

Carnegie Mellon University

**THE INFLUENCE OF COMMUNICATION NETWORKS AND TURNOVER ON
TRANSACTIVE MEMORY SYSTEMS AND TEAM PERFORMANCE**

Jonathan Kush

A dissertation submitted in partial fulfillment of the requirements for the degree of
Doctor of Philosophy to the Tepper School of Business at Carnegie Mellon
University

April 5, 2016

Committee:

Linda Argote, Tepper School of Business, Carnegie Mellon University

Brandy Aven, Tepper School of Business, Carnegie Mellon University

Jim Herbsleb, School of Computer Science, Carnegie Mellon University

Anita Woolley, Tepper School of Business, Carnegie Mellon University

Table of Contents

CHAPTER 1: The Influence of Communication Networks and Turnover on TMS and Team Performance	4
CHAPTER 2 (Paper 1): The Moderation of Role Change and Turnover on the Effect of Transactive Memory Systems on Group Performance	16
Methods.....	26
Results.....	32
Discussion	36
CHAPTER 3 (Study 2): The Effects of Communication Network and Membership Stability on Transactive Memory Systems and Group Performance: An Experimental Investigation	39
Methods.....	52
Results.....	58
Discussion and Conclusion	68
CHAPTER 4 (Study 3): Ties that bind and ties that tear: The influence of network centralization and density on shared social identity and group performance	75
Methods.....	86
Results.....	93
Discussion	106
CHAPTER 5: General Discussion	114
References	121
CHAPTER 2 - TABLES	137
CHAPTER 2 – FIGURES.....	139
CHAPTER 3 - TABLES	141
CHAPTER 3 – FIGURES.....	143
CHAPTER 4 – TABLES	147
CHAPTER 4 – FIGURES.....	151

The Influence of Communication Networks and Turnover on Transactive Memory Systems and Team Performance

Jonathan Kush

Abstract

In this dissertation, I investigate predictors and consequences of transactive memory system (TMS) development. A transactive memory system is a shared system for encoding, storing, and recalling who knows what within a group. Groups with well-developed transactive memory systems typically perform better than groups lacking such memory systems. I study how communication enhances the development of TMS and how turnover disrupts both TMS and its relationship to group performance. More specifically, I examine how communication networks affect the amount of communication, how the structure of the communication network affects the extent to which the group members share a strong identity as a group, and how both of these factors affect a group's TMS. I also analyze how turnover disrupts the relationship between transactive memory systems and group performance. In addition, I examine how the communication network and turnover interact to affect group performance. I analyze these effects in three laboratory studies. The controlled setting of the experimental laboratory permits me to make causal inferences about the relationship of turnover and the communication network to group outcomes. Results promise to advance theory about transactive memory systems and communication networks.

Keywords: Transactive memory systems, shared social identity, communication networks, communication centrality, groups, group performance, turnover

CHAPTER 1: The Influence of Communication Networks and Turnover on TMS and Team Performance

Introduction

Groups are vital to organizations as they are often the primary unit to which tasks are assigned and as they frequently do the most important tasks within the firm. Groups have access to more expertise and more varied expertise than individuals do (Bunderson, 2003). As group members interact with one another, they begin to develop an understanding of who knows what within the group, also called a transactive memory system (Wegner, 1987), which helps groups perform efficiently (Liang, Moreland, & Argote, 1995). The development of a transactive memory system (TMS) has been found to be related to the amount of communication within the group, because communication allows for information about expertise to transfer within the group (Hollingshead & Brandon, 2003). Prior work has also found that the level of shared social identity within the group—the extent to which members feel like they are a group—also increases a group’s development of TMS (Liao, Jimmieson, O’Brien, & Restubog, 2012).

In this dissertation, I theorize that the structure and qualities of the group’s communication network affect the amount of communication that occurs within the group, the extent to which members share a social identity and the extent to which they develop a TMS. The two dimensions of communication network structure I focus on are density and centralization, which are commonly used to define the structure of a group’s network (Katz, Lazer, Arrow, & Contractor, 2004). This work adds to the literature on both social networks and transactive memory systems and helps us understand which aspects of communication most influence transactive memory development and team performance.

The distributed nature of expertise across group members can make their performance susceptible to damage from external phenomena such as employee turnover. Turnover is common within small groups, but less work has been done on its influence on group performance, compared to the research on its antecedents. In this dissertation, I propose that turnover reduces a group's ability to use its TMS to improve performance. I anticipate that turnover will also be more damaging to the performance of decentralized groups compared to that of centralized groups, because centralized groups operate on principles that make them more resilient to membership change. This dissertation expands the research related to the development of transactive memory systems and increases our understanding of the relationships of communication networks and turnover to TMS and group performance through three laboratory studies.

Transactive Memory Systems

A transactive memory system is a shared system for encoding, storing, and retrieving information about others (Wegner, 1987). Transactive memory systems were first envisioned as a way of explaining how cognitive labor can be distributed between individuals in close relationships so that individuals share responsibility for remembering the collective knowledge they need. Researchers extended this concept to the group level and found that transactive memory systems help groups perform better and be more creative than groups that do not have transactive memory systems (Liang, Moreland, & Argote, 1995; Gino, Argote, Miron-Spektor, & Todorova, 2010). These systems improve group performance by allowing group members to coordinate their work and combine their expertise more efficiently than groups that do not have a TMS (see Ren & Argote, 2011 for a review). Transactive memory systems are more impactful

on group performance than other forms of cognitive interdependence such as shared mental models (DeChurch & Mesmer-Magnus, 2010).

Research has identified several predictors of TMS. Experience working or training together has been found to lead to the development of TMS within groups of strangers in the laboratory (Liang, Moreland, & Argote, 1995). Communication also fosters the development of TMS through the exchange of information that is then encoded in the group's transactive memory system (Brandon & Hollingshead, 2004). After the information is encoded in the group's transactive memory, it can later be retrieved when a group member needs to assign new work or has a question. Groups can also develop an effective TMS if they are provided information about other members' knowledge and skills directly (Moreland & Myaskovsky, 2000). The use of a developed transactive memory system is typified by group members becoming better able to coordinate their work, develop specializations, and see each other as credible sources of information (Liang et al., 1995).

Shared Social Identity

Social identity theory has become a fundamental theory in social psychology and organizational behavior (Hogg, 2006). Social identity theory proposes that individuals categorize themselves and others based on actual and perceived characteristics (Tajfel & Turner, 1985; Turner, 1982). If individuals share a characteristic—for instance, both are European—then we assume the individuals are similar to one another and potentially different from us, if we do not share that characteristic. Shared social identity is the extent to which individuals feel they are part of the category, or group, that they identify themselves as being a member of (Doosje, Ellemers, & Spears, 1995; Ashforth & Mael, 1989). If members have shared social identity, they are more likely to be satisfied in their groups and also to engage in more information exchange

(Kane, Argote, & Levine, 2005). More recent research has proposed that groups that have a shared social identity may be more willing to rely on their peers when engaged in interdependent tasks and, thus, be more likely to develop strong transactive memory systems (Liao, Jimmieson, O'Brien, & Restubog, 2012). In chapter 4 of this dissertation, I add to the growing body of work relating shared social identity to TMS.

Communication Network Structure

Communication networks are the relationships that define who can or does speak with whom within a group. The pattern and number of these connections are defined by two structural characteristics of networks: centralization and density. Centralization means that ties between individuals are uneven, such that one member is more connected than others (Freeman, 1979). Density is the number of connections that exist divided by the number of connections that could exist. Density affects the group's ability to communicate, such that groups with more dense networks will communicate more than those with sparse networks (Hansen, 1999). These two network dimensions are informative about the entirety of the structure within a group as opposed to the individuals' positions within the network. Both dimensions influence the extent to which group members are more similar or different in their connections to one another. By definition, centralization increases differences between members within a group. Density often decreases differences by providing more closure (Coleman, 1988), but its effect depends on the underlying centralization of the network.

