

Social Roles and the Evolution of Networks in Extreme and Isolated Environments*

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This article reports on the evolution of network structure as it relates to formal and informal social roles in well-bounded, isolated groups. Research was conducted at the Amundsen-Scott South Pole Station. Data was collected on crewmembers' networks of social interaction over each of three winter-over periods, when the station is completely isolated. In addition, data was collected on the informal roles played by crewmembers (e.g., instrumental leadership, expressive leadership). The study found that globally coherent networks in winter-over groups were associated with group consensus on the presence of critically important informal social roles (e.g., expressive leadership) where global coherence is the extent to which a network forms a single group composed of a unitary core and periphery as opposed to being factionalized into two or more subgroups. Conversely, the evolution of multiple subgroups was associated with the absence of consensus on critical informal social roles, above all the critically important role of instrumental leader.

Keywords: network evolution, global vs. local coherence, core/periphery structure, informal roles, norm consensus, role consensus

"This could have made for serious problems if there was not clear and open communications between the Station Manager and Construction Coordinator. Open communications and respect for each other were key factors in making our relationship an excellent one."
(South Pole Station Manager from one year of the study; from Winter-over Turnover Reports)

Introduction

A number of researchers have begun to recognize the increasing importance of broader sociological, anthropological, and social psychological issues in the study of humans in isolated and extreme environments, particularly with respect to the social complexity of larger groups (Johnson and Finney, 1986; Harrison and Connors, 1984; Pierce 1985). Most notable among the potential concerns are the relationship of structural concepts such as position, status, role, and norms to group evolution and function. Harrison and Connors (1984) have pointed out that little actual research employing structural theory and concepts had been carried out prior to their review. This is still basically true today.

The absence of the application of structural concepts in earlier work on social groups is somewhat understandable, since much of it has involved less than seven participants (Johnson and Finney, 1986). Even in research on larger groups in exotic environments such as polar research stations and among submariners, most of the attention has focused on questions of health and psychological well-being (c.f. Gunderson, 1974; Gunderson and Palinkas, 1991; Taylor, 1987) with little attention to the social, cultural, or social psychological issues. Structural concepts begin to increase in their explanatory value as groups become larger than seven. This number is the upper limit (5 ± 2) for the size of a single clique (Killworth and Bernard, 1974). Beyond this limit, groups have the potential to form multiple cliques or subgroups. One of the few early examples of the application of structural concepts to a study of groups in exotic environments is Smith's (1966) sociometric study of an Antarctic work group. In this study, seven members of a single work expedition were observed and interviewed. Thus, one of the few applications of structural concepts to research in exotic environments was somewhat limited in terms of structural complexity. The point is that in larger, more complex groups, structural factors become difficult to ignore (Johnson and Finney, 1986).

Weak leadership has been associated with catastrophic failure in polar expeditions (Leonov and Lebedev, 1975) and with low morale in other isolated settings (Hammes and Osborne, 1965). Leadership has been one of the most intensely studied aspects of small group phenomena, generating a vast array of definitions and a variety of methods for identifying or evaluating leaders. For example, consider the difference between the "functions" approach of Goudan (1970), which emphasizes the characteristics of leaders, and the "integrative" approach of Gibb (1969), which emphasizes leader-follower relations.

Many distinguish between “instrumental” or “task-motivated” leaders who are focused on the accomplishment of goals, and “expressive” or “relation-motivated” leaders who play more solidarity building roles in a group (Bales, 1953, 1958; Bales and Stodtbeck, 1955; Hare, 1976; Slater, 1955; Bales and Slater, 1955; Fiedler, 1971; Rees and Segal, 1984). Termed “role differentiation theory,” it has been criticized because it fails to consider the integration of the two leadership roles into one (Lewis, 1972; Meeker and Weitzel-O’Neil, 1977). House (1977) too questions the mutual exclusivity of these roles in that the most successful groups tended to be those in which leadership roles were integrated rather than differentiated. Such leaders were termed “charismatic.”

The literature on leadership also demonstrates the importance of the distinction between informal (emergent) and formal group structure. As Smith (1966) noted in observations of an Antarctic work group, informal or emergent roles will often replace or supplement more formal roles. During the course of selecting expedition members for his attempt at the South Pole, for example, Amundsen was painstakingly aware of the potential problems associated with the possible conflict between informal and formal roles. Amundsen deliberately kept the backgrounds of members homogeneous, thereby avoiding the problems associated with background heterogeneity (e.g., scientists vs. non-scientists). He also tested potential crewmembers’ stance toward authority by giving them intentionally obscure work assignments (Huntford, 1984). The purpose of the test was simply to assess an individual’s potential competition for Amundsen’s role as leader. If someone in the course of the test questioned his authority, the individual was eliminated from consideration as a member of the crew.

Palinkas (1989c, 1990) observed that effective leadership appears to be based on prior experience, articulation of goals, flexibility, and degree of interaction with other winter-over personnel. Data obtained on leaders of previous Antarctic winter-over crews indicated that evaluations of effective leadership were based on the ability of individuals assuming these roles to minimize group conflict, effectively address problems such as abusive or alcoholic station members before they began to affect station morale, keep projects on schedule without overworking personnel, make calm and rational decisions during an emergency, be fair and impartial particularly in conflicts between navy and civilian personnel, and maintain a certain level of communication with other winter-over personnel through work-related and social activities without becoming too “chummy.” Leaders lacking these abilities were harshly criticized and blamed for low moral, group conflict, and inability to successfully complete projects with a minimum of mistakes.

“Leaders” and “followers” are labels for two major “statuses,” or “group positions,” but it is important to realize that there may be informal or covert statuses that are not so easily identified. Formal status terms do not always cover the range of statuses and roles found in groups (Goodenough, 1969; Merton, 1957).

The saying “Too many cooks spoil the stew” expresses the idea that group heterogeneity is important and that competition for leadership should be kept at a minimum. In a particularly interesting instance of this principle, Klein and Christiansen (1969) analyzed the relative effectiveness of basketball teams as a function of variation in role expectations, status consensus, achievement motivation, and focused leadership. Teams that have both high average achievement motivation and high variance in achievement motivation tend to have higher status consensus, display higher degrees of group coherence, and therefore, win more often. They also found that variations on the task-orientation of the players increased the chances that differing role expectations would be met. Roberts has obtained similar results for groups in a variety of competitive situations, including the military (Roberts and Wicke, 1971; Roberts et al., 1972; Roberts et al., 1980), drivers (Roberts and Kundrat, 1978), and athletes (Roberts and Nuttrass, 1980). He consistently found that teams that combined individuals with different problem solving styles (e.g., potents and strategists) out-competed homogeneous teams.

Early on, Hall (1955) recognized the crucial importance of members’ agreement on group roles for producing coherent groups. In the absence of role consensus, we find “role collision,” described by Hare (1976) as a “type of conflict which may occur if two different individuals in a group perform roles which overlap in some respects.” Heterogeneity can produce effective groups by simply reducing the potential for role collision. The value of status and role heterogeneity is counterposed by the potential corrosive effect of heterogeneity in group members’ backgrounds (e.g., nonscientists vs. scientists) and other characteristics (Palinkas, 1989a; Johnson and Finney, 1986; Bernard and Killworth, 1973).

The Amundsen example also illustrates the importance of role heterogeneity; varying the role characteristics of group members allows them to fit in and function well with each other. By screening the role characteristics of possible expedition members, Amundsen minimized the potential for conflict due to role collision. This observation is reinforced by the reexamination of Bavelas-type experiments by Freeman et al. (1979), which show a relationship between group effectiveness and variation in centrality; groups with large variation in members' centrality were more effective than groups with little or no variation in member centrality. (We expect that variation in role characteristics corresponds to variation in centrality.) Similarly, MacKenzie (1976) demonstrated the relationships among group hierarchy, task processes, and group efficiency; more hierarchical groups processed tasks more effectively and were more efficient.

Note that status and role heterogeneity does not simply refer to heterogeneity of personality traits. Communication, interaction, and mutual reinforcement among group members leads to good morale and individual effectiveness; individuals must fit in with one another. In basketball, the networks formed by passing the ball

determine who “fits in.” As Klein and Christiansen (1969) demonstrated, role heterogeneity resulted in effective communication and efficient ball passing. We would also expect to find relationships among network structure, achievement motivation, and performance.

Outside of the psychotherapy literature, there have been few studies of deviants or low status individuals in small groups. Earlier small-group research focused on the negative aspects of deviants, in particular, on their non-conformity and rejection by the group (Newcomb, 1943; Chowdry and Newcomb, 1952; Festinger, 1954; Riecken, 1952). Similar findings for groups in exotic environments have been reported (Harrison and Connors, 1984).

Others, however, have recognized the positive aspects of such stigmatized statuses by noting the important functions of deviants or low status individuals (Dentler and Erickson, 1959; Johnson and Miller, 1983). Deviant roles emerge in many enduring groups, especially those in isolation (e.g., military and work groups [Dentler and Erickson, 1959]; Antarctic exploration groups [Johnson and Finney, 1986], and isolated commercial fish camps [Johnson and Miller, 1983]). The deviants in these examples function positively: promoting group solidarity, reducing boredom, and inhibiting group conflict. Dentler and Erickson (1959) point out that deviance is not only a natural part of social groups; it is institutionalized, accepted, and rewarded.

The positive functional aspects of such low status positions can make a considerable contribution to producing harmonious and effective small-groups. Just as “charismatic” leadership (House, 1977) is important, so too is the presence of “charismatic” deviance (Johnson and Miller, 1983). Occupants of such a social position will function in roles that provide a common reference point (e.g., mascot) for all other group members, thereby promoting group cohesion. This role will typically manifest itself in humor and joking behavior. As Earls (1969) and Dunlap (1965) point out, such behavior is essential for coping with boredom brought about by prolonged periods of isolation.

In the Antarctic, Palinkas (1989a, 1992a) identified two major categories of deviants in American winter-over crews. In the first category is the individual who fails to conform to group norms and expectations. These include individuals who break rules regarding personal or group safety, resulting in injury or death, which affect the morale of the entire station; individuals who abuse alcohol and become hostile to other crewmembers or who fail to perform their work assignments; individuals who fail to perform routine duties such as housekeeping; and individuals in positions of authority who fail to exercise leadership or fulfill group expectations of the leadership role. Although these individuals serve to unify the group as a whole by serving to define the boundaries of acceptable and unacceptable behavior and thereby reinforce group norms, they may also serve to weaken morale and lead to wider social conflict if little or nothing is done to control their behavior or minimize its effects on other group members.

The second category of deviant is the individual who acts as the station clown or jester. Frequently, this person is the cook, a civilian contractor employee, or a junior enlisted Navy man who will perform pranks and exaggerate his or her behavior sufficiently to be outside the mainstream of behavior on the station, yet not enough to be considered disruptive or threatening. This behavior provides a certain measure of relief to the stress imposed by the monotony of the physical and social environment. These individuals also provide an important communication function in that they are frequently allowed to express frustrations or dissatisfaction with disruptive individuals or undesirable conditions in a socially acceptable manner without causing additional stress or conflict.

