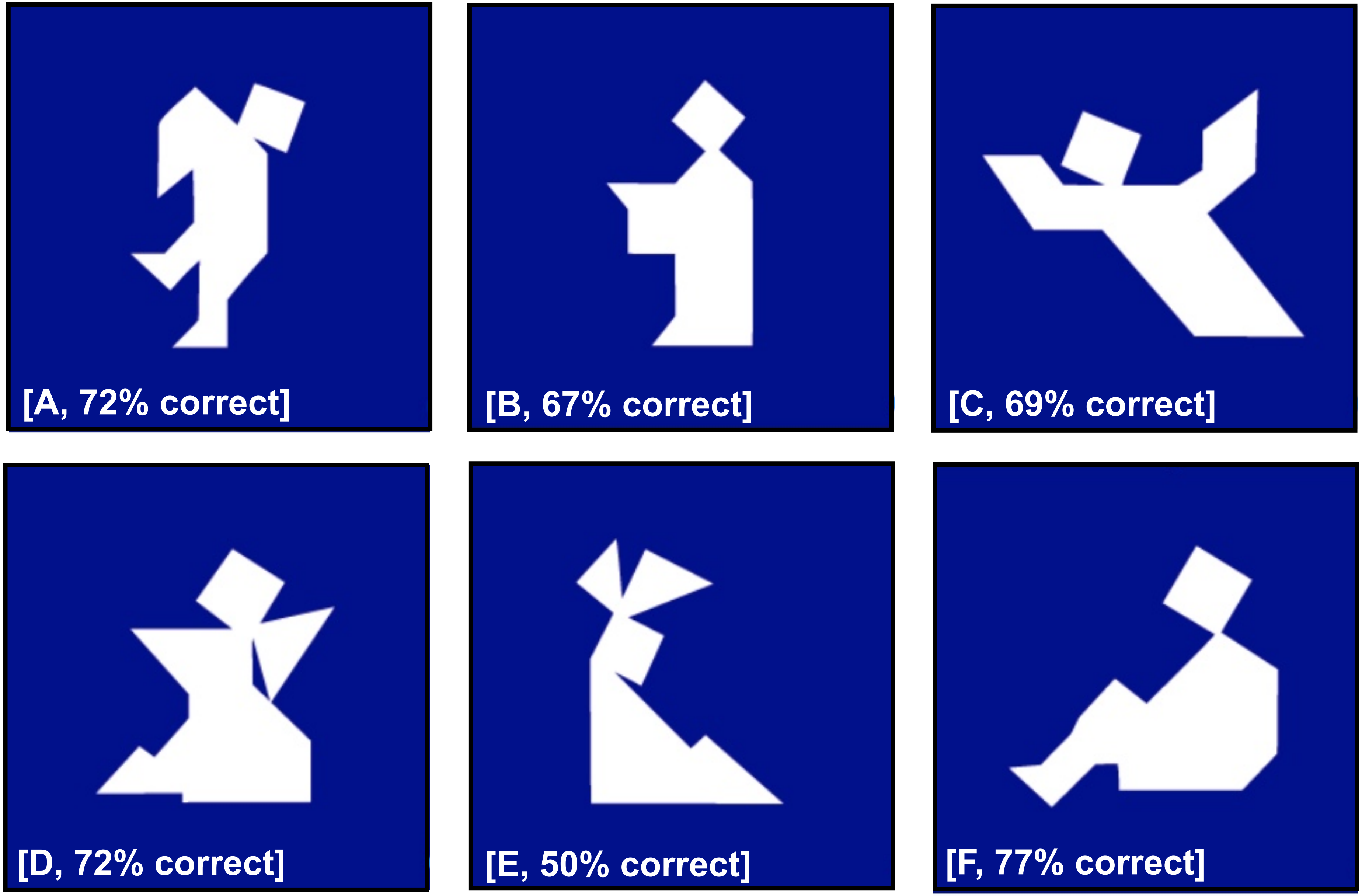
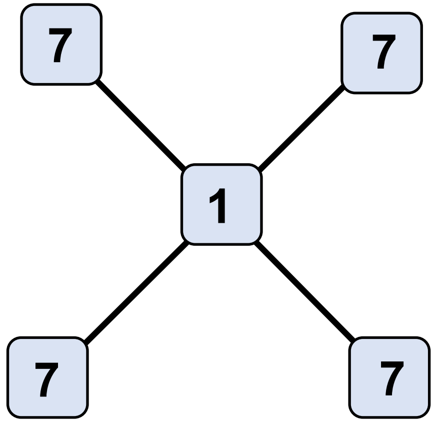