In Chapter 3, I use a strong manipulation of centralization—that also affects the network's density—to determine how the effect of centralization on a group's communication and TMS changes based on whether the group experiences turnover. Though communication is typically seen as positively related to TMS (Hollingshead & Brandon, 2003), little research has

focused on the effect of the structure of communication on transactive memory system development. Chapter 4 in this study provides a closer examination of the interactive relationship between network centralization and density on group members' recognition of differences within their group.

Turnover

Turnover, used in chapters 2 and 3 of this dissertation, refers to the loss and replacement of a member within a group. Turnover has been studied in the TMS literature since nearly the beginning of its study in groups. Moreland, Argote, and Krishnan (1996) demonstrated that the performance benefits of a TMS do not travel with individuals when they switch groups. Partial turnover within groups, where some members leave the group and others stay, seems to harm group performance more than complete turnover in which the membership of a group is totally scrambled (Lewis, Belliveau, Herndon, & Keller, 2007). This suggests that though a TMS gives some benefits to the group, when a group's TMS is damaged but not completely disabled, the group may perform worse than it would with no TMS at all. In chapter 2, this dissertation extends this research by examining whether the extent to which the group developed a transactive memory system previously, and the steps that groups make to accommodate for new members, lead to different effects of member turnover on a group's TMS or performance. In chapter 3, turnover is used to investigate whether the centralization of a network has different effects on how much groups communicate based on their network structure. We propose that turnover may actually increase the communication—and, thus, the TMS and performance—of centralized groups because their structure and organizing principles facilitate the integration of new members. Research on the four aspects of the dissertation—TMS, shared social identity, communication networks, and turnover—has implications for team design and maintenance.

Overview of the Dissertation

This dissertation consists of three studies, each intended to act as a stand-alone, independent paper. Each addresses a separate set of hypotheses and each chapter contains a separate theoretical background, methods, and results. A summary of each paper is below.

Paper 1

In the first study, I examined the influence of transactive memory systems on how groups are affected by turnover. One way in which groups benefit from developing a transactive memory system is that it allows members of the group to become more specialized in an aspect of their work (Liang et al., 1995). This increased specialization leads groups to become more interdependent, which in turn leads to increased performance. Increased interdependence could, however, come at the cost of groups being more susceptible to changes in the task or in their group's membership.

Lewis et al. (2007) found that when groups lost a member, but the majority of the group remained intact, the group performed worse than if all members had worked together before or if all members were new. The researchers suggested that this was because the group's existing TMS prevented them from integrating the new member into their group. Instead, groups that experienced turnover assumed that the new member would play the same role as the previous member and maintained the same distribution of work within the group as before turnover. These studies demonstrated two scenarios where a group's transactive memory system was either not helpful (Moreland, Argote, & Krishnan, 1996) or damaged the group's ability to perform (Lewis et al., 2007).

The past work has not investigated if the degree of influence that turnover has on TMS's effect on performance varies based on the strength of the groups' TMS before turnover. I expect

that groups that have a strong TMS are more interdependent and, thus, would be more hurt by membership change than groups with a weaker TMS. Groups with lower levels of TMS would not be as adversely affected by membership change as those with stronger TMS.

Embedded in the concept of expertise and specialization is that of roles. Roles are the set of functions that an individual is responsible for within the group (Katz & Kahn, 1966). If the members who play specific roles within the group continue playing those roles for a period of time, they become more specialized. Due to poor fit with a role or due to other reasons, a group may engage in role change, whereby the members of the group change the parts of the task for which they are responsible. If a group has a TMS, it is more likely to be able to make appropriate role change decisions, because the group members have a better understanding of who would do a good job in which role compared to groups with a weak TMS. Additionally, if the group has experienced turnover, there is greater possibility for the group to make an efficient set of changes in who will be playing which role. I proposed, therefore, that role change behavior would moderate turnover's effect on TMS.

To test these hypotheses, I conducted a laboratory experiment with sixty-eight groups of three members who performed a circuit construction task. I manipulated the group's TMS through training and also manipulated whether turnover occurred. This training manipulation has been effectively used to create weak and strong TMS in the past (Liang et al., 1995). The circuit task is similar to those used in past TMS research (Liang et al., 1995) and is a complex environment where expertise is needed to effectively solve problems.

I investigated whether turnover and role change would influence a group's ability to use its TMS. I replicated prior work showing that TMS mediated the effect of group training on errors. Surprisingly, turnover did not affect TMS or moderate the relationship of TMS to

performance as predicted. Role change, however, moderated turnover's effect on TMS such that engaging in role change improved performance for groups with low TMS that had experienced turnover but not for other groups. Groups that had developed a strong TMS were less affected by turnover than those with a weaker TMS, the opposite direction than I had predicted. Groups with a weaker TMS were negatively affected by turnover unless they engaged in role change. If groups with weak TMS engaged in role change, they performed better compared to other weak TMS groups or groups that engaged in role change but had not experienced turnover. This effect suggests that groups that operate in conditions of high turnover may be able to overcome that disadvantage by engaging in role change behavior.

Paper 2

This paper (coauthored with Linda Argote and Brandy Aven) analyzed the relationship between communication networks and member turnover on amount of communication, transactive memory systems, and performance. The predominant structural feature in a group's communication network is the level of centralization—the extent to which there is variance in the number of connections or number of bridging connections the individuals in a group have. Groups that are highly centralized can exchange information more efficiently than groups with decentralized networks, but members in the center can become overloaded if the task is complex (Shaw, 1964). Decentralized networks have more communications, because the average member will have more communication pathways, which increases their likelihood of using them (Hansen, 1999). When turnover occurs, however, centralized groups may have an advantage because they have implicit organizing principles that help dictate the roles that each member within the group should play (Guetzkow & Simon, 1955). These principles may help the group easily incorporate a new member into the group after turnover.

We hypothesized, therefore, that centralized network structure and turnover would interact in predicting performance. We proposed that centralized groups would benefit from new members joining the group, whereas decentralized groups would be hurt by turnover because the new member would not be deeply integrated. We anticipated that the interactive effect of network centralization and turnover on performance would be driven in part due to groups varying in how much they communicated after turnover. We predicted that centralized groups would communicate more after turnover, whereas decentralized groups would communicate less. Building on prior literature, we predicted that this communication would help groups develop a transactive memory system. Thus, the effect of the interaction between centralization and turnover on group performance could be explained due to the mediating effects of communication and TMS.

In order to test these hypotheses, we used a laboratory experiment with one hundred and nine groups of four individuals who performed a computer programming type task and a creative task. Groups communicated with one another through an instant text messenger, using one of two communication networks, centralized or decentralized; see Chapter 3's Figure 3. In half of the groups, a randomly chosen member left the group halfway through the experiment. In centralized groups, this member was the central member half the time and another member the other half of the time. We found few differences based on which member centralized groups lost.

We found that centralized networks communicated more per available path than decentralized groups, and this difference increased after turnover. More communication led to stronger transactive memory systems, which led to better performance. For groups that did not experience turnover, being centralized had a direct negative effect on group TMS, even though

centralized groups communicated more, because the direct effect was much larger in magnitude than the positive effect through their increased communication. Thus, centralized groups performed worse than decentralized groups when turnover did not occur. These results reversed, however, for groups that experienced turnover; centralized groups performed better than decentralized groups when turnover occurred. This was primarily due to the relationship between centralization and communication per path increasing dramatically for groups that experienced turnover. This led to centralization having an overall positive effect on performance when groups experienced turnover. These results suggest that the effectiveness of communication networks depends on whether the groups experience turnover.