There is abundant anecdotal evidence that lower social statuses have been important in past Polar expeditions. For instance, on his Antarctic expedition, Amundsen brought with him a cook named Lindstrom. As “Chef, baker, pastry-cook he provided surrogate domesticity. He was also instrument maker, taxidermist, housepainter...and clown (334).” In his marginal social position as cook, Lindstrom provided not only food, but also humor and comic relief, and greatly contributed to group harmony during the long winter. Because of his marginal position, Lindstrom was able to play the role of clown or court-jester without fear of any sanctions. Thus, inter-personal and inter-subgroup conflicts were reduced by the inclusion of this single member.

In a study of Italian commercial fishermen in an isolated camp in Alaska, Johnson and Miller (1983) and Johnson and Finney (1986) described the example of a deviant member (i.e., the worst fisherman of the group) who helped to mitigate conflict between the two major subgroups within the network of fishermen. During the fishing season of 1980, a strike had idled most of the fishermen in the camp. This was a period of boredom, high stress, and high potential for inter-personal and inter-subgroup conflict. However, the deviant, because of his status and personal characteristics, emerged in the role of “court jester,” providing comic relief and a common reference point for all group members irrespective of subgroup affiliation. The other fishermen made fun of him, played pranks on him, and he was a fun topic of conversation. He was rewarded for his role and received valuable salmon as compensation. He maintained moderate proximities among members of both subgroups. His role was important in minimizing conflicts during this tense period. As other group members described him: “He is the bridge between the two groups,” and “He belongs to everyone,” (Johnson and Miller, 1983:67).

A substantial body of research has focused on the evolution of network structure. Doreian (1983) and Doreian and Stokman (1997) provide statistical models for assessing the amount and character of change in network structure. Romney et al. (1989) discussed models of longitudinal network data in a reexamination of the Newcomb’s (1961) study of 15 weeks of interactions among members of a fraternity. They found that the structure of the group converged quickly to a stable final structure. Others, too, have been concerned with statistically modeling stability in

social networks over time, particularly in fixed node networks (Snijders 1990; Sanil, Banks, and Carley 1995) where only edges vary from one time point to the next. Still others have looked for possible explanations underlying stability or change including such things as reciprocity, tie strength, transitivity, and structural embeddedness (Feld 1997). The related work of Sanil et al. (1995), Snijders (1990, 1996, forthcoming), Van de Bunt et al. (1999), and Snijders and Van Duijn (1997) is important for establishing models for statistical tests of network change in this vein. The work of Snijders (forthcoming) is particularly noteworthy in his more recent discussion of models of network change that are the result of stochastic network effects (e.g., transitivity) and various covariates (e.g., gender). In many ways, this work is similar to what we attempt here in that network change is related to one or more exogenous variables. Whereas most of these models attempt to understand dynamics as a function of effects and covariates within a single group over time, our work attempts to understand such dynamics both within and between three evolving networks. This research also focuses to a greater degree than earlier work on the relationship of the evolution of network structure to group function.

Propositions

Based on the literature discussed above we might expect the evolution of a globally coherent group structure (defined below) to be related to the emergence of and agreement on various informal social roles. We specifically explore the following propositions as they relate to the evolution of network structure over time:

P₁: The greater the consensus on informal leadership roles, the more globally coherent the network.

P₂: The greater the overlap of informal and formal leadership roles the more globally coherent the network.

P₃: The greater the consensus on expressive leadership roles, the more globally coherent the network.

P₄: The greater the overlap of instrumental and expressive leadership roles, the more effective the leadership and the more globally coherent the network.

P₅: The greater the consensus on positive deviant roles (as opposed to negative deviance), the more globally coherent the network.

We examine these propositions in a setting that allows for clear network boundaries and little influence from factors outside the network of interest. A “natural” laboratory for the study of humans in isolation, the South Pole Station is the setting for an examination of the propositions.

The Setting

The Amundsen-Scott South Pole Station is located at 90° South Latitude. An American station, the site has been occupied since the International Geophysical Year in 1956. The original polar station was abandoned in the early

seventies being replaced by a larger station whose most prominent feature is a large geodesic dome that provides protection for a number of modular buildings.

The station is run by the National Science Foundation and its primary purpose is concerned with scientific investigation in various fields, most notably astrophysics. Although initially the winter-over crews at South Pole included both civilian and Naval personnel, it is now exclusively a civilian operation (with the exception of C-130 flights in and out of the pole piloted by the military). Winter-over crews consist of two primary groups of people. First, there are the support personnel (referred to here as “trades”) who work for a private firm contracted to run the day-to-day operations of the station. These include plumbers, carpenters, electricians, mechanics, cooks, material handlers, science and computer technicians, and the station manager. Second, there are the NSF grantees and their employees (graduate students, science technicians, post-doctoral fellows), often referred to by the “trades” personnel as “beakers.”

Winter-over crewmembers begin training as a group in August preceding their deployment to Antarctica in October and remain at the South Pole Station from October of one year through November of the next. They are in each other's company for over 15 months. Crewmembers are not allowed to stay two successive winters, although this rule has been broken. Winter temperatures are so cold (record temperature at South Pole -119°F) that flights to the station are next to impossible, even in medical emergencies. Thus, for the 8.5 months of the Austral winter, the winter-over crew is completely isolated at the station with no crewmembers entering or leaving. The nearest American base (McMurdo Station) is over 800 miles away. Joking behavior and pranks are an important part of station culture; crewmembers are assessed on their ability to both make and take such jokes. Sometimes the pranks stretch what might be considered in “jest” and verge on being mean-spirited. Over the course of our study, alcohol problems were generally limited to isolated individuals rather than to an entire subgroup. The increase in the proportion of female crewmembers at the station over the past 15 years has had a restraining influence both on the incidence of “pranks” and on the use of foul language. Members of the winter-over crews can be divided into a number of 'natural' categories: male versus female; smokers versus non-smokers; science personnel versus contract personnel; and within the contract personnel, support versus construction crew.

The Data

The network data for this study was collected over a three year period with three distinct winter-over crews in the 1990's at the Amundsen-Scott South Pole Station. Year A had a total winter-over crew of 28 with 9 females and 19 males. Year B had a total winter-over crew of 27 with 20 males and 7 females. Finally Year C had a total winter-over

crew of 22 with 4 females and 18 males. Winter-over crews were the focus of the inquiry and most of the data reported here is for the 8.5 month winter-over period. During this period, winter-over crews were in complete isolation with no one coming in or leaving the station between approximately February 15 and October 25 of a given year. On the 15th day of each of the 8.5 months of the isolation period (March-October), the station physician distributed and collected questionnaires that asked a number of network and social-psychological questions. Here, we focus on two primary types of data collected during this period.

The first of these are crewmembers' self-reports of ratings of social interactions with each of the $n-1$ other crewmembers over the prior two weeks. The ratings scale ranged from 0 to 10 with 0 representing no interaction and 10 representing a great deal of interaction. These were collected for a total of 8 months. This resulted in a series of 8 $n \times n$ asymmetrical matrices representing valued networks of reported interactions. Finally, additional network data was collected at the end of the winter in October. This consisted of successive pile-sorts (Boster, 1994) of crewmembers' perceptions of who "hung-out" with each other. This data provided the means for comparing informants' perceptions of group structure (i.e., cognitive networks) as well as providing a picture of the overall final group structure (i.e., social network).

The second primary type of data consisted of a sentence frame completion task (Metzger and Williams 1963; D'Andrade et al. 1972; Johnson and Weller, forthcoming) asking crewmembers to associate crewmembers, including themselves, with each of eleven possible informal social roles. Crewmembers were asked to circle all the names that fit a sentence such as "_____ is a natural leader in getting things done around station." This task was collected at the beginning, middle, and end of the period of winter-over isolation. In addition, and in conjunction with the successive pile-sorts, crewmembers were asked at the end of the winter to associate crewmembers with each of 22 informal social roles or role attributes. This differed from the eleven informal roles used in the questionnaire described above in that an additional set of more negative roles were included. The positive informal roles/role attributes included "social director" (expressive leader), "leader" (instrumental leader), "everybody's buddy," "peacemaker," "jokes with," "comedian/clown" (positive deviant), "storyteller," "counselor," "someone to count on," "committed to work," and "volunteer". The more negative informal roles/attributes included "self-exile," "loner," "rigid," "cliquey," "disruptive," "know-it-all," "whiner," "hypertense," and "alcohol problem." These informal role descriptions were obtained from a set of open-ended interviews with informants who had wintered at the South Pole prior to the beginning of our three year study. We focus primarily on three informal roles. The first of these we refer to as instrumental leadership and was elicited by asking crewmembers to name "natural leaders in getting things done around station." The second is expressive leadership and was elicited by asking crewmembers to name "social

directors” and organizers of social events. The final roles concern positive deviance (i.e., clowns and comedians) and negative deviance (i.e., the negative roles and related attributes listed above).

Global Coherence

We will first examine the extent to which a globally coherent structure evolves and changes over time in each of the three networks. A *globally* coherent network is one that forms a single group composed of a unitary core and periphery and lacks clearly defined cliques or subgroups, whereas a *locally* coherent network is one that is factionalized into multiple subgroup or clique structures. This idea is similar to the notion of cohesion as discussed by Pattison (1993) and more recently by Borgatti and Everett (2000a).

There are many ways of determining the degree to which a network is composed of multiple subgroups. Borgatti and Everett (2000a) identify core/periphery structures using a block model approach. Their approach maximizes the correlation between a structure matrix representing a theorized core/periphery structure and a partitioning of the raw data itself. This sorts actors into core and periphery blocks in which the upper left block of the model will contain actors with high frequencies of interaction and the lower right block will contain peripheral actors with low frequencies of interactions.

We measure global coherence by looking at the similarity in patterns of interactions between all *i*'s and *j*'s or, simply, the degree of structural equivalence among all the actors. The advantage of basing the search for coherence on structural equivalence as opposed to, say, interaction intensity (i.e., cliques) is two-fold. First, the means for determining the degree to which actors in the network form a single group of jointly occupied positions is computationally straight forward, particularly for valued data of the kind here, in comparison to any of the alternative clique approaches (e.g., *n*-cliques, *k*-plexes). More importantly, however, the use of structural equivalence as an index of global coherence is theoretically appealing because of its conceptual relationship to such notions as social homogeneity, social similarity, norm consensus, and social homophily (Burt 1982,1983; Johnson 1986). Structurally equivalent actors will have a greater tendency to share attitudes, beliefs, and norms (Burt 1983, 1982; Johnson 1986) even if *i* and *j* themselves are not directly connected. Thus, globally coherent groups will be characterized by a single group norm whereas locally coherent groups will have more of a tendency to display multiple norms where such norms may often be at odds with one another (Festinger et al. 1950). We would expect that globally coherent networks would have greater group harmony and higher function compared to locally coherent networks.

We have avoided the use of density as an index of global coherence. Density as a summary index obscures true differences in the structural characteristics of networks (Borgatti and Everett 2000b). Two networks can have identical densities, but have profoundly different structures. For example, a network with moderate ratings among all members could yield an identical density as another network with high ratings within subgroups but low ratings between subgroups.