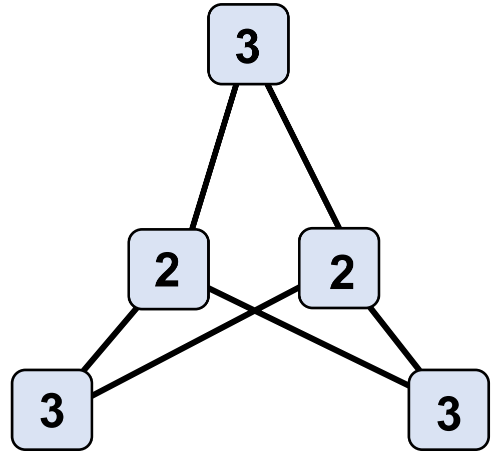
Figure 4. Subject's Hand Is Five of These Tangram Symbols.

NOTE — Identification in brackets does not appear on game screen (see Figure 3).

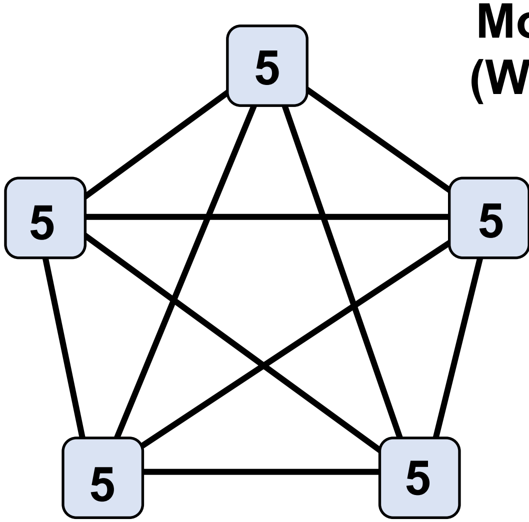
Figure 5. Four Team Networks.



Monopoly Broker (WHEEL) Network

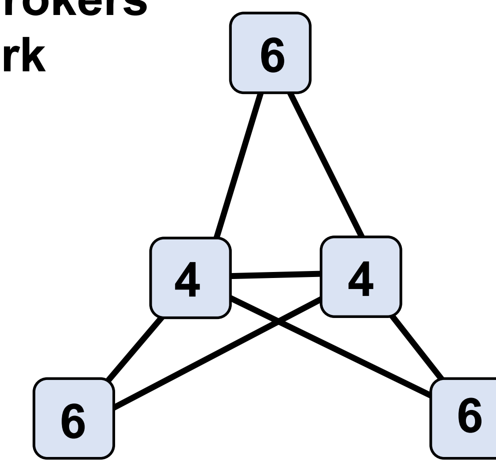


Disconnected Brokers (DB) Network



CLIQUE Network

ID	Position
1	6-hole broker
2	3-hole broker
3	1-hole broker
4	3-hole broker
5	5-person clique
6	3-person clique
7	pendant