Paper 3

This study investigated the relationship between communication networks, shared social identity, transactive memory systems, and performance within groups. Though there are many measures that define communication networks, two fundamental dimensions are centralization and density. Centralization in the communication network is the extent to which there is variance in individuals' connections to one another. Network density is the number of connections that exist divided by the number that are possible. In this paper, I argue that centralization and density interact with one another in affecting the extent to which group members feel like members of the group, a concept called shared social identity.

Shared social identity increases within groups as members recognize similarities between group members (Tajfel & Turner, 1985). Absent other information, individuals use characteristics of their communication network in order to make some of these judgments. If members all share the same relative connections, therefore, members will all feel similarly connected to their network. In this type of network, group members will have more shared social

identity than in networks where some members have more or fewer connections than others. I formally define these differences as role equivalent classes, the number of categories of members who have the same relative connections (Hanneman & Riddle, 2005). As this number increases, the group members will feel less like a group and, thus, have higher shared social identity. In this paper, I argue that centralization and density interact in affecting shared social identity because increasing the number of ties increases the number of role equivalent classes for centralized groups but decreases the number of classes for decentralized groups. Based on prior theory, I hypothesized that shared social identity would increase TMS (Liao et al., 2012). Finally, I propose that shared social identity and TMS will mediate the effects of centralization, density, and their interaction on group performance.

In order to test these hypotheses, I used an experiment in which the centralization and density of the network were kept roughly orthogonal to one another. In order to accomplish this, four networks of four members each were created by connecting individuals with an instant messenger. The four networks are available in Chapter 4's Figure 7. I used a 2x2 factorial design, manipulating centralization (high vs. low centralization) and density (3 versus 4 ties). I determined that there was an interactive effect of centralization and density on shared social identity such that, for dense groups, centralized groups felt much less like a group than dense, decentralized groups or sparse, centralized groups. This finding was in line with my hypotheses. Next, I found that groups with high shared social identity developed stronger transactive memory systems, and transactive memory systems improved group performance. Mediation analyses demonstrated that the effect of network centralization on group performance was due to the mediating effects of shared social identity on TMS and these effects were moderated by network

density. To complete the hypotheses tests, I found evidence that the network structure's effect on performance was due, in large part, to these group psychological processes.

In an additional set of analyses, I demonstrated that a direct measure of TMS works similarly to the more common indirect measure of group TMS in predicting performance. These analyses provide support that the indirect measure of TMS is getting at the underlying transactive memory system in the group, but also suggest that the direct measure has additional utility. Lastly, analyses on simulated data provide support for the argument that the interactive relationship between centralization and density on group shared social identity is likely to persist in groups that have more members and over larger range of density and centralization values used in this experiment.

This paper contributes to the literature by investigating the relationship between network phenomena and group phenomena, an area for which there is a growing interest (Casciaro, Barsade, Edmondson, Gibson, Krackhardt, & Labianca, 2015). Centralization and density were demonstrated to have differing and interactive effects on group processes. Thus study also suggests that shared social identity appears to be strongly related to group communication network structure. Future work investigating this relationship could be helpful in further connecting research on networks and group phenomena. Additionally, the demonstration that two very different measures of TMS appear to have the same predictive ability was also novel and a demonstration of the robustness of these measures.

CHAPTER 2 (Paper 1): The Moderation of Role Change and Turnover on the Effect of Transactive Memory Systems on Group Performance

Abstract

Though transactive memory systems (TMS) help improve group performance by increasing the ability of groups to coordinate and specialize, little work has investigated under what conditions TMS is more or less helpful for a group. Past work has explored ways that TMS can be disabled, such as through member turnover, but both turnover and role change after turnover could alter a group's ability or willingness to use its TMS to improve future performance. Sixty-eight groups of three individuals produced an electrical circuit in an experiment where both the group's TMS and turnover were manipulated independently. Group TMS reduced errors in producing the circuit and acted as an overall mediator of group training's influence on performance, replicating prior work. Even though turnover was not directly related to performance or TMS, turnover moderated TMS's effect on performance when member role change was taken into account. Role change increased the strength of the relationship between TMS and performance in groups that did not experience turnover. In groups that experienced turnover, role change reduced errors and reduced the strength of the relationship between TMS and performance. This study suggests new directions for research and proposes solutions for some inconsistent findings in past literature.

Keywords: transactive memory systems, turnover, groups, role change

The Moderation of Role Change and Turnover on the Effect of Transactive Memory Systems on Group Performance

A transactive memory system within a group (TMS)—i.e., individuals have a shared understanding of who knows what—helps explain why groups perform better over time, but is it as helpful for groups with unstable membership? Wegner (1987) proposed that the shared repository of information that makes up a TMS helps multiple individuals specialize the information they have, allowing for both broader understanding and depth of knowledge in the collective. However, transactive memory systems have typically been seen as fragile and easily damaged by changing membership of the group (Wegner, 1987; Moreland, Argote, & Krishnan, 1996). In the current paper, I argue that prior TMS and turnover affect how individuals approach future tasks, such that groups will not attempt to use their TMS to improve performance if they have previously experienced turnover. In order to clarify the relationship between TMS and turnover, this study manipulates a group's TMS first, and then whether or not the group experiences turnover. These two manipulations, novel in combination, allow for differentiation between the influence of turnover on groups that have low versus high levels of TMS before or after turnover.

This paper builds on prior work and proposes role change as a way to help explain the influence of turnover on a group's ability to use its TMS. Role change, the ways in which group members restructure their groups, can also affect a group's ability to use its TMS. I argue that although experiencing turnover makes a group less willing to use its TMS to improve performance, if group members engage in role change, they can more effectively leverage their TMS, even if they have experienced turnover. This paper hopes to help reconcile prior work relating TMS and turnover.

Turnover and TMS, respectively, influence the presence and use of human capital within a group (see Hancock, Allen, Bosco, McDaniel, & Pierce, 2013 for a meta-analysis on turnover). In the initial theoretical work on TMS, Wegner (1987) proposed that the loss of access to transactive memory is one reason that separations between spouses can be disorienting for both parties. In the same vein, research has typically found that membership change within work groups has a direct negative effect on a group's transactive memory.¹ Initial work proposed turnover as a mechanism through which TMSs were disabled (Moreland, Argote, & Krishnan, 1996) but later work investigated more nuanced possible effects of turnover on group TMS (Lewis et al., 2005; Lewis et al., 2007). In the current project, I take a different perspective and propose that turnover has a larger effect on a group's ability to use its developed TMS than on the strength of the group's TMS itself. This research serves to extend theoretical understanding of TMS and how groups use TMS to improve performance. I performed a laboratory experiment in which the group's transactive memory system and turnover were manipulated and the extent to which the group engaged in role change was measured.

Transactive memory systems

A transactive memory system (TMS) is the system by which a group of individuals know “who knows what” within the group (Wegner, Giuliano, & Hertel, 1985) through the encoding, storage, and retrieval of information about all group members' areas of expertise (Wegner, 1987). Though a group-level concept, a TMS is formed by individual perceptions held by the group members. Each individual within the group has information about other members' expertise. TMS helps group members better recognize who is best suited for a task or who to go to for advice, leading to better performance (Liang, Moreland, & Argote, 1995; see Ren &

¹ Due to differences among definitions, this paper defines turnover as the loss of one member from a group. Other kinds of membership change are noted as such when they are discussed.

Argote, 2011, for a review). After a TMS has developed, group members are able to specialize and to identify those from whom they can get assistance (Wegner, 1987). For example, imagine two employees at a printer repair firm, each of whom has a specialization, one in hardware and one in software. If the first employee has a question about software, she knows that she can go to the second employee for that information. Neither employee needs to remember details of the other's area of expertise as long as they each have access to their partner, leading to further specialization of the individuals and refinement of the TMS. Researchers have found that TMS is a good explanation of why a variety of groups perform better over time (Hollingshead, 1998; Moreland, 1999; Hollingshead, Brandon, Yoon, & Gupta, 2010).