Visualizing Coherence

In the following sections, we assess the degree of global coherence in a group in several ways. Initially, network graphs of the social interactions ratings for each of the months and the successive pile sort data collected at winters' end will provide a visual check for the presence of global coherence. Figures 1-3 show the final group structures (i.e., at winter's end in October) for each of the three years in multidimensional scalings (Kruskal 1964) of the successive pile sort data of crewmembers' perceptions of who "hung-out" with each other. An inspection of the three configurations reveals that Year A (Figure 1) has a classic core/periphery structure with the core members interacting frequently amongst themselves and peripheral members having less interaction with either the core or other periphery members. This is indicative of global coherence. Crewmembers did not distinguish subgroups during exit interviews. Year B (Figure 2) has some of the same characteristics as Year A, but has three actors in the periphery and a core that contains some degree of subgrouping. In this year, crewmembers in exit interviews distinguished three major subgroups within the core: a subgroup of 10 individuals who hung-out in the galley and was referred to as the "couch group" (a mix of both science and trades crewmembers); a subgroup of three individuals who worked the night shift; and a subgroup of 4 couples, many of whom had had several previous winter-overs at the South Pole. Year C (Figure 3) stands in stark contrast to the other two years in that there is a clear clique structure in which three well bounded subgroups are evident, thus displaying more local coherence. In exit interviews, crewmembers reported that members of these subgroups had a tendency to "hang-out" with one another in three separate locations in the station. Crewmembers labeled these cliques according to the area in the station where members of the groups watched videotapes such as the "biomed group," the "library group," and the "bar group". In addition, there are a number of crewmembers that lie between the three subgroups (one of whom was the expressive leader) and one clear outlier.

[Insert Figures 1-3 here]

In a further visual examination of the evolution of group structure, we now turn to a comparison within and between years of the 8 months of social interaction data. Figures 4-6 show the results of a series of correspondence analyses (Greenacre 1984) of the stacked interaction ratings matrices over the 8.5 month period. Correspondence analysis provides a means for graphically displaying structural comparisons or structural change (see Kumbasar et al. 1994 for a network example). For each of the figures only the initial position and final position for each crewmember is shown. The vectors indicate the direction of the movement for each crewmember from March to October (i.e., each member's position in March [with label] and October [no label]). Year A, with a few exceptions, has most crewmembers moving inward toward the center of the space. In Year B, movement is somewhat complicated with many crewmembers moving in the same relative direction while others move slightly in the opposite direction. The core subgroups discussed above are also indicated on the graph. Finally, Year C stands in contrast to the other two in that there is a clear movement of crewmembers outward from the center of the space to the periphery in a kind of structural explosion. In addition, the movement of clusters of crewmembers in basically three different directions reflects the formation of well-defined subgroups shown in the MDS of the successive pile sort data. Thus, two distinctly different methods for determining network structure (successive pile sorts and interaction ratings) yield strikingly similar results.

[Insert Figures 4-6 here]

Table 1 summarizes the movement of actors in each of the three years. Based on a visual inspection of the plots, counts were made as to whether actors were moving toward each other in the center of the space or away from each other. There are obvious differences in trends, as illustrated by the table. Year A has the most movement inward followed by Year B. In Year C, most of the movement is outward as the structure changes from a coherent core/periphery structure to one that is factionalized into distinct subgroups.

[Insert Table 1 here]

Coherence as Structural Equivalence

In discussing goodness-of-fit tests for subgroups determined on the basis of structural equivalence, Burt (1983) used factor analysis to test the truth of a given equivalence hypothesis and to determine the extent to which actors are

engaged in structurally equivalent relations. Here, we apply Burt's approach to test whether the whole network forms a single set of structurally equivalent actors using a much weaker criterion than that used by Burt (i.e., moderate degrees of overlapping relations rather than identical relations). As he notes, "structurally equivalent actors have similar distances to every other actor in a system so that distances to structurally equivalent actors are almost perfectly correlated. In other words, a factor analysis of the covariance matrix among distances to structurally equivalent actors should yield a single factor if the actors are equivalent under a strong criterion" (ibid: 277). We, too, are interested in a single factor solution as an indication of the extent to which actors are structurally equivalent, but we are interested in much weaker degrees of structural equivalence (see Johnson 1986 for a discussion).

The columns of the 24 interaction rating matrices (3 years x 8 months) were correlated to produce 24 inter-rated correlation matrices. These matrices reflect structural equivalence: the similarity of the actors in their pattern of social interactions with other group members. These inter-rated similarity matrices were then factored using minimum residual factor analysis (Comrey, 1962). In this case, the first factor score is a measure of the degree of which each individual in the group is similar to others in his or her pattern of interactions. To determine the degree of global coherence in a network, we look at the means, standard deviations, and signs of the first factor scores. A globally coherent network is one in which the scores are all positive with relatively small variance (with the possible exception of a few outliers). Figures 7 and 8 show the means and standard deviations of these first factor scores by month for each of the three years. Both show similar trends across the three years. Years B and C each start with high mean scores which decline at various rates over time. However, Year C declines dramatically over the winter. In contrast, Year A begins low and steadily moves upward. A look at variance shows a similar trend with the standard deviation increasing the most for Year C and declining dramatically for Year A. Figure 9 shows the coefficient of variation or the ratio of the standard deviation of the first factor score to one plus the mean of the first factor score ($\sigma/(1 + \bar{x})$) by month for each of the three years. Figure 10 shows a dot box plot of the first factor scores over time for each of the years. This graph confirms the trends illustrated in the graphs above but provides more details on the distribution of the scores over time. The distribution of the scores for the final month (i.e., October) is especially important for our argument. By winter's end, 41 percent of the actors in Year C have factor scores less than or equal to zero, reflecting clear subgroup structure. Although Years A and B display much less variation by winter's end, Year A's distribution displays the most coherence. Figure 11 is a dot box plot comparing the distributions of scores for the final month of the winter. It shows that Year A is much more coherent in its structure than Year B. Additionally, the distribution of scores within years corresponds well with earlier analyses in terms of the presence of subgroups within the core for Year B, multiple subgroups for Year C, and a well delineated core for Year A.

[Insert Figures 7-11 here]

For a statistical examination of the evolution of network structure over time, we turn to a two factor repeated measures analysis of variance comparing scores in each of the years over time. The model that compares 3 levels of factor A (year), having n subjects per level of A, and 8 levels of B (month) is

$$y_{ijk} = \mu + \alpha_i + \pi_{j(i)} + \beta_k + \alpha\beta_{ik} + \varepsilon_{ijk},$$

where α_i , β_k , and $\alpha\beta_{ik}$ are fixed effects corresponding to main effects for A (year), B (month) and their interaction and ε_{ijk} is the effect of random residual error. A random effect due to the j th subject in the i th level of A is denoted by $\pi_{j(i)}$ with the assumption that $\pi_{j(i)}$ be independent and normally distributed (with mean μ and standard deviation σ_π^2). The problem of independence in linear models in relation to network data has been discussed elsewhere (Sanil et al. 1995).

Table 2 shows the results of the analysis for both main and interaction effects. There is a significant difference between years ($F=3.494$, $p<0.035$) in the first factor scores over the 8 months of the winter-over. More importantly, however, there is an interaction effect between year and month indicating significantly different trends ($F=6.465$, $p<0.0005$) in the first factor scores across time¹. The dramatically different trends for Years A and C are clearly evident from an inspection of Figures 7-9. Whereas Year B had the least amount of change over the 8 months of winter moving from a strongly coherent structure to one that was slightly less coherent, Year A moved from a less to a more coherent structure while Year C moved in the opposite direction. These trends are further supported by polynomial tests for the interaction term of the extent to which the changes are linear, quadratic, or cubic. There is a highly significant linear trend for the interaction effect (linear [$F=10.45$, $p<0.0005$], quadratic [$F=4.276$, $p<0.02$], cubic [$F=3.844$, $p<0.03$]).

[Insert Table 2 here]

Given the differences in years in terms of the evolution of network structure, we can now proceed with tests of the various propositions. If the propositions are to be supported, then there should be markedly different role

distributions in Years B and A as compared with Year C. In the following sections, we examine the evolution of various roles as they relate to global coherence.

Evolution of Instrumental and Formal Leadership

In this section, we examine the propositions concerning the relationships between the evolution of group structure and the corresponding evolution of social roles. In the first two propositions, we expect a globally coherent group structure to be associated with both group consensus on instrumental leadership (i.e., informal work leader) (**P₁**) and the overlap of informal instrumental leadership with formal designated leadership (**P₂**). Our exploration of these propositions should be considered tentative, given we that our number of cases (three) is insufficient to conduct statistical tests. Nevertheless, a visual examination of the data should reveal general trends if, in fact, they are present.

Table 3 shows changes in the degree of consensus on the instrumental leadership role between the beginning and end of winter. We consider strong consensus to be when 67 percent or more of those responding assign a role to a given individual. We consider moderate consensus to be when 33 to 66 percent of those responding assign a role to a given individual. The table reveals two important trends that are both in the predicted direction. First, the two most coherent years move from a lack of consensus on instrumental leadership to strong consensus: for Year A, all of the respondents agreed that the formal leader (i.e., the station manager) was an informal instrumental leader. On the other hand, Year C moves from consensus to strong disagreement on informal instrumental leadership. More importantly, however, is the trend toward both high agreement on and the overlap of both formal and informal leadership roles for Years A and B as compared to Year C. In Years A and B, agreement on instrumental leadership increases over time and the formal leader, the station manager, exclusively occupies the informal leadership role. For Year C, the change is in the opposite direction. At the beginning of the winter, there is strong consensus that the station manager is the informal leader. However, by the end of the winter there is competition between the formal leader and two other crewmembers for informal instrumental leadership, leading to role “collision.” This corresponds with the shift from global coherence with the manager as the clear informal leader to greater factionalization with competition among many informal leaders towards the end of the winter.

[Insert Table 3 here]

Figures 12-14 illustrate the consolidation of the role of informal leader in relationship to group structure. They show a correspondence analysis of the October (winter's end) network structures with formal leaders (station

managers) indicated by white circles. In order to show relations of moderate strength and above, the social interactions ratings data for each of the years were dichotomized using the following criterion.

$$X_{ij} = \begin{cases} 1, & \text{if } r \geq 4 \\ 0, & \text{otherwise} \end{cases}$$

In Year A (Figure 12), the manager is positioned in the center of the dense core of the network. In Year B (Figure 13), the formal leader is in the center of a slightly less dense network core. Finally, in Year C (Figure 14), the formal leader is central to one of the three main subgroups found in the network, but not in a position that is central to the entire network structure.