Connected Brokers (CB) Network

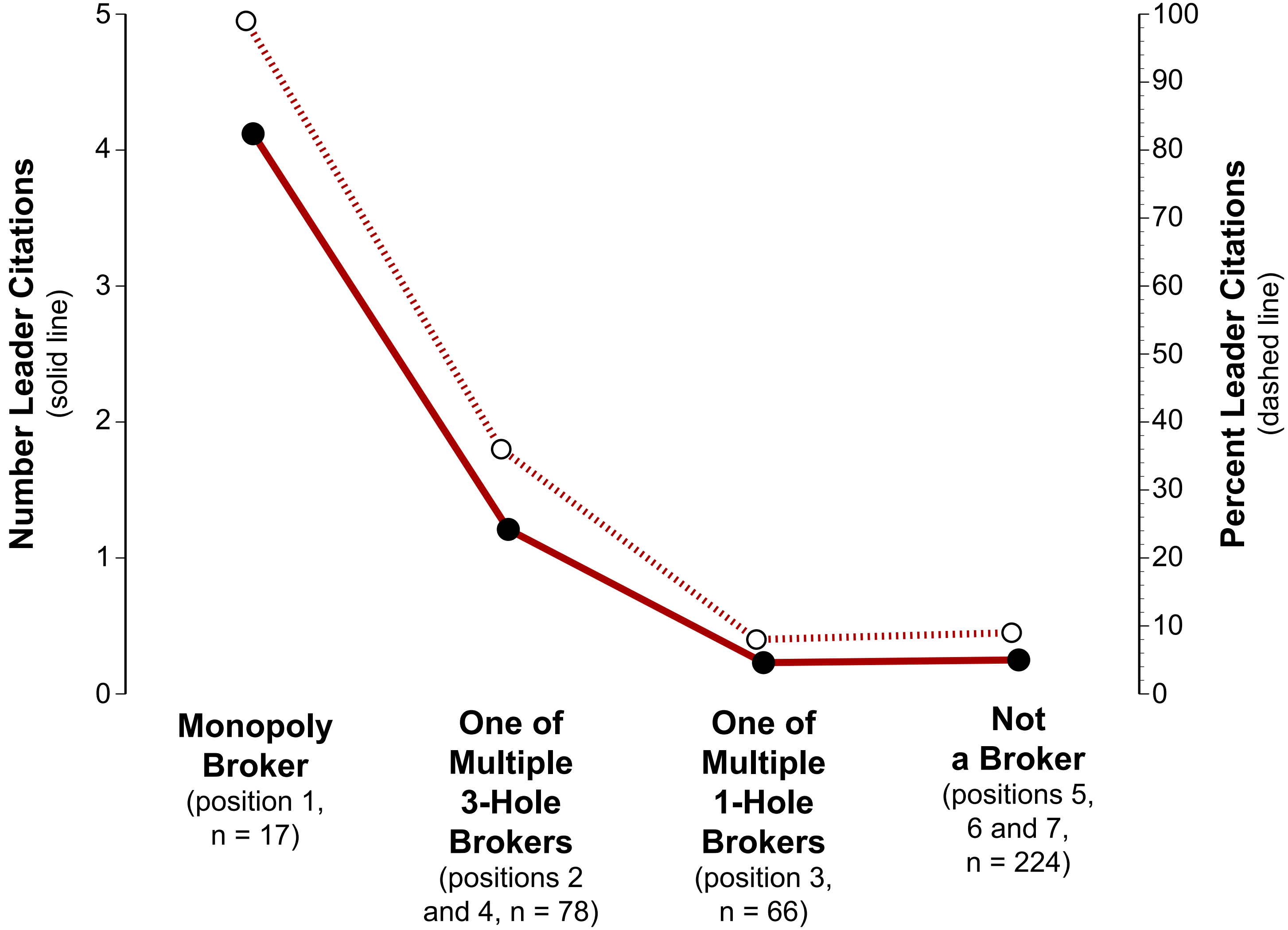