In order for TMS to develop, group members must have access to information about their peers that allows the group to work closely on the task, divide the task according to expertise, and recognize which members can answer questions. Training group members together (Liang, Moreland, & Argote, 1995) or increasing the amount of communication between members (Hollingshead & Brandon, 2003) can increase both access to knowledge about group members and, consequently, their TMS. Experimental work has confirmed that the expertise information itself drives TMS development by giving participants information about each other's areas of expertise (Moreland & Myaskovsky, 2000). These groups performed just as well as those who trained together. In the laboratory and field, researchers have found that developed transactive memory systems improve performance through reducing errors, increasing quantity of production, and increasing group creativity (Liang et al., 1995; Lewis, 2003; Gino, Argote, Miron-Spektor, & Todorova, 2010). Thus, group training will serve as a manipulation of TMS in this study, and TMS will reduce errors.

The processes of encoding, storing, and retrieving information develop a sense of shared understanding of who knows what within a group by building up a shared mental map of who has what expertise within a group. This map constantly shifts as more information is encoded. This can occur when individuals learn new skills, when others learn that an individual has those new skills, or when it is revealed that an individual does not actually have some knowledge or skill. As this information is revealed to a group member, the encoding process updates the map of who has what expertise in the group's transactive memory system. If new members enter the group or leave, these processes must re-enact in order for accurate information to be included in the group's TMS (Hollingshead, Brandon, Yoon, & Gupta, 2010). The next section investigates the effects of member instability: on the developed TMS, on the processes that lead to TMS, and on the group's ability to use its TMS.

Turnover

Turnover disrupts members' routines (Goodman & Leyden, 1991) and reduces access to the knowledge that departing members may exclusively have (Argote, 2012). Yet, there are positive effects of turnover, typically revolving around newcomers bringing new task approaches or ideas into the group (Levine & Choi, 2004; Kane, Argote, & Levine, 2005; Glebbeck & Bax, 2004; Choi & Thompson, 2005). The theoretical foundation for TMS suggests that TMS is a unique combination of the knowledge that individuals have and the people who are interacting (Wegner, Giuliano, & Hertel, 1985). Thus, if the individuals within the group change, the TMS is utterly destroyed. The initial conceptualization of TMS, however, was developed with dyads in mind, where one member leaving destroys the TMS is necessarily true. As TMS developed into the group-level, however, this assumption persisted in some form (Liang et al., 1995; Moreland et al., 1996). If all group members have not interacted with one another, then the group has no

TMS to use, just individual knowledge and experiences. If portions of the group members have persisted in the group, however, then some form of TMS could still be present and useful to the group members. Thus, turnover should, by definition, negatively influence the group's TMS, but it does not destroy all of the group's TMS or necessarily prevent the group members from developing a new TMS, given time and experience. If we think of a TMS as a network of knowledge between members, then the removal of an individual from the network will certainly damage the structure, but other connections exist and new connections can be formed to fill in the gap.

Conversely, turnover could also affect the extent to which the group can use its developed TMS. There are two current views in the literature about the influence of turnover on a group's ability to use its TMS. One view is that a strong TMS is a liability for groups that experience turnover. Another view, with less experimental support, is that a strong TMS ensures that a group knows what is lost after turnover, allowing it to recover more easily than groups without a TMS. Though I test both of these hypotheses, I propose and examine a third hypothesis, that turnover in the past prevents a group's ability to use a newly developed TMS unless group members have engaged in role change behaviors. With this hypothesis, I extend prior theory about the development and use of TMS to account for dynamic effects of turnover on groups.

The first perspective I investigate is whether a strong TMS prior to turnover leads a group to be more unable to use its TMS in improving future performance. As described above, consensus about turnover's relationship to TMS in the literature is primarily that if a group's membership substantially changes, any TMS that the group developed is disabled. Interestingly, researchers have found that a smaller amount of turnover can lead groups to have worse performance, due to group members relying on an inaccurate TMS (Lewis et al., 2005, 2007;

Hollingshead, Brandon, Yoon, & Gupta, 2010). In several of these studies, the researchers considered the extent to which there was stability in members' concentration of effort or the new members' contributions. There was some evidence that the more stable the expertise individuals reported having in the group, the better the group's performance. In some cases, however, incumbent members in groups that have experienced turnover are too stable, to the detriment of the integration of the new member (Lewis et al., 2007). Lewis and colleagues (2007) suggested that the group's prior TMS was not updated and, thus, led to the group performing worse than either groups that did not experience turnover or newly formed groups.

Past work, therefore, has suggested that a strong TMS may hurt a group's ability to deal with turnover because it leads the group members to be less willing to integrate new members into the group. TMS may, consequently, increase the inertia of the way in which a group structures its work. This could be, in part, because the group members spent effort developing an initial TMS that led to a distribution of work and do not want to invest more effort into updating their TMS.

Hypothesis 1a: Turnover moderates the path from TMS to performance such that TMS is positively related to performance when there is no turnover and negatively related when there is turnover.

Though I have argued that TMS makes groups more susceptible to damage from turnover, some theoretical and empirical research has rejected that a group's TMS could lead to inefficiency in response to turnover. Christian et al (2014) found that the loss of a relatively low-skilled member did not affect the group's ability to use its TMS to improve performance, but if the group lost a relatively highly skilled member, the groups with high and low TMS both performed poorly. These results suggest that the extent to which an individual has information

encoded in the TMS may influence the extent to which the group's performance is negatively affected by that member leaving the group. Some researchers have suggested that the TMS of groups will allow them to better recognize the areas of expertise for the remaining members or know the expertise that was lost, leading to a lessened effect of turnover (Moreland & Argote, 2003). These articles give support to an alternative hypothesis that turnover will negatively affect groups with low TMS more than it will affect groups with a strong TMS. Because a group's integration of a new member will likely be affected by the group having an understanding of the current distribution of work, groups with a high level of TMS may make better decisions than groups in the same condition that have a low level of TMS.

Hypothesis 1b: Turnover moderates the path from TMS to performance such that TMS is positively related to performance when there is no turnover and more positively related when there is turnover.

Hypotheses 1a and 1b focus on TMS's effect on group performance based on their strength and whether the group experiences turnover. As Lewis et al. (2007) demonstrated, however, the group's interaction with the new member, which may be influenced by the group's prior TMS, will also have an important influence on the extent to which TMS affects the group's performance. When participants were told to consider the knowledge that they lost, they were much more willing to engage the new member, leading to no negative effects of turnover on their performance (Lewis et al., 2007). These authors proposed that the group members made more of an effort to integrate or accommodate the new members in this final condition. In the following section, I propose that a group's engagement in role change can turn on or off—moderate—the influence of prior turnover on a group using its TMS to improve performance.

Role change

Roles are the way that each individual within a group or within an organization helps the collective accomplish overall goals. Katz and Kahn (1966) defined roles as “specific forms of behavior associated with given tasks...required of all persons playing a part in a given functional relationship (p. 37).” Roles define the ways in which members of a group participate and interdependently accomplish tasks. Roles are inherently intertwined with the concept of specialization, because individuals’ assignment to roles often means individuals will gain expertise in those roles. Matching an individual’s *a priori* expertise with his or her role increases group performance and could be related to greater satisfaction (Hackman & Oldham, 1976). Additionally, role changes that match expertise will allow better information to be encoded in a group’s TMS, strengthening it and making it more useful in improving a group’s performance. Role changes within a group, however, could be difficult, unhelpful, or too costly, leading groups to not engage in them.