[Insert Figures 12-14 here]

Evolution and Expressive Leadership

Although not as critical as instrumental leadership, expressive leadership is also important for positive group interaction. Propositions three and four concern the relationship of coherent group structure to consensus on expressive leadership and to the integration of expressive and instrumental leadership roles (House 1977). Table 4 provides data on the changes in consensus on expressive leadership over the course of the winter. Years A and B shift from a lack of consensus on expressive leadership to a consensus on expressive leadership, especially in Year A. Year A ends with high agreement that three individuals play the role of expressive leader with moderate consensus on two others. This is as predicted by **P₃**. However, in this year, the expressive role is not integrated with the informal instrumental leadership role, violating **P₄**. Year B goes from the total absence of expressive leadership to one of moderate consensus on two crewmembers (one of whom is the station manager), in conformance with both **P₃** and **P₄**. There seems to be slightly more support for role differential theory over the role integration approaches advocated by, for example, House (1977).

[Insert Table 4 here]

Year C, on the other hand, moves from high consensus on one individual and moderate consensus on another (the station manager) to the complete disappearance of anyone occupying an expressive leadership role. The coupling of the loss of the expressive leader with the loss of group global coherence conforms to both **P₃** and **P₄**.

Evolution and Deviant Social Roles

Finally, **P₅** is tested through an examination of the presence or absence of both positive (e.g., “joker/clown” or comedian) and negative deviant roles (e.g., “rigid,” “disruptive,” “whiner”) at the end of the Austral winter in the three years. Table 5 shows the frequency counts for both positive and negative roles. Years A and B have a number of individuals playing positive deviant roles with little or no negative deviance. In contrast, Year C has only one moderately agreed upon positive deviant role while there are two crewmembers seen as playing more negative roles. Thus, the two years with the more coherent structures have a higher degree of positive deviance while the least coherent year has the highest amount of negative deviance, in support of **P₅**.

[Insert Table 5 here]

Discussion and Summary

The evolution of network structures over the winter varies in the three years. Year A has the highest coherence at winter’s end. The structure for this year evolves from a less coherent to a more coherent structure at the end of the winter. Year B has the second highest coherence and follows a slightly different structural pattern over the winter. In this case, the structure of the group displays a slow decline in coherence having moderate coherence by the end of the winter. Finally, Year C moves from a highly coherent structure at the beginning of winter to a more factionalized structure by winter’s end. Figures 12-14 illustrating the final network structures also confirm the difference in global coherence in the three years. These differences in the evolution and stability of networks over time suggest that instability is not necessarily either positive or negative; its evaluation depends on the kind and direction of change that occurs. For Year A the instability is positive in that change led to the development of group coherence over time. For Year C, the instability is negative in that the group shifted from a coherent to a factionalized network structure over the course of the winter.

Agreement on instrumental leadership increases over time for years A and B but diminishes in Year C reflecting competition among individual crewmembers for this role. More importantly, there is consolidation of informal with formal instrumental leadership in Years A and B, while in Year C the trend is in the opposite direction. Expressive leadership roles disappear completely in Year C, while Year A has high consensus on multiple individuals

in that role and Year B has moderate consensus for two individuals in that role, including the station manager (i.e., a case of role integration).

At winter's end, positive deviant roles, such as clowns or comedians, are present in Years A and B, but mostly disappear in Year C (moderate consensus on one crewmember). Instead, Year C has the highest amount of negative deviant roles of the three years studied. Events transpired in Year C to undermine the ability of the formal leader to maintain his/her informal leadership role. This was further exacerbated by the disappearance of the only expressive leader sometime in the middle of winter (due in part to harassment by a marginalized crewmember). Lack of multiple expressive leaders meant that the group was very dependent on a single individual to perform this important role over the course of the entire winter. The efforts of some of the disruptive crewmembers (i.e., negative deviants) eventually led to the withdrawal of the expressive leader. This made the formal leader's ability to maintain group coherence much more difficult.

The importance of expressive leadership lies in the ability of individuals in these roles to bring people together in a variety of social contexts (e.g., dinner parties, sporting events, role playing games, movie nights). In these settings, higher rates of social interaction aid in limiting gossip and slow the formation and maintenance of negative stereotypes (e.g., particularly as it relates to the trades vs. beakers distinction), all potential contributors to conflict and division. There appears to be a clear advantage in having several individuals in the role of expressive leader. Unlike the role of instrumental leader where the effects of role competition or "collision" can be detrimental, multiple individuals playing the role of expressive leader ensures that there will be adequate expressive leadership despite the psychological stresses due to isolation and confinement.

Conclusion

There is reasonable tentative support for four of the five hypothesized propositions, albeit with a small number of cases. The exception is **P₄** concerning the integration of leadership roles. The evidence suggests that the presence or absence of certain informal social roles in groups is important in allowing or preventing the evolution of a globally coherent group structure.

It should be pointed out that the informal roles discussed here are not independent of one another. A globally coherent group is one that has individuals playing a combination of informal roles that are essential to the proper functioning of the group. In Year C, the formal group leader lost his/her recognition as the informal leader in part because of the loss of an expressive leader and because of the emergence of negative deviants. Competent leadership alone is not enough to grow and maintain a globally coherent network structure. Rather, it is necessary to have a

combination of positive social roles filled by different individuals so that members of the group mesh with one another and contribute to group solidarity and norm consensus. It is the interplay of these various roles at various levels that ultimately determines the evolution of network structure in isolated and extreme environments, and probably in other settings as well.

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Footnotes

1. Other assumptions of the model, such as compound symmetry, are generally met as indicated by the ultraconservative adjusted probabilities of the Greenhouse and Geiser statistic ($p < 0.0005$) and the multivariate tests provided in SYSTAT which are all in agreement.

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Table 1. Comparison of direction of movement from t_1 to t_8 .

	Out	In
Year A	7	21
Year B	12	15
Year C	18	3

$$FI(x) = 18.58$$

$$\text{Exact } p = 0.001$$

Table 2. Two factor repeated measures analysis of variance comparing first factor scores over time for the three years.

Between Subjects

	SS	df	MS	F	P
YEAR	3.567	2	1.784	3.494	0.035
Error	37.776	74	0.510		

Within Subjects

	SS	df	MS	F	P
Month	0.547	7	0.078	1.335	0.231
Month*YEAR	5.295	14	0.378	6.465	0.000
Error	30.305	518	0.059		

Table 3. Comparison of consensus on instrumental leader role and isomorphism with formal leadership role between beginning and end of winter-over.

Year	Beginning		End	
	High Consensus ($c > .66$)	Moderate Consensus ($.33 < c < .67$)	High Consensus ($c > .66$)	Moderate Consensus ($.33 < c < .67$)
A	0	2*	1*	2
B	0	1*	1*	1
C	1*	1	0	3*

*denotes formal leader in frequency count

Table 4. Comparison of consensus on expressive leader role between beginning and end of winter.

Year	Beginning		End	
	High Consensus ($c > .66$)	Moderate Consensus ($.33 < c < .67$)	High Consensus ($c > .66$)	Moderate Consensus ($.33 < c < .67$)
A	1	0	3	2
B	0	0	0	2*
C	1	1*	0	0

*denotes formal leader in frequency count

Table 5. Comparison of the presence of positive and negative deviants at end of winter.

Year	Positive		Negative	
	High Consensus ($c > .66$)	Moderate Consensus ($.33 < c < .67$)	High Consensus ($c > .66$)	Moderate Consensus ($.33 < c < .67$)
A	2	4	0	1
B	3	0	0	0
C	0	1	1	1

*denotes formal leader in frequency count

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Figure 13. Graph of October (final) structure from stacked correspondence analysis showing the position of the manager in Year B.

Figure 14. Graph of October (final) structure from stacked correspondence analysis showing the position of the manager in Year C.