Figure 6. Brokers, Especially Monopoly Brokers, Are Perceived To Be Team Leaders

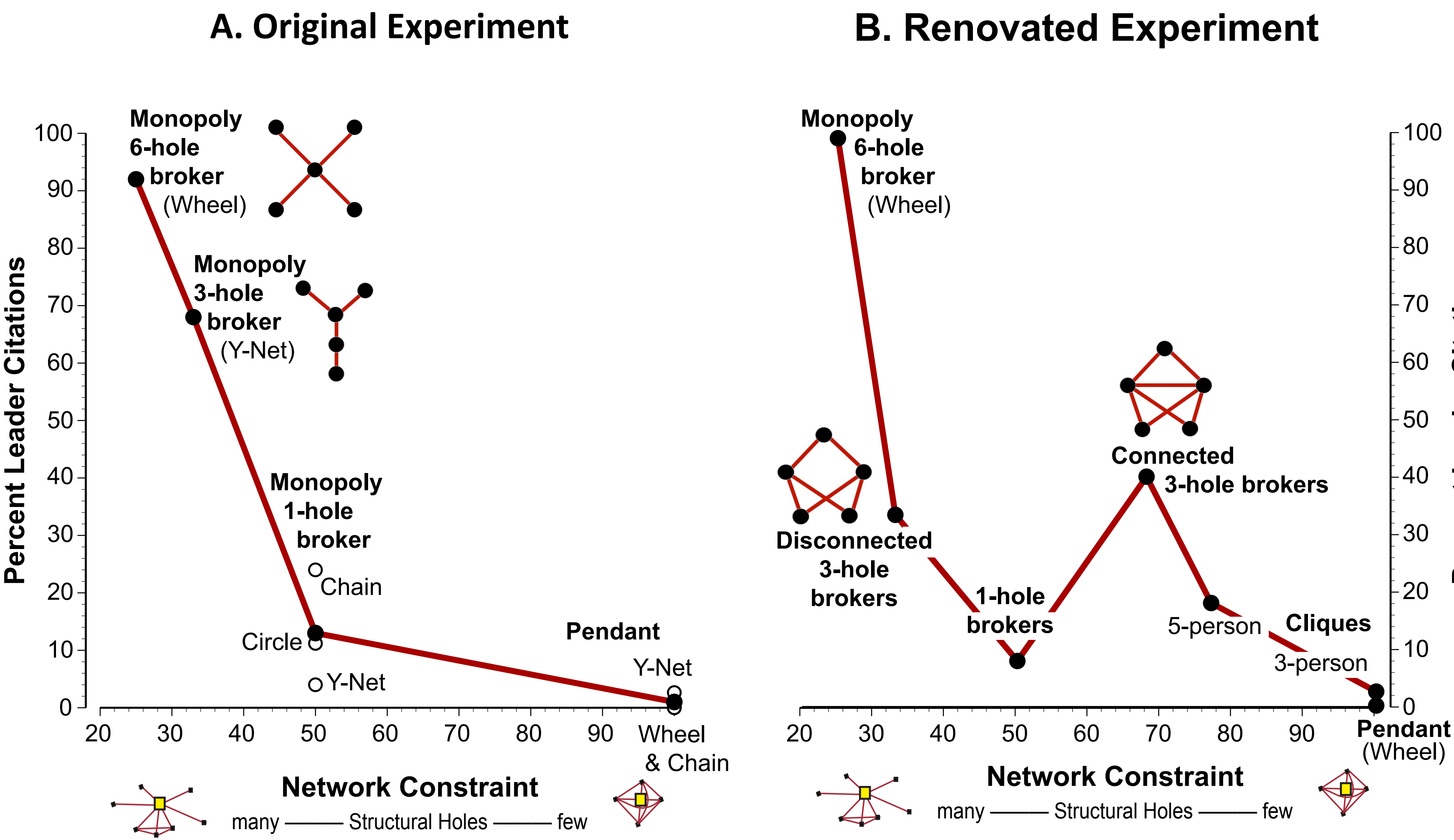
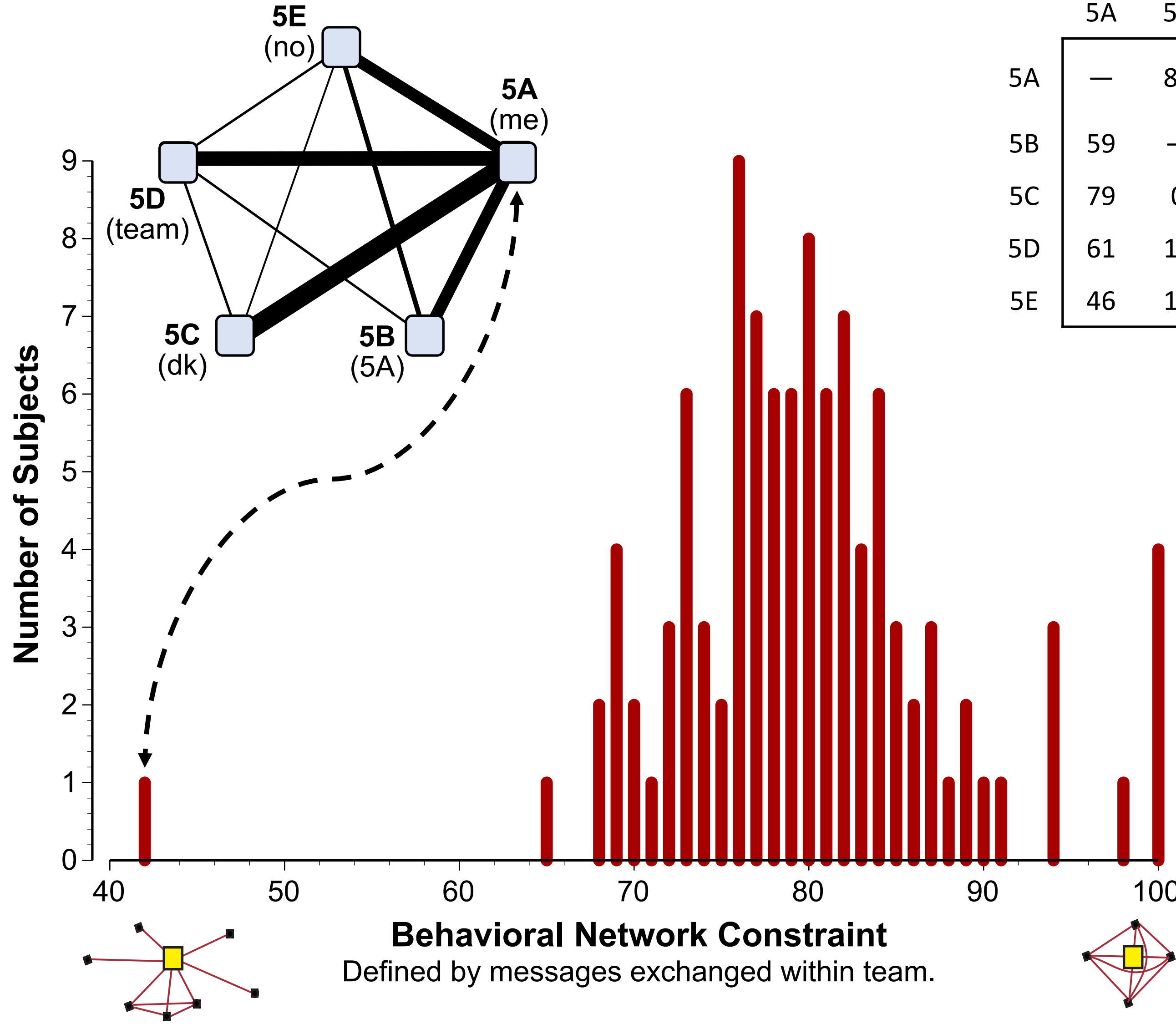