Little prior research has been done on the relationship of TMS and role changes within groups. The majority of this work manipulated (Baumann, 2001) or measured (Lewis et al., 2005; Lewis et al., 2007) the extent to which members’ areas of expertise remained constant across performance periods. In general, these papers found that groups that retained stable areas of expertise (roles) developed stronger TMS and performed better. The question in this paper is, however, different from the questions of these studies. Regardless of whether role change has a main effect on TMS, does it change the ability of the group to use its TMS to affect performance, an interactive effect on the dependent variable?

TMS improves group performance by allowing group members to implicitly organize and coordinate due to their shared understanding of who knows what (Liang et al., 1995). When groups engage in role change, they are changing who does what within the group. Group

members may more effectively use their TMS to improve their performance if the group's role changes enable the group to specialize more. Role change could also hurt a group's performance because members may be doing work that they are less good at than they did in their previous role. Knowledge of who knows what would be essential in making good role change decisions; thus, I propose that TMS measured after performance will interact with group role change in predicting group performance. In other words, role change will increase the importance of a group's TMS in determining its performance.

After membership changes such as turnover, role change within the group becomes less costly to group members. When there is vacant space in the group, the group has more flexibility to change its distribution of work. Because role change is less costly, it may have an even larger importance in a group leveraging its newly formed TMS. When turnover and role change co-occur, therefore, more expertise to role matching can occur than when there is no turnover. That is, the interaction between TMS and role change will be larger when the group experiences turnover than when the group does not experience turnover.

In hypothesis 1a, I proposed that turnover will make TMS—as measured after performance—less related to improved group performance when groups experience turnover. Then, building on a separate stream of theory, I proposed that turnover may actually improve the relationship of TMS to performance. Lastly, I proposed that turnover, role change, and TMS will interact such that TMS will be the most important in predicting performance when groups experience turnover and role change, and TMS will be the least important when groups experience turnover but not role change. Due to this complex series of relationships, I propose that a three-way interaction between TMS, turnover, and role change will be necessary to see these effects. See Figure 1 for a visualization of this relationship.

Hypothesis 2: Role change will moderate the relationship of turnover's interaction with TMS, such that groups who experience role change and turnover will have a TMS that is more strongly related to performance than groups who experience role change but do not experience turnover.

Methods

Participants

Seventy groups composed of three individuals between the ages of 18 and 28 participated in the experiment at a mid-Atlantic university (46.6% female, mean age = 21.0, SD = 2.0). Any given group consisted entirely of one gender. Gender is not of direct interest in this study, but groups were segregated by gender to reduce potential gender effects. This choice was made because the task involved electronics, which could be perceived as a male dominated domain. There were no gender differences in task performance; thus, this control variable was not used in the analyses. Of the 70 groups collected, two were excluded from the analyses due to violations of the task rules. The sample was diverse, with 32% Caucasian, 34% Asian or Asian American, 8% African American, and 6% of participants reporting other ethnicity. Participants were recruited for this study through two online participant pools, a paid pool and a pool for course credit. Participants recruited through the paid pool were compensated \$10 for their participation while those recruited through the credit pool received one hour of course credit.² There was an additional \$10 per member incentive for the groups that performed best in each experimental condition.

Design

² Paid participants and those receiving credit always performed in groups separate from one another. Including payment as a control in the analyses does not change the results; therefore, the models presented do not include this variable.

The experiment followed a 2 (lower TMS vs. higher TMS) X 2 (no turnover vs. turnover) design. Participants were randomly assigned to groups, each of which was randomly assigned to one of the four conditions.³ Groups in the lower TMS conditions trained as individuals whereas groups in the higher TMS conditions trained together as a group on the task. This type of manipulation of TMS has been frequently used in past studies (see Moreland, 1999). Halfway through the one hour study, half of the groups experienced turnover; a randomly selected member—the turnover member—was and replaced with a different individual—the replacement member—who had trained separately. The replacement member had trained on the task individually—just like those in the lower TMS condition. As one member left and another joined, groups were only ever composed of three members working on the task together. The replacement member interacted with the other group members during the performance task for a maximum of 10 minutes.

Task

The participants completed an electrical circuit construction task using an educational electronics kit. Although this task required a level of interaction among group members similar to that required by the radio assembly tasks used in previous research on TMS (see Moreland, 1999), this task could be completed faster, allowing multiple performances in a single hour-long experiment. The participants used 30 electronics parts to complete a circuit using motors, lights, diodes, and music generating integrated circuits, among other pieces. This task was complicated and effective completion of the task within the time-frame of the study necessitated that members of the group become specialized in different areas of the task in order to have good performance. This task was very complicated and was difficult for members training alone to remember all of the parts of the task. Correct assembly of the circuit produced identifiable

³ Random numbers were generated using random.org for assigning groups to condition.

sounds and lights that gave the participants feedback on their progress. Using the categorization that Lewis and Herndon (2011) developed, this task was an execution task that was divisible, cooperative, and intellective. These characteristics would suggest that a TMS would be helpful on this task.

Procedures

As participants arrived at the laboratory, they were brought to a waiting room until all participants arrived. The participants were then led from the waiting room to a smaller room with several tables and chairs. In the turnover condition, the individual who would replace an existing group member was randomly selected from the participants in the waiting room and led to a separate room. The replacement member was treated identically to the other participants for the practice phase. The participants were all shown a video that demonstrated the circuit's construction, the operation of the circuit, and what sounds and lights a properly operating circuit made. The group members watched this video together while the replacement member watched the same video in a separate room.

The group then began a ten-minute training phase where members attempted to construct the circuit from memory. In the lower TMS condition, the members worked at different tables facing away from one another on separate electronics kits and were not allowed to see other's work or converse. In the higher TMS condition, all three members remained at the same table and worked on the same kit. The replacement member worked in a separate room during the training phase thus this individual was in a synonymous position to those in the lower TMS condition. After ten minutes, each participant received a diagram of the circuit for an additional three minutes in order to check work or assist them in completing the circuit. The circuit diagram provided a standardized method of providing feedback while limiting experimenter effects. Next,

the participants returned to the central table if they had been working individually. All participants were told to discuss their “problems and successes” in building the circuit for two minutes. Group members discussed openly while the replacement member was given paper to write a response which was then collected.

Participants then began the practice phase which was to build the same structure from the training phase, working on one circuit kit, and within a ten-minute time limit. Replacement members worked separately and individually in a separate room. After the practice task, the circuit board was removed and the participants individually completed a paper-and-pencil survey containing a measure of TMS. At this point in the study, the individually trained members had interacted for 12 minutes and the group-trained members had interacted for 25 minutes. In the turnover condition, one participant was then randomly chosen to leave the group and was taken to a third room. The replacement member was then brought into the same room as the group to take the place of the turnover member. Group members were told that this individual had completed the same training and practice phases as the group, though individually. The experimenter informed participants that their performance would be judged based on the number of errors in their circuit and time to completion. The participants then began the performance, which was to reconstruct the same circuit from the training and practice phases. After the ten-minute performance phase, the participants were given a final survey (containing measures of TMS and other measures), were debriefed, and received compensation.

Measures

Performance. The primary performance measure was the total number of *errors* the group made in the circuit, similar to measures in past work (Liang et al., 1995; Moreland & Myaskovsky, 2000). Errors were problems that prevented the circuit from working as described

in the video and circuit diagram; group members were told to put the most weight on this aspect of their performance as opposed to completion time. *Arbitrary errors* were also recorded, though not included in the errors count. Arbitrary errors are alternative ways of constructing the circuit that do not change the circuit's performance but vary from the circuit shown in the training materials. The incidence of arbitrary errors could indicate that participants understood the concept of the electrical circuit but were not able to replicate a circuit identically to the one in the diagram. The number of times the group tested the circuit was recorded by the experimenter in an attempt to limit unwarranted testing of the circuit. The *time to completion* was either the number of seconds until the group submitted a circuit it believed to be complete or the entire ten-minute performance period. Fifty percent of the groups submitted their circuit within the ten-minute performance period and the other half did not turn in their circuit (whether complete or not) within the ten-minute time limit.