Figure 1

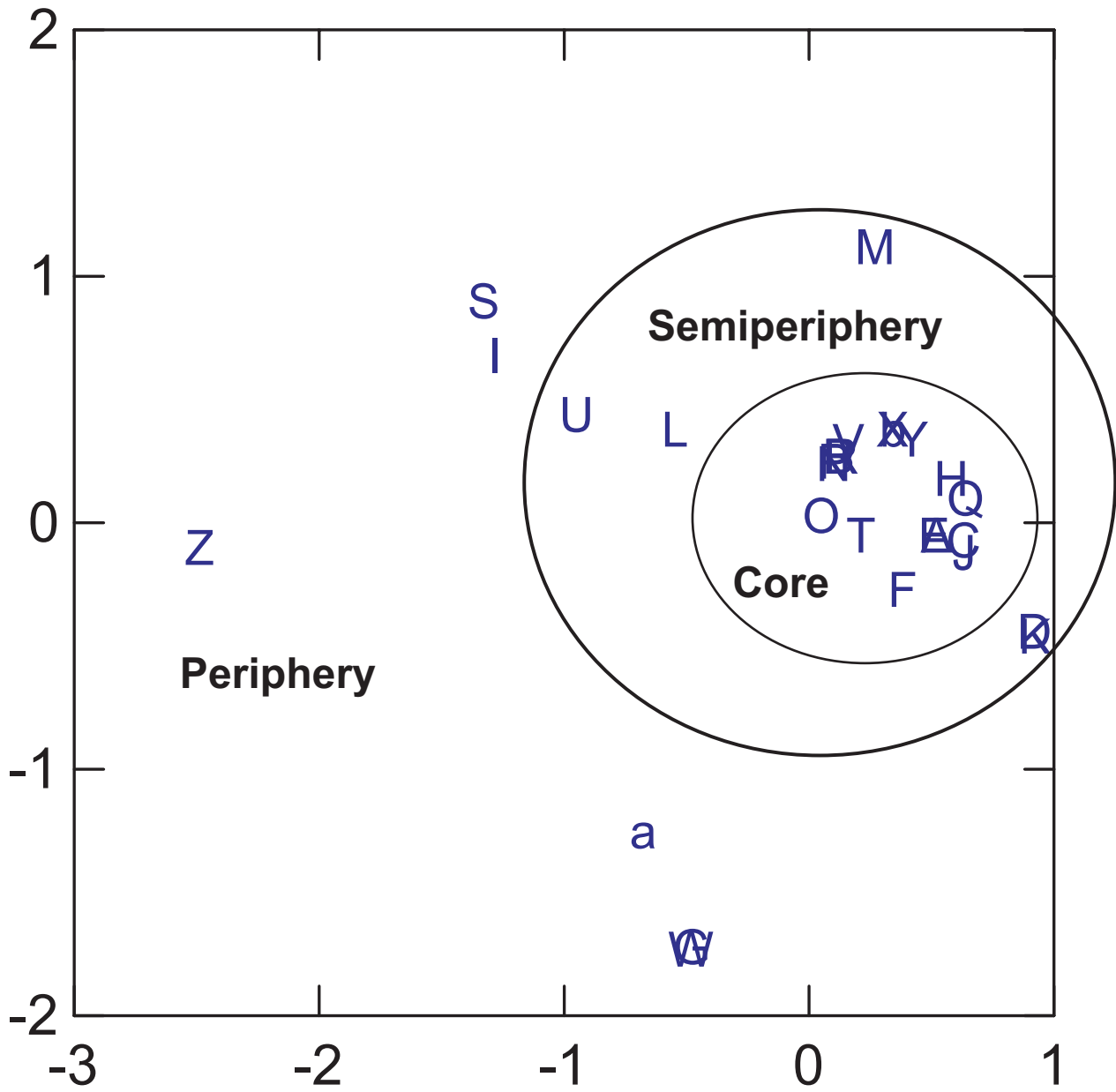


Figure 2

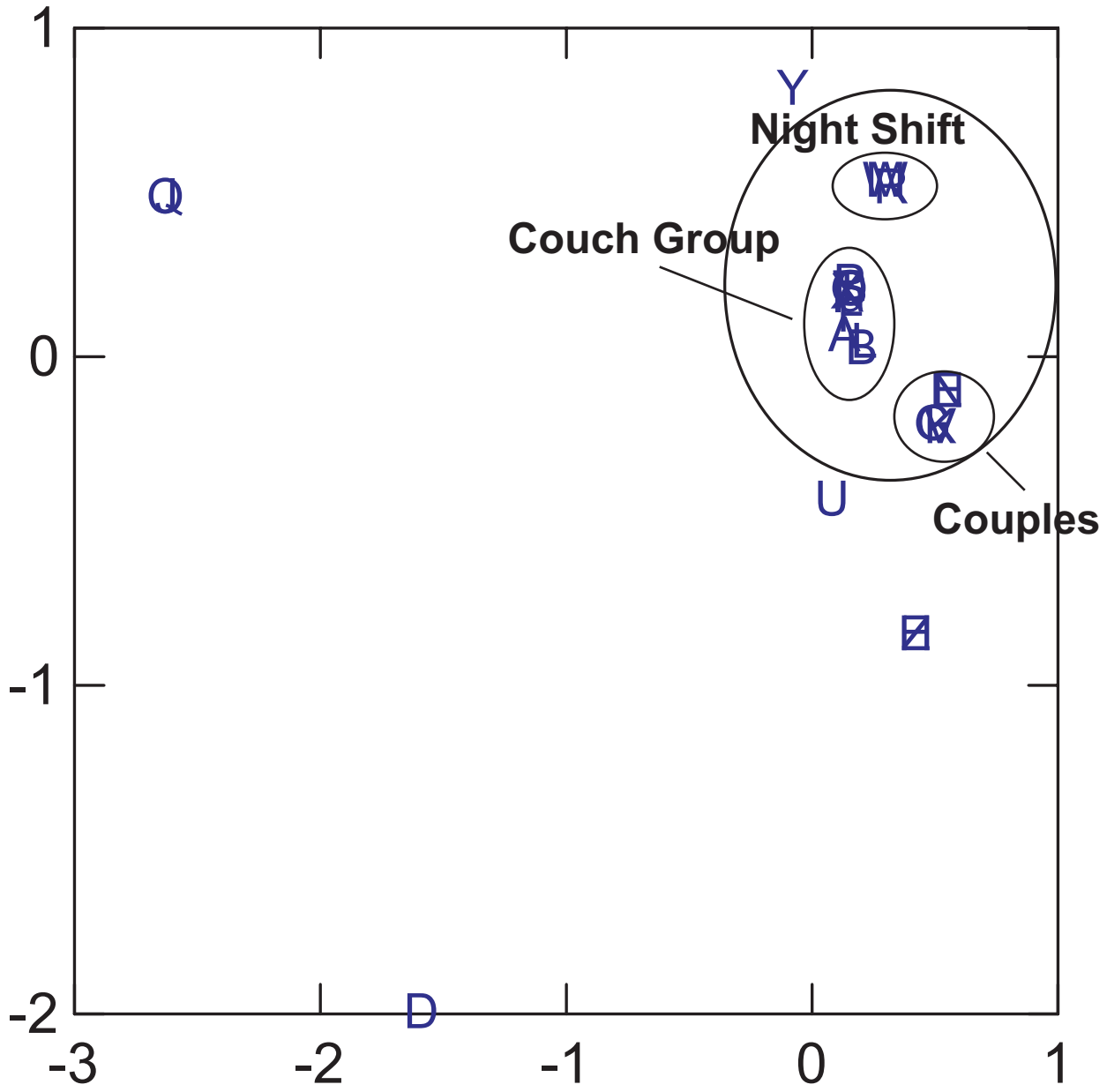


Figure 3

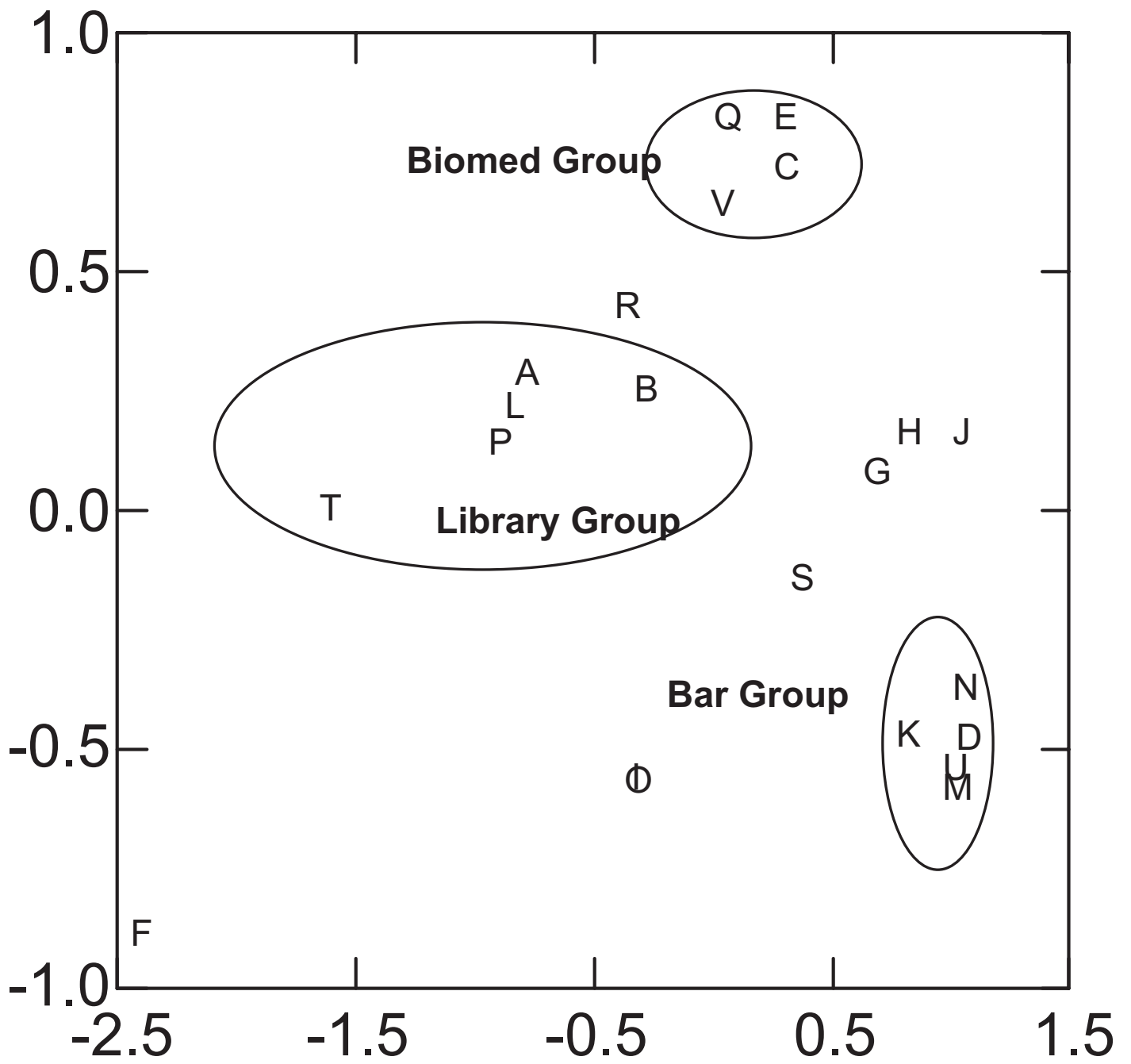


Figure 4