Figure 7. Original and Renovated Experiment Results

Vertical axis is percent of citations to subject in response to question: "Did your group have a leader? If so, who?" Solid dots are mean number of citations received by subjects at the same level of network constraint. Data in graph A are from Leavitt (1949:38).



	5A	5B	5C	5D	5E
5A	—	89	111	100	59
5B	59	—	0	10	22
5C	79	0	—	10	6
5D	61	19	17	—	16
5E	46	17	10	11	—

Figure 8. Behavioral versus Defined CLIQUE Networks

Note: Histogram shows distribution of behavioral network constraint scores for 105 subjects in CLIQUE networks. Network constraint is 77 in CLIQUE networks defined by the experiment (Figure 5). Insert table gives number of messages sent from row to column in an example team, and the relative number of messages defines line weight in the sociogram. Dashed line connects leader in the sociogram to her place in the distribution. Parentheses contain subject leadership votes.

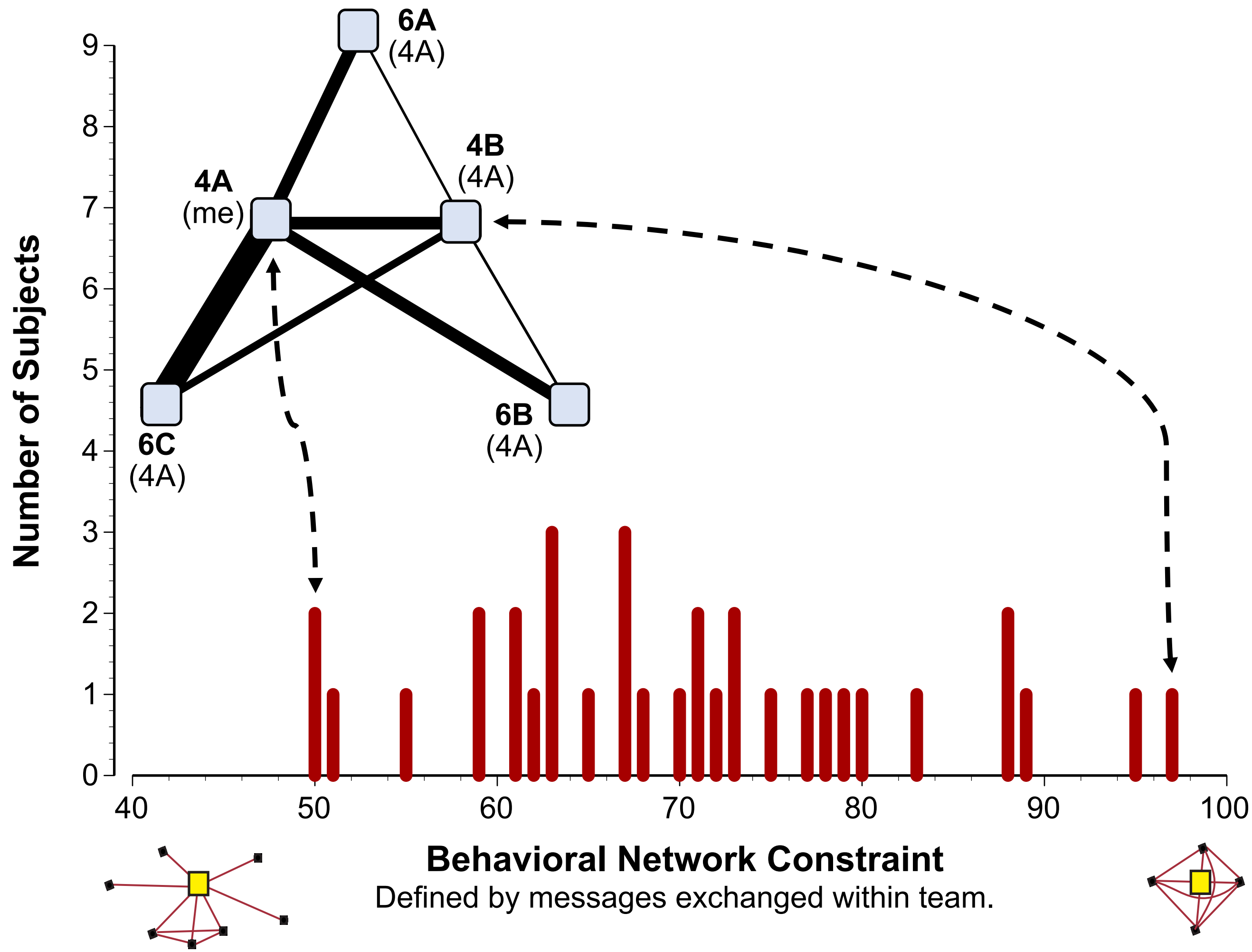


Figure 9.
Behavioral versus Defined for Position 4 in CB Networks

Note: Histogram shows distribution of behavioral network constraint scores for 34 subjects in Position 4. Defined network constraint is 68 points (Figure 5). Number of messages exchanged defines line weight in sociogram. Dashed line connects the two Position 4 subjects in sociogram to their places in the distribution. Parentheses in sociogram contain subject leadership votes.