Transactive memory systems. I used the 15-item Lewis (2003) scale of transactive memory, as it has become the most widely adopted measure of TMS (Ren & Argote, 2011). This scale contains measures of three indicators of transactive memory: specialization, coordination, and credibility. Each dimension is measured using five items on a 5-point scale (from 1 = *Strongly Disagree* to 5 = *Strongly Agree*). The three components were combined into a single measure of group-level transactive memory as suggested by Lewis and Herndon (2011). I measured TMS within the group before the performance phase and after the performance phase. In both calculations, the group members that were working together during were all included (the turnover member in TMS before performance and the replacement member in TMS after performance). As TMS is a group-level construct, the individual scores within each measurement must have within-group agreement to support aggregation (James, Demaree, & Wolf, 1984;

LeBreton & Senter, 2008). All groups beside one had rwg values of .8 or higher, suggesting that aggregation was appropriate. The intraclass correlations suggest the groups are differentiable from one another based on TMS measured before performance, ICC1 = .22 and ICC2 = .46 ($p < .01$). These values are even stronger for TMS measured after performance, ICC1 = .42 and ICC2 = .68 ($p < .001$).

Role change. In order to isolate the effects of integrating the new member while controlling for other types of learning, I measured self-reported role change in all groups. Role change was an individual-level measurement of whether a participant perceived that his or her contributions to the group were different in the performance period than in the practice period. Role change was measured at the end of the experiment. Participants were asked to respond yes or no to whether their role on the task changed between the practice and performance periods. This value could vary between 0 and 3. Groups that experienced turnover could have a maximum of 2 members report that they experienced role change. Due to this, an alternative measure of role change was developed: the percentage of members who could change their role who did. The results with this variable were practically identical to those attained from the initially described measure; thus, only the count of members who claimed to engage in role change was used.

Replacement member quality and expertise similarity. For groups that experienced turnover, two members participated both before and after turnover. These participants were asked to respond to the following statement using a five point scale from strongly disagree to strongly agree: “The new member performed better than the previous member.” Expertise similarity was measured with a questionnaire composed of ten items measuring self-report perceptions of areas of task expertise (e.g. motor, switches, secondary circuit, etc.), attained from

pre-tests, using a 1 to 5 scale (1 = *no expertise* and 5 = *a lot of expertise*). The survey was given to the group after the performance and to the member who left before the performance in groups that experienced turnover. These measures were used to compare task expertise of the member who left the group and the new group member using a correlation between matrices of both measures.

Results

Means, standard deviations, and correlations for all the variables are available in Table 1.

Manipulation Checks

I begin by confirming that my manipulation of TMS—group training—was effective. As errors is a count variable, I calculated all analyses using over-dispersed Poisson (due to the inflated Pearson Chi-squared statistic) and linear regressions. There were no differences between these analyses in the majority of cases, thus the linear regressions are reported for ease of interpretation, and differences are noted as they occur. Using linear regressions, group training is a significant predictor of TMS before performance ($B = 2.79, p < .01$) and TMS after performance ($B = 3.22, p < .05$).⁴ Additionally, though group training is a significant predictor of errors on the performance task ($B = -2.74, p < .05$), prior work would suggest that TMS would explain group training's effects on errors. This effect becomes not significant when TMS is added to the model (TMS measured before performance, $B = -.52, p < .01$; or TMS measured after performance $B = -.59, p < .001$). Indirect effects tests using PROCESS (Hayes, 2013), a

⁴ Analyses reported include a control for turnover. Turnover is not significant and the results are virtually identical with and without control.

regression based SPSS macro for testing moderation and indirect effects, confirmed that TMS served as a significant mediator of the effect of group training on performance.⁵

Using linear regression, I also tested if turnover or role change had an effect on TMS as measured after performance to determine the appropriateness of testing the moderation proposed in hypothesis 2. This linear regression included the main effects of group training, turnover, role change, and TMS as measured before performance predicting TMS as measured after performance. TMS as measured after performance was significantly predicted by both TMS from before performance ($B = .75, p < .001$) and marginally by role change ($B = 1.55, p < .1$). The effect of role change on TMS (even if it were $p < .05$) is relatively small in magnitude and was not considered to be a concern. Differing from prior work on TMS and turnover, however, I did not find a significant main effect of turnover on either TMS or performance. I will discuss this in more detail later in the paper.

Hypotheses Tests

Hypothesis 1 proposed that turnover moderates the effect of a group's TMS as measured before performance on performance. Hypothesis 1a proposed that this moderation would be negative, whereas hypothesis 1b proposed that the moderation would be positive. I did not find support for either of these hypotheses; see Table 2 Model 3. I probed these moderations using PROCESS (Hayes, 2013). TMS before performance is not a significant predictor of errors for groups that did not experience turnover ($B = -.49, p = .11, 95\% \text{ CI } [-1.10, .11]$) but is for groups that experienced turnover ($B = -.55, p < .05, 95\% \text{ CI } [-1.01, -.09]$). The interaction between TMS and turnover is not significant ($B = -.06, p = .88$), suggesting that TMS's effect on errors does not vary based on turnover. Thus, I found no support for hypothesis 1. I was surprised not to find

⁵ TMS acts as a significant mediator of training's effect on performance using TMS measured before (95% CI: -2.71, -.58) or after performance (95% CI: -3.79, -.34) controlling for turnover (Hayes, 2013). Mediation was tested using 10,000 bias-corrected bootstrap samples.

evidence that turnover operated as a moderator in these analyses. Potential reasons for this are considered in the discussion section.

Hypothesis 2 proposed that the relationship of TMS after performance on performance would be moderated by both whether the group experienced turnover and whether the group engaged in role change. In other words, turnover reduces the strength of the group's TMS on performance but role change reverses that effect. All necessary interactions were first entered into a linear regression predicting performance; see Table 2 Model 5. There was a significant 3-way interaction, suggesting that TMS's effect on performance was indeed moderated by turnover and role change.

The easiest way to understand the 3-way moderation is to separate the sample into groups that did not experience turnover and those that did; see Figure 2. I probed this interaction using PROCESS (Hayes, 2013). Within groups that did not experience turnover, group engagement in role change increased the strength of the negative relationship between TMS and errors, as hypothesized. Groups in which one member engaged in role change behavior performed worse than groups that did not engage in role change when their TMS was weak (below 50.2). If one member reported role change, a group whose TMS was one standard deviation below the mean (45.3) made almost 3 additional errors compared to groups at the mean level of TMS (51.2). Conversely, groups with a strong TMS (above 62.1) performed better when they engaged in role change compared to groups that did not engage in role change. These results suggest that, for groups that do not experience turnover, role change increases the strength of the relationship of TMS on performance both positively and negatively.

Hypothesis 2 predicted that the effect seen in groups that did not experience turnover would be exaggerated in groups that experienced turnover, as role change could lead to even

more benefit in these groups. As shown in Figure 2, this hypothesis was not directly supported. Within groups that experienced turnover, role change was generally helpful in reducing errors. For all groups with a weak to average strength TMS (less than 52.3), those groups in which one member engaged in role change had significantly better performance than groups in which there was no role change. This supports the argument that role change may have a larger impact on groups that experienced turnover, because those groups have more flexibility than groups that did not experience turnover. As TMS in these groups has an overall positive effect, groups with a TMS stronger than 52.3 performed no differently, regardless of the amount of role change in which they engaged. Within groups that experienced turnover, TMS was less negatively related to errors as groups engaged in more role change. Overall, role change, therefore, made TMS more important in groups that did not experience turnover and less important in groups that experienced turnover. These results provide partial support for hypothesis 2. Role change made TMS more important for group performance when groups did not experience turnover but made TMS less important in groups that experienced turnover. These findings reinforce the supposition that role change was an important moderator.