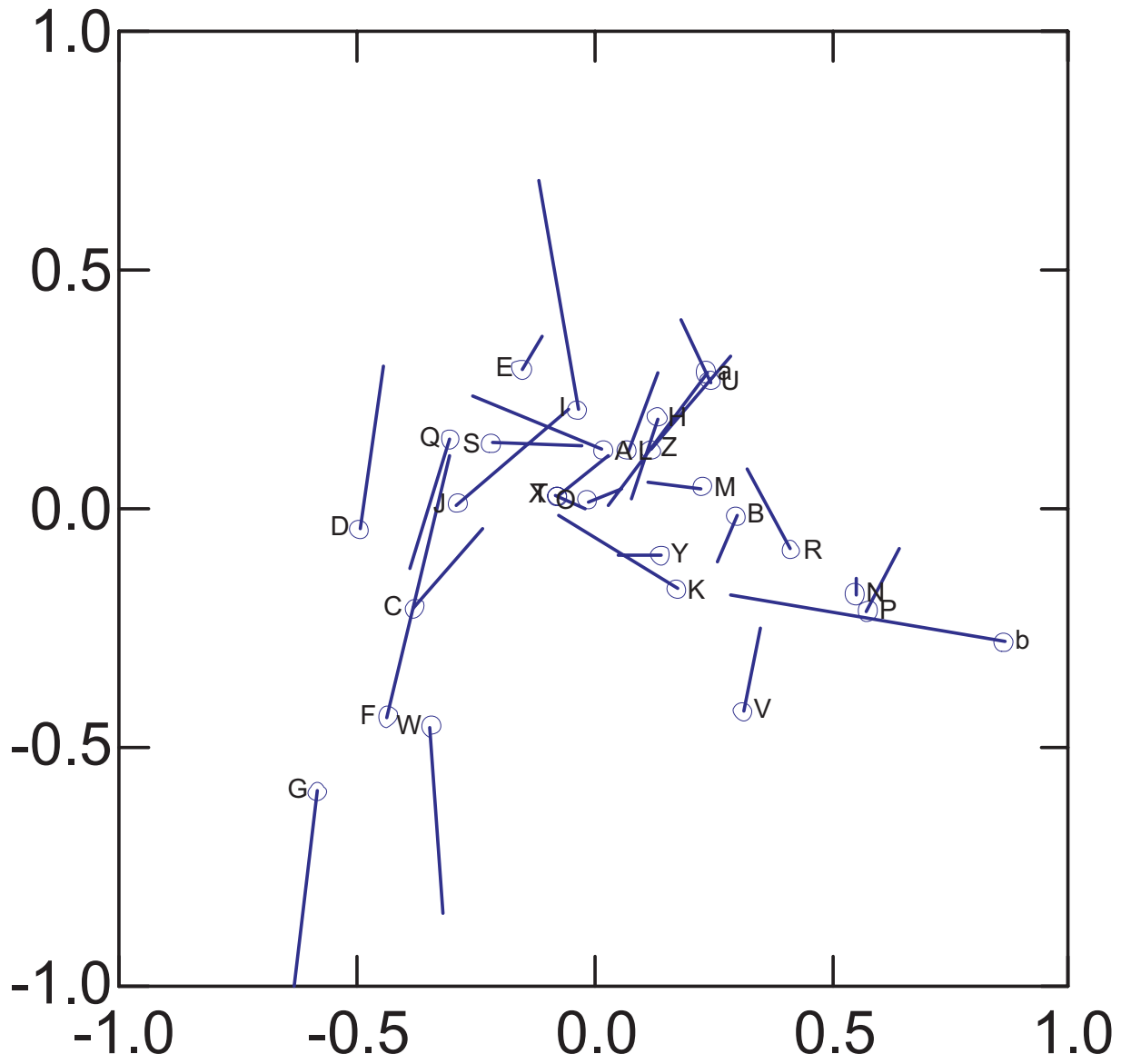


Figure 5

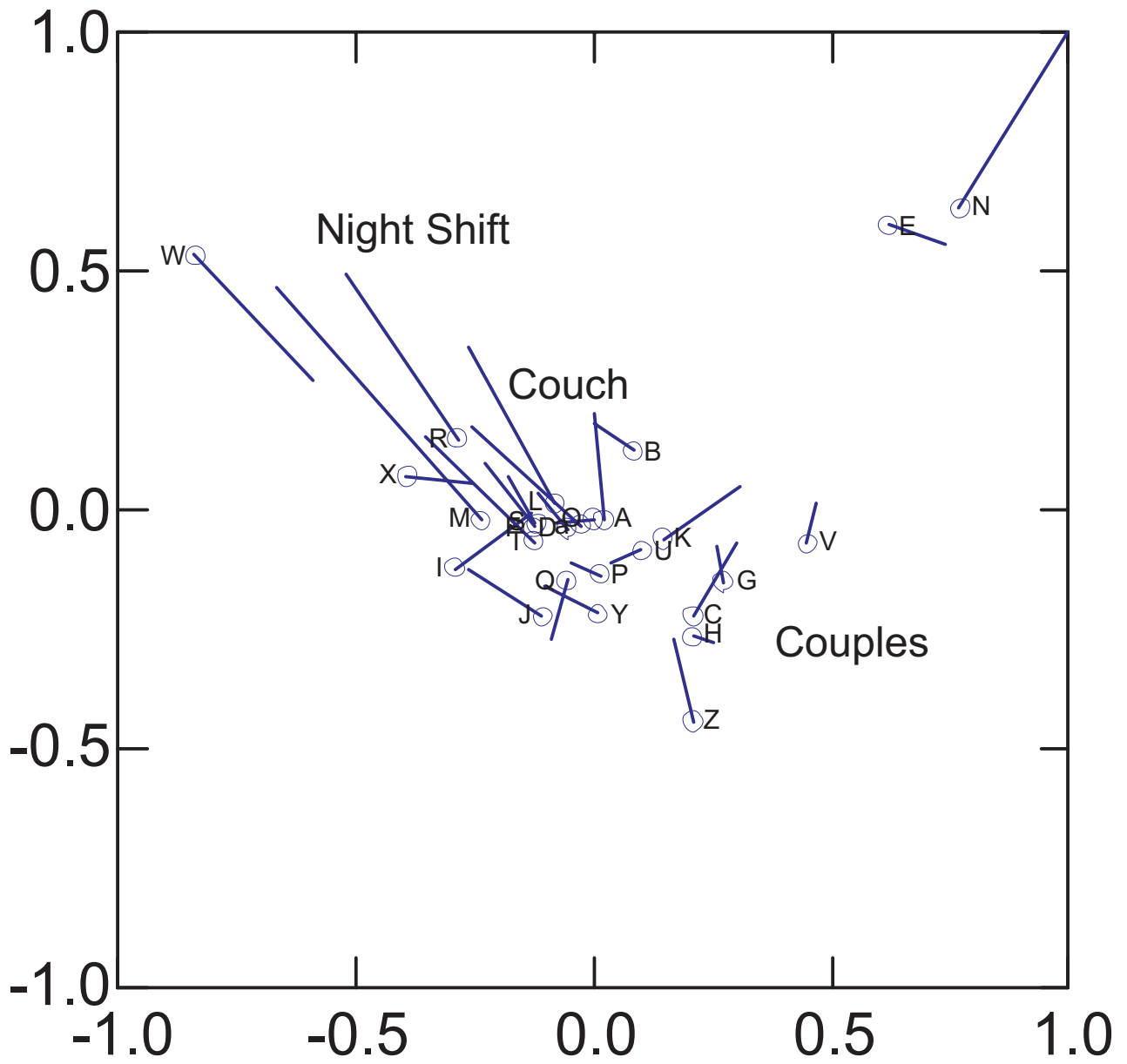


Figure 6

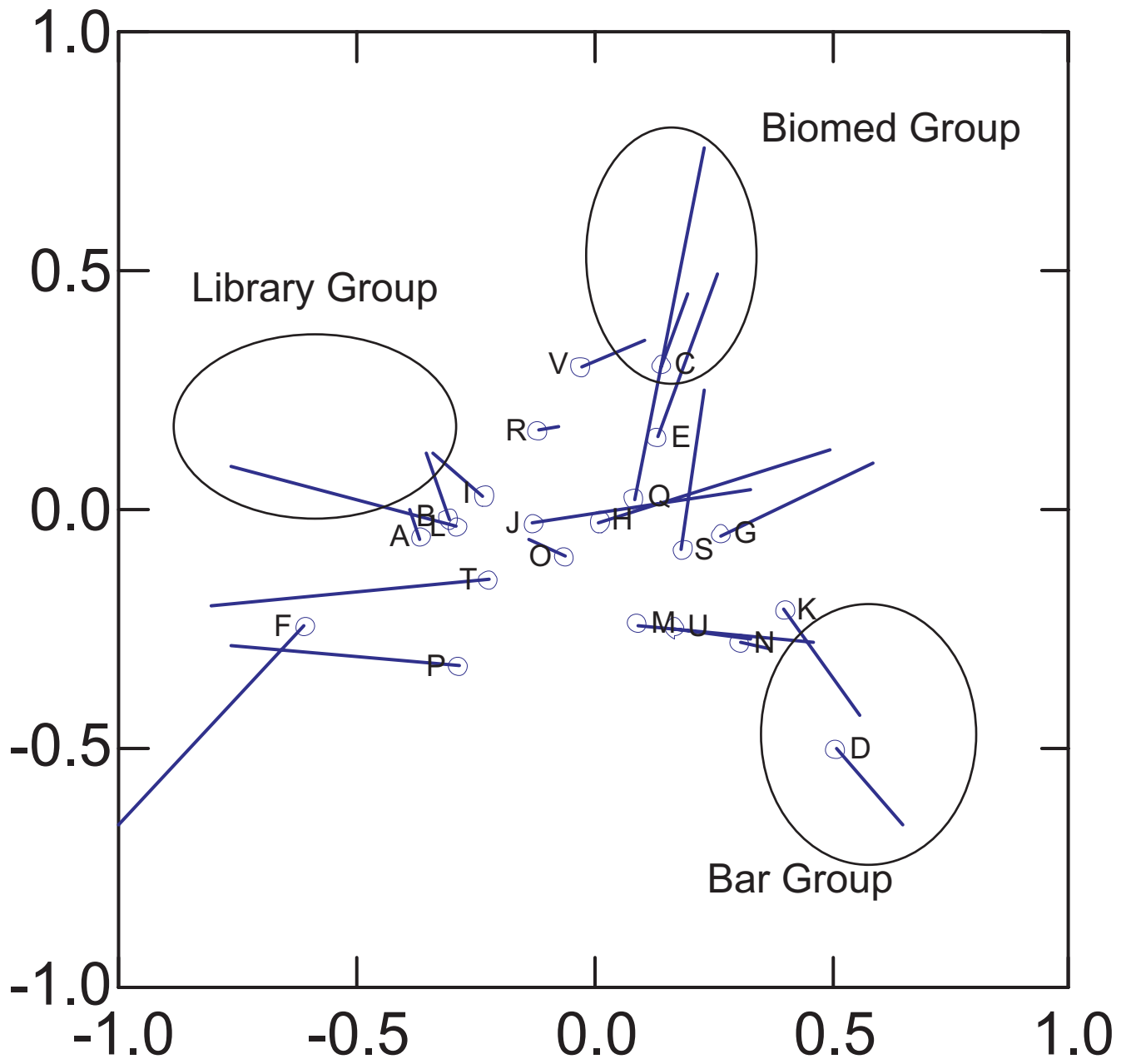


Figure 7

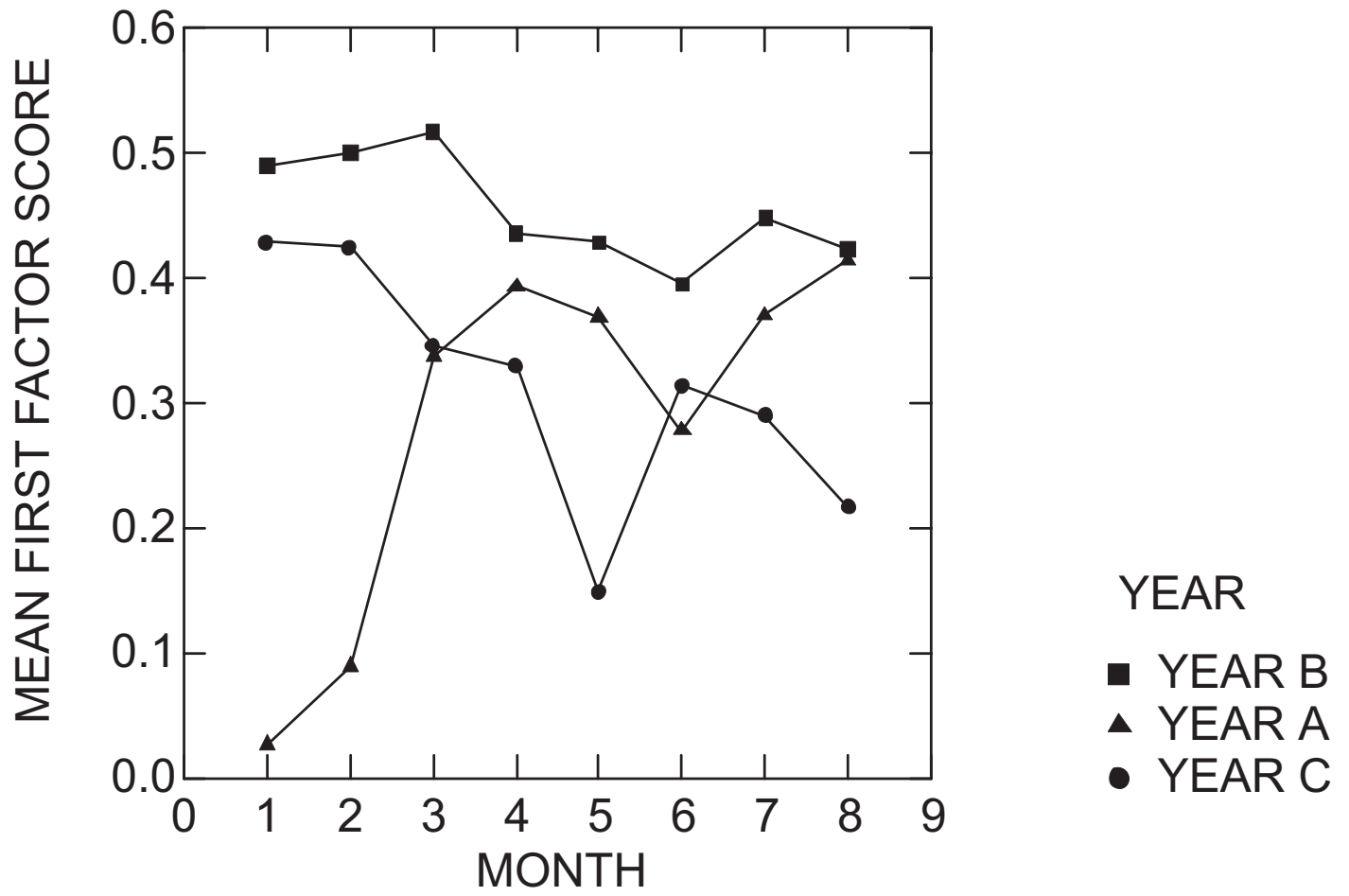