beta	t-test	Network Constraint
-.29	-5.24	Defined
-.45	-6.74	Behavioral
-.63	-13.91	Relative

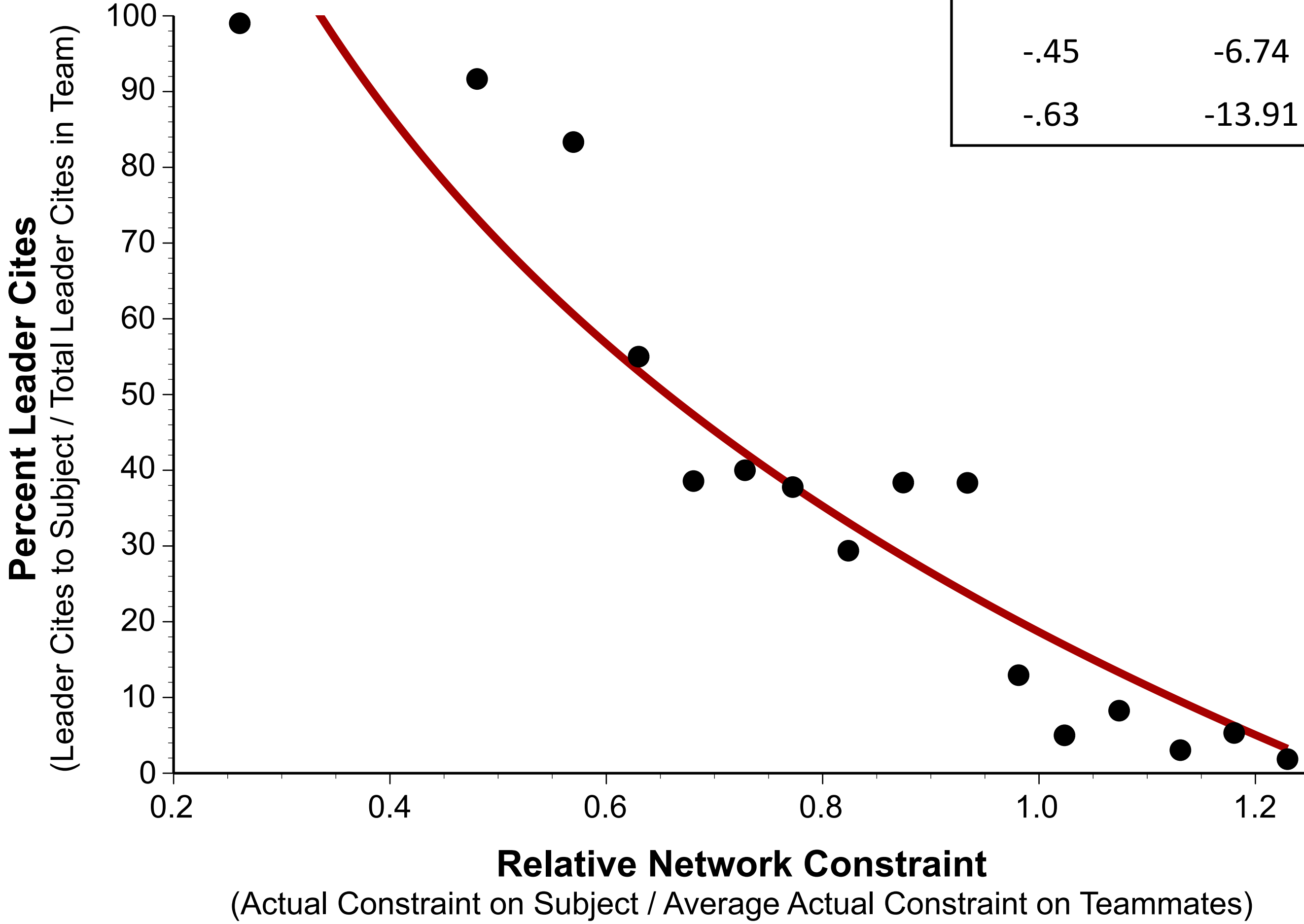


Figure 10.
Network Brokers Are Perceived To Be Leaders

NOTE — Data are averaged within .05 intervals of relative network constraint. Inset table contains standardized regression coefficients and test statistics for constraint predictions in Models D, E, and F in Table 4.