These analyses were repeated using time to completion as the dependent variable. Hypothesis 1 was not supported, suggesting that the effect of TMS before performance on time to completion was not significant. Yet there was no evidence that turnover or role change moderated the relationship of TMS as measured after performance on time to completion. These analyses were repeated where time to completion was dichotomized into groups that completed in fewer than 10 minutes and groups that took all 10 minutes (half of the sample was in either category). Neither hypothesis was supported in these analyses.

Discussion

This study examined the effects of turnover on the usefulness of a group's transactive memory system in a laboratory study where the group's transactive memory system and turnover were manipulated. TMS mediated the influence of group training on performance, replicating prior studies (Liang et al., 1995; Faraj & Sproull, 2000). I did not find that the effect of a group's TMS prior to turnover on performance was moderated by turnover, hypothesis 1. The usefulness of a group's TMS as measured after performance, however, was moderated by both turnover and role change. When groups had stable membership, group engagement in role change meant that the group's TMS had a bigger positive effect on group performance. When group membership was not stable, group engagement in role change reduced the importance of TMS on a group's performance. In these cases, though, role change itself increased a group's performance for the majority of groups. This paper helps add to the growing work exploring the relationship of TMS, turnover, and group role change on performance.

One contribution of this paper is measuring and manipulating TMS, turnover, role change, and their interrelationships. This paper demonstrates the importance of understanding role change in considering the effect of turnover. Not measuring role change could have hidden the interaction between TMS and turnover in predicting group performance. Although role change played an important part in conditioning the effect of turnover, it was measured rather than manipulated. Manipulating role change as part of the design is an important next step in fully understanding its effects. Role change manipulation would allow us to determine if role change by itself can improve performance or if other characteristics of the group or the group's environment must also co-occur for role change to have an effect.

In this study, it was unclear why some groups engaged in role change and others did not. This is beneficial in the sense that role change can be treated as exogenous to group characteristics. Prior work has suggested that the level of interdependence in the group and the group's diversity have an interactive effect on the group's willingness to reflect on its past performance (Schippers, Hartog, Koopman, & Wienk, 2003). Other researchers have suggested that member turnover can have an influence on the group's willingness to change the way it approaches the task (Arrow & McGrath, 1993; Rink, Kane, Ellemers, & Van Der Vegt, 2013). Future work could investigate ways to potentially encourage role change in groups that are most likely to benefit from it (e.g., stable groups with strong TMS or unstable groups).

As mentioned above, turnover in this study did not have an overall effect on group performance. This finding differs from much prior research on turnover and from my expectations. The average turnover and non-turnover groups typically acted differently at the beginning of the performance period. For groups that did not experience turnover, the members typically did not discuss the practice task directly. Within groups that experienced turnover, however, members questioned one another and the replacement member about performance on the practice task. This led to a discussion of individual and group performance on the practice task. This discussion included information about individuals' areas of expertise. Though turnover destroyed a group's access to its prior TMS, the groups in this study may have been able to quickly rebuild TMS, leading to the overall non-significant effect of turnover on TMS.

Additionally, there appeared to be more task-relevant information exchanged during this period when groups experienced turnover. If a group member changed his or her role in the task after turnover, therefore, there may have been more information available to help the group make a good decision about how to change roles. This particular situation could explain why TMS was

not a significant predictor of performance in groups that experienced turnover and engaged in role change. It should be noted that Lewis et al. (2007) found a similar effect where groups whose members were encouraged to consider their own areas of expertise were not adversely affected by turnover and performed better than all other groups.

Though similarities exist between the findings in this study and those in other papers, this experiment makes a unique contribution in two areas. First, prior work has typically considered turnover to have a direct negative effect on TMS, which explains the performance effects of turnover. In this study, however, I demonstrated that turnover has a demonstrable effect on a group's ability to use the TMS it develops after experiencing turnover. Additionally, this paper demonstrates that the influence of role change also varies based on the strength of a group's TMS and whether it previously experienced turnover. The current paper extends previous work by demonstrating the importance of role change on a group's ability to leverage its TMS.

CHAPTER 3 (Study 2): The Effects of Communication Network and Membership Stability on Transactive Memory Systems and Group Performance: An Experimental Investigation

Abstract

We theorize that the communication network that is most effective for groups with stable membership differs from the network that is most effective when membership change occurs. More specifically, we hypothesize that groups with decentralized communication networks perform better when membership is stable than when turnover occurs because their lack of structure prevents integration of new members into the group. The structure and explicit coordination logic of centralized networks, however, allow these groups to gain benefits from membership changes. We empirically analyze the effects of communication network and member turnover on group performance in an experiment of 109 four-person groups performing two collaborative, creative problem solving tasks. When team membership was stable, decentralized groups developed stronger transactive memory systems (TMS) than centralized groups which explained the relationship between communication network and performance. When turnover occurred, however, centralized groups communicated more per available path, leading to a positive effect of being centralized on TMS through communication. Having this additional communication allowed centralized groups to capitalize from turnover by better incorporating the contributions of new members than decentralized groups. Our results indicate that the stability of group membership is an important factor that determines the effects of communication networks on group performance.

Keywords: Social networks, groups, transactive memory systems, turnover, communication, performance

The Effects of Communication Network and Membership Stability on Transactive Memory Systems and Group Performance: An Experimental Investigation

Organizational activity is largely comprised of the coordination of individuals to solve complex problems. Group members must identify the expertise of others, access information held by different members and coordinate that information to accomplish shared goals. Member turnover, the exit of an incumbent member and introduction of a new member, in groups can complicate the identification and coordination of expertise and information (Arrow & McGrath, 1995; Levine & Moreland, 1985). Groups with stable membership are able to learn each other's skills and expertise, to allocate tasks to the most qualified members and to coordinate the interdependent activities of their members. When turnover occurs, however, incumbent members know little about the expertise and skills of the new member and coordination can become challenging (Lewis, Belliveau, Herndon, & Keller, 2007). Yet, new members can nonetheless be a source of new ideas and perspectives that improve group performance (Choi & Thompson, 2005).

We theorize that the effect of turnover on group performance depends upon the group's communication network. From a network perspective, groups can be categorized by their structural features, and—in particular—their degree of centralization (Katz, Lazer, Arrow, & Contractor, 2004; Leavitt, 1951). Centralization, in turn, affects the coordination logic of the group. A group is categorized as centralized when its communication network consists of one or a few members who are connected to multiple members whereas the other members are not. In centralized groups, the number of communication paths available to each group member varies, and as this variation increases, centralization also increases for the group. Centralized communication networks direct how information is shared and how the members coordinate

(Blau, 1974; Bunderson & Boumgarden, 2010; Hall, 1999). By contrast, in decentralized groups, there is little to no variation in the number of connections individual members have. Generally, members of decentralized groups can communicate directly with all other members and the communication structure does not mandate either the means by which information is shared or how members coordinate (Burns & Stalker, 1961).

When membership is stable, the decentralized communication network provides advantages because group members can rapidly and effectively establish a transactive memory system (TMS). A TMS is a collective system for encoding, storing and retrieving information, where members share both a cognitive map of expertise in the group and a coordination logic (Wegner, 1987; Lewis & Herndon, 2011). In decentralized groups, individuals can directly communicate with every other member in their group, which enables them to learn more about each other's expertise and to tailor the group's coordination logic to account for each member's preferences and abilities. Both the direct communication between all members and the greater ability to coordinate in a manner that suits individual members' characteristics enhance the development of a strong TMS in decentralized groups. Alternatively, the limited communication pathways among members in centralized groups can impede the development of a strong TMS. In centralized groups the restricted communication network limits direct communication among all of the members, which hinders their ability to determine other's expertise. Rather than being able to communicate along all pathways to all members, centralized members must rely on fewer pathways and indirect pathways to share information. Also, centralized communication networks force members to coordinate in a particular manner, irrespective of members' preferences and abilities. Rather than provide members with the opportunity to customize their coordination logic, centralized group members must all channel information to the central member(s) who

then can orchestrate the group's activities. Hence, the coordination logic in centralized groups is independent of the particular members and their attributes because the communication network mandates how members collaborate and share information (Bunderson & Boumgarden, 2010).