Figure 8

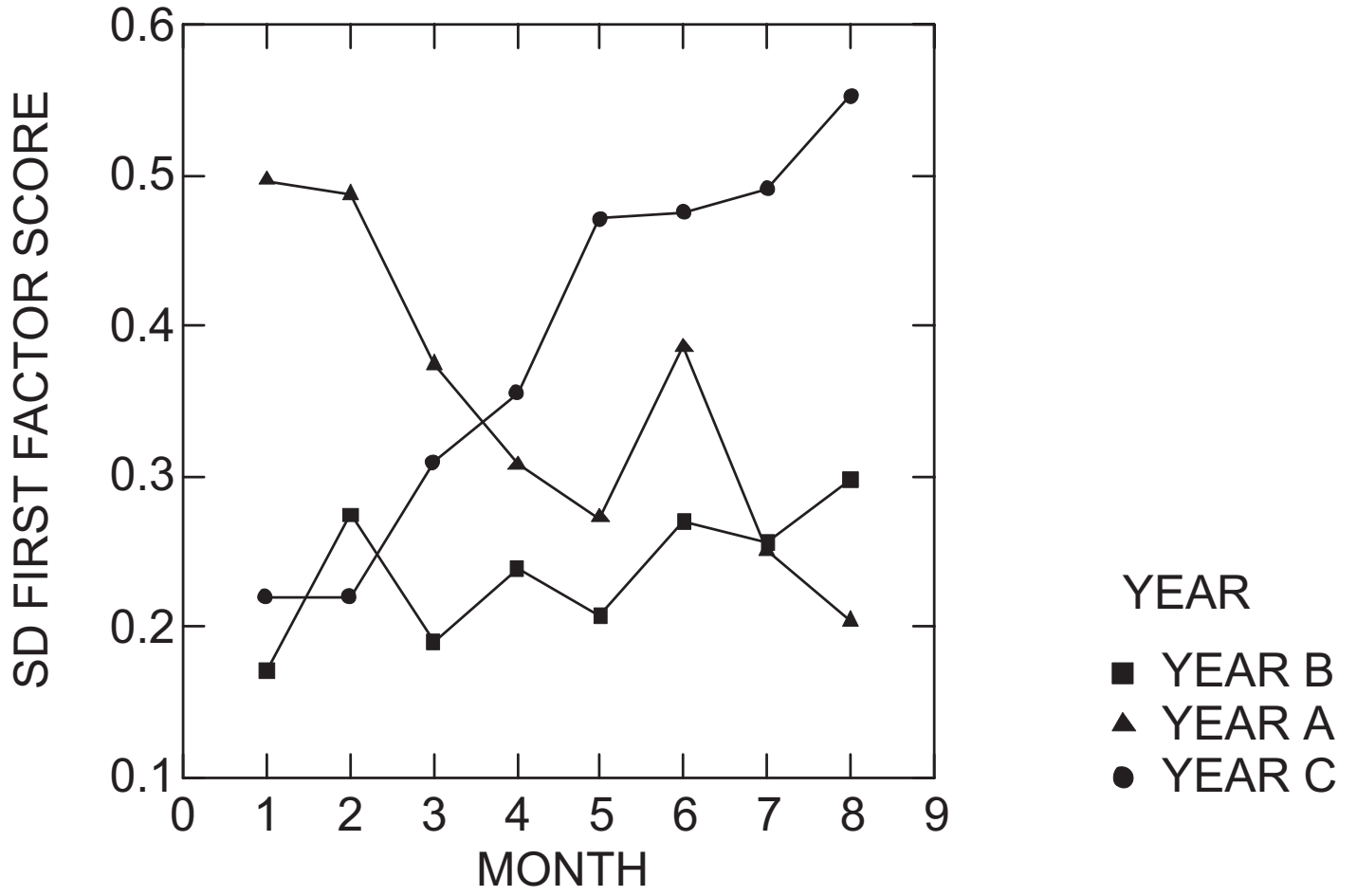


Figure 9

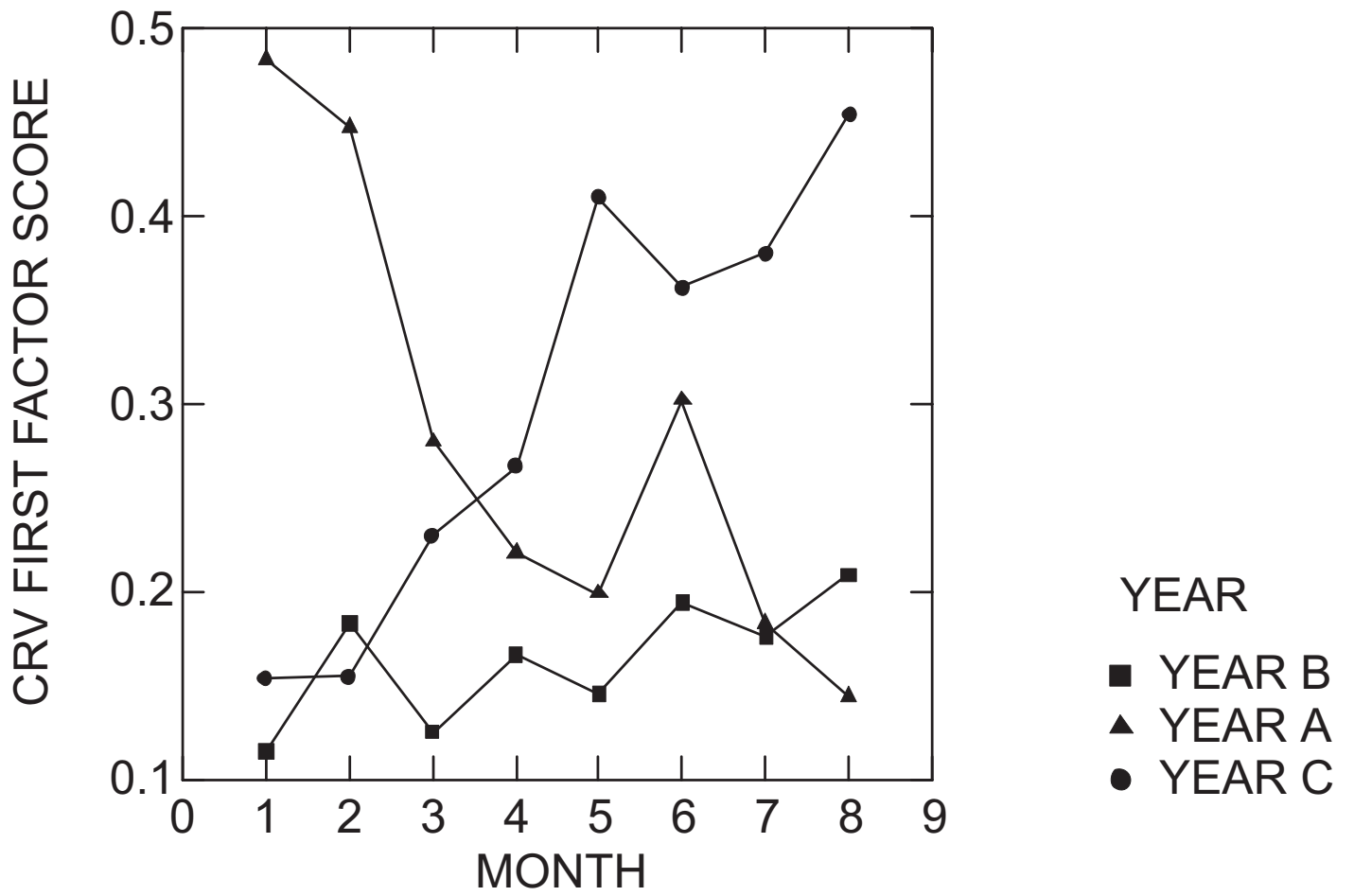


Figure 10

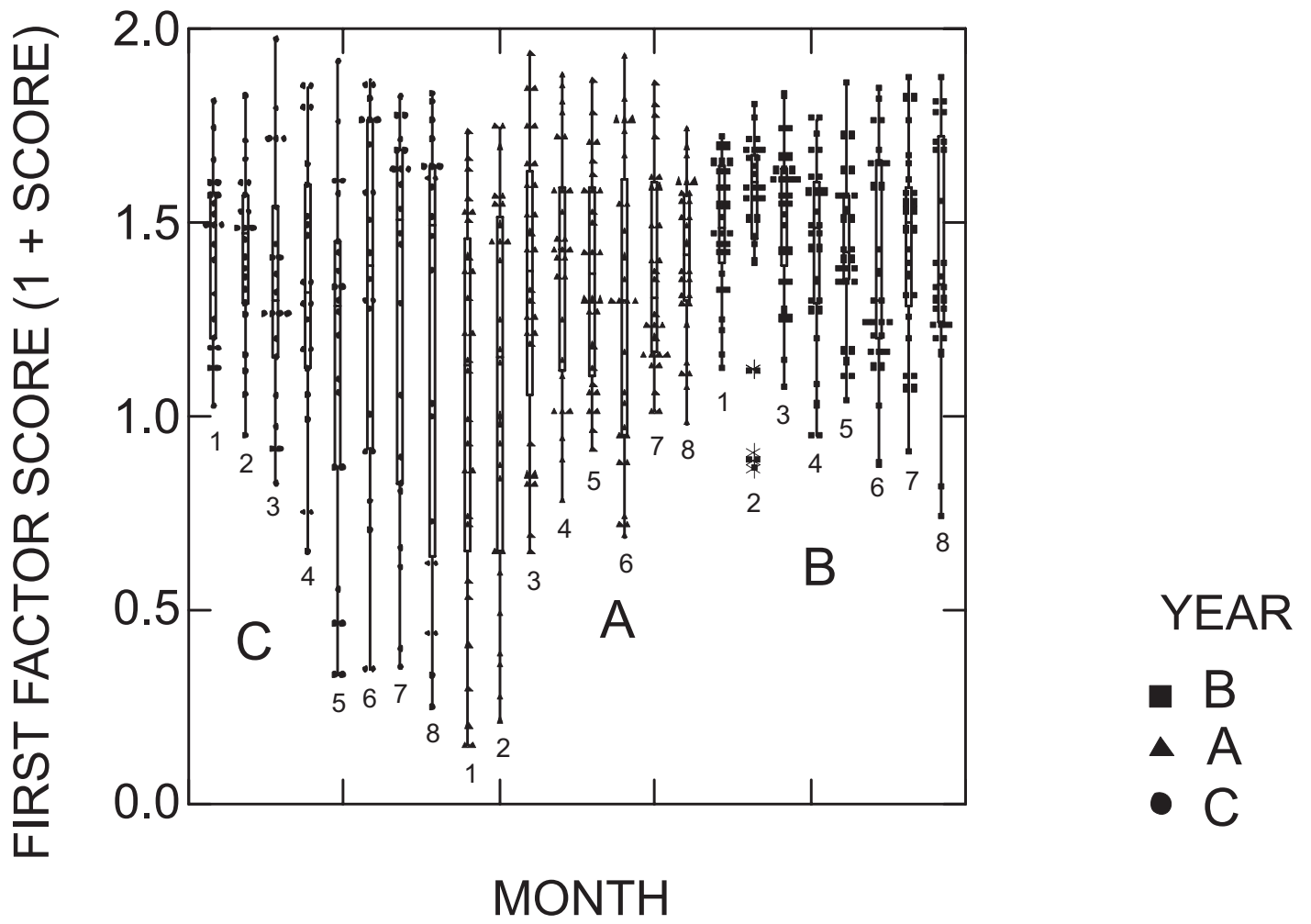