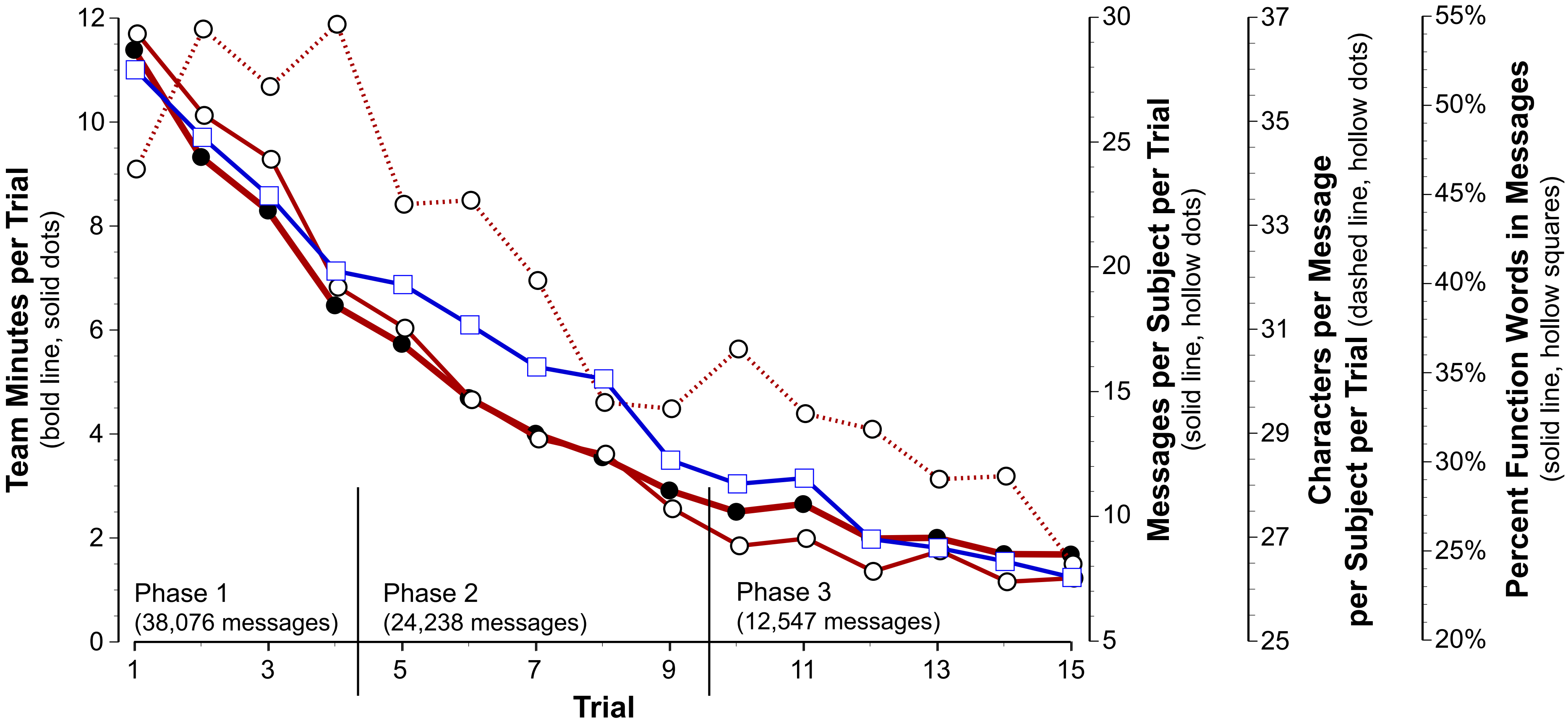


Figure 11.
Message Learning Curves