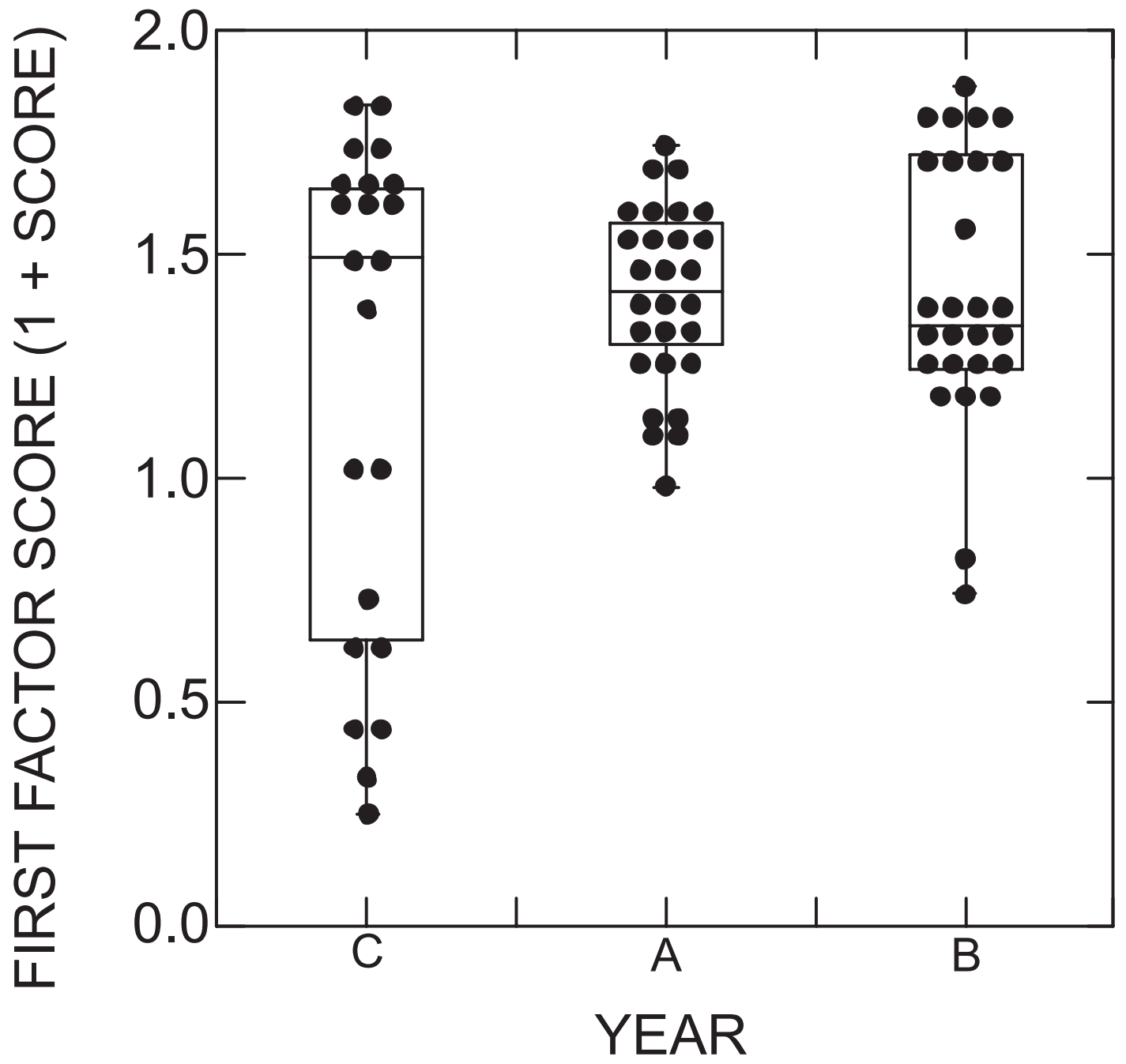


Figure 11



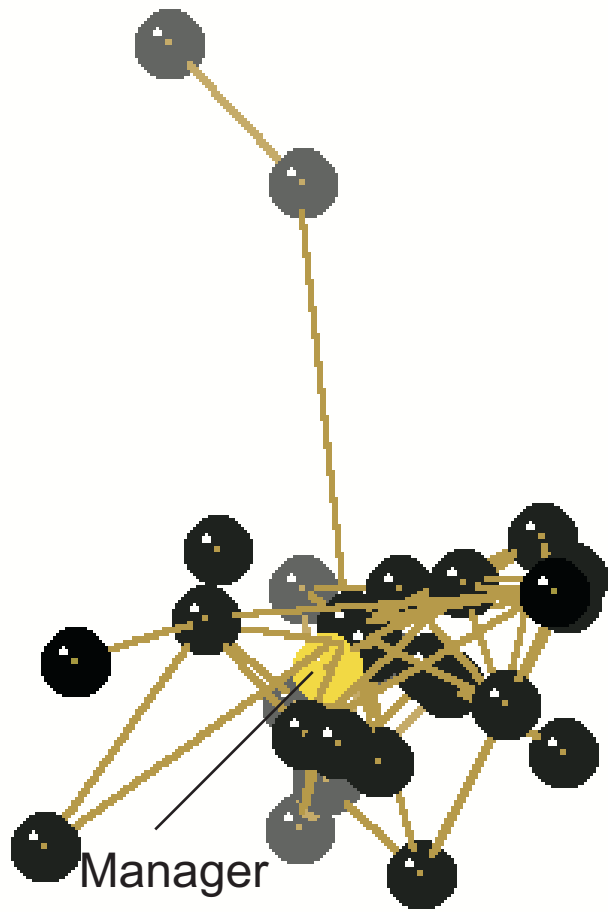


Figure 12

Figure 13

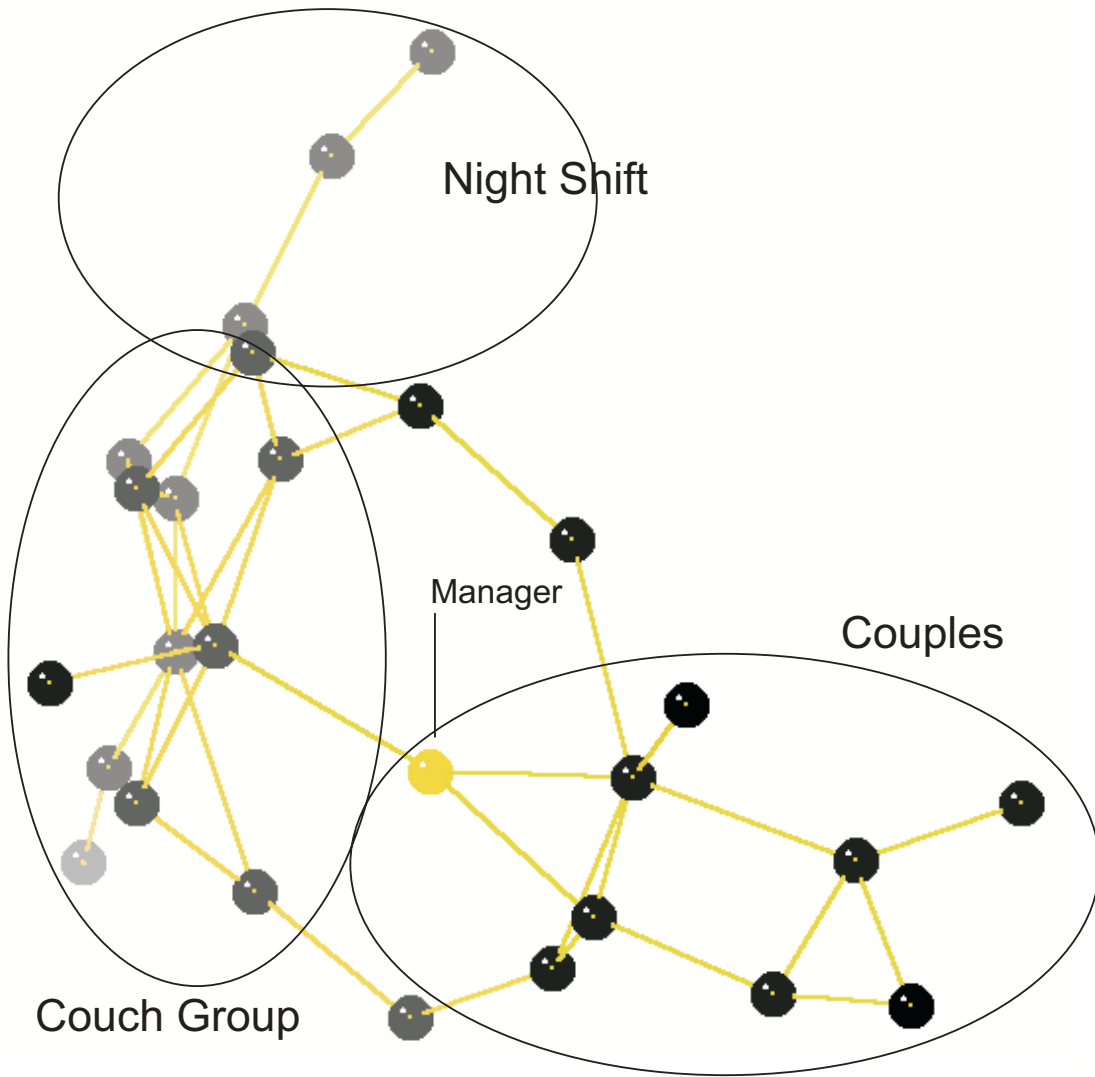


Figure 14