While decentralized communication networks facilitate group performance by encouraging the development of a strong TMS, decentralized networks can also hinder the integration of new group members. First, the strong TMS that is more likely to emerge within decentralized groups entails an implicit coordination logic that cannot be readily observed or understood by new group members. Second, decentralized communication fosters the development of a TMS where the coordination logic is tailored to individual members' unique abilities and characteristics. Since new members might not have the same attributes and knowledge as the departing member, the substitution of a new member is then challenging for these groups. Finally, when a group with a strong TMS experiences a change in membership, the incumbent members expect the new member to know the coordination logic of the group, which inhibits the new member from contributing to the group (Lewis et al., 2007). Thus, in the case of decentralized groups, turnover can undermine the group's ability to function and perform.

By contrast, the limited communication network of centralized groups improves the group's ability to integrate a new member, which can result in improved group processes and performance. First, although the restricted communication pathways in centralized networks force members to coordinate through the central member(s), the coordination logic is readily discernible by both incumbent and new members. When new members can easily identify the coordination logic, the new member's ability to contribute to the group is enhanced (Bunderson & Boumgarden, 2010; Morrision, 2002). Second, because member roles in centralized groups are not customized to individual members, it is more likely that the new member can adequately

perform the activities of the departing member in centralized than in decentralized groups. Finally, the restricted communication pathways in centralized networks require greater reliance on the few existing pathways to coordinate than in decentralized networks. This greater reliance reduces the likelihood that any communication pathway and its respective member are neglected. These factors enable a centralized group to learn about a new member and to incorporate his or her contributions. When groups are able to integrate a new member, it improves both group processes and outcomes for tasks involving problem solving and creativity (e.g., Wells & Pelz, 1966; Choi & Thompson, 2005). The introduction of a new member to a centralized group then should promote both the development of TMS and enhance group performance.

In the sections that follow, we develop theory for why membership stability conditions the effect of the communication network on group performance. We then describe the methods of an experiment in which we randomly assigned groups to predetermined communication networks, centralized and decentralized, and to turnover or no turnover conditions. This experimental design allows us to investigate the mechanisms that explain how member turnover and communication networks interact to affect group processes and performance. The design also allows us to make causal inferences regarding the influence of communication networks and turnover on group performance. Following the discussion of our methods, we present our findings and develop their implications for theory and practice.

Transactive Memory Systems and Communication Networks

Transactive memory systems have been found to improve group performance on a variety of tasks in both the laboratory and in the field (Liang, Moreland, & Argote, 1995; Hollingshead, 1998; Faraj & Sproull, 2000; Lewis, 2003). Early research on TMSs focused on operational outcomes such as the amount of time groups took to perform a task (Faraj & Sproull, 2000) or

the errors they made (Liang et al., 1995) and found that these outcomes were better in groups with strong TMS. More recent work has shown that TMSs can also enhance group creativity by enabling group members to combine their ideas and expertise in new ways (Gino, Argote, Miron-Spektor, & Todorova, 2010). Transactive memory systems can be distinguished from related constructs, such as shared mental models, because the knowledge held by group members in a TMS is differentiated through specialization (Lewis & Herndon, 2011). For example, if a group has a shared mental model, they share the same understanding of how the task should be completed, but in groups with a TMS, the members have different information about how to complete their sub-parts of the collective task (DeChurch & Mesmer-Magnus, 2010). With a well-developed TMS, group members are able to specialize their expertise and effectively coordinate their activities (Wegner, 1987). As members continue to work with the same group members, they are better able to discern the skills and abilities of the other members, which allows them to both fine-tune their division of labor and improve their coordination. Given that the formation and development of a TMS is affected by the group's communications, differences in the communication network should affect group performance through their influence on the group's TMS.

A group's communication network serves to channel information among group members and coordinate their activities. Much like an organization's formal reporting structure determines how members exchange information, communication networks also shape information sharing within groups. Take for example two different communication networks for groups with four members: centralized and decentralized. In the decentralized group, all of the members are connected to each other directly (see Figure 3, Image A). The greater number of communication pathways available in decentralized groups provide members with more opportunities and

freedom to tailor each member's activities to their individual abilities and to communicate in a manner that is best suited to each member. This flexibility in communication also permits decentralized groups to develop a coordination logic based on the attributes and preferences of their individual members. By contrast, in the centralized group (see Figure 3, Image B) only member C has communication pathways to the other members (A, B, and D), and members A, B, and D only have one pathway to member C. In order to both communicate and coordinate activity, the peripheral members (A, B, and D) must rely on the central member C. The centralized communication network simplifies the coordination logic: all peripheral members communicate to the central member and the central member dispatches information to peripheral members.

Decentralized groups have more direct communication paths among all the members, which enable the members to learn about each other's abilities and communication preferences. In turn, decentralized members can quickly develop a coordination logic customized to the group. Direct communication amongst all members fosters an understanding of member expertise and encourages the development of TMS (Hollingshead & Brandon, 2003; Lewis, 2004; Kanawattanachai & Yoo, 2007; Yoon & Hollingshead, 2010; Yuan, Fulk, Monge, & Contractor, 2010). Providing information about other members' areas of expertise also increases the strength of a group's TMS, suggesting that this information drives the development of a TMS (Moreland & Myaskovsky, 2000). Mutual connections among three members, such as closed triads, which are common in decentralized groups, have also been positively related to TMS development (Lee, Bachrach, & Lewis, 2014). Thus, the transactive memory systems of decentralized groups become tailored to the different skills, knowledge and preferences of group

members. With increasing information about the same members, the implicit division of labor that is emblematic of TMS is developed and refined within these groups (Wegner, 1987).

Within centralized groups the communication network prevents all of the group members from directly interacting with one another and developing a coordination logic that is well-suited to the particular members of the group. Instead, similar to organizational forms examined in the organizational theory literature, the communication structure of centralized groups imposes a particular coordination logic on the group (Gouldner, 1954; Weber, 1947). The limited number of communication pathways hinders members from directly learning about each other's areas of expertise, which in turn, inhibits the development of a strong TMS. Finally, because the coordination logic is prescribed by the communication network and is independent of members' abilities and preferences, the centralized structure is not likely to be optimal for any particular group (Scott, 1992).

Turnover

Turnover or membership change commonly occurs within work groups (Kush, Williamson, & Argote, 2012). In some instances, turnover can benefit the group by invigorating it with information and perspectives from the new member, which improves its performance (Choi & Thompson, 2005; Hancock, Allen, Bosco, McDaniel, & Pierce, 2013). In other instances, membership change can hinder group outcomes because the new member might not share the same skills as the departing member or understand the coordination logic of the group (Hausknecht & Holwerda, 2013; Lewis et al., 2007). Yet, turnover can improve group performance on tasks involving creativity and innovation (Choi & Thompson, 2005). For example, Wells and Pelz (1966) found that turnover in groups of scientists improved group performance. When a new member actively contributes, he or she can provide a perspective that

improves the group's processes as well as increases the group's task effectiveness (Choi & Levine, 2004; Levine, Choi, & Moreland, 2003; Levine & Moreland, 1985).

For groups that have a well-established TMS, turnover can undermine performance. Lewis, Belliveau, Herndon and Keller (2007) found that when only one group member was replaced in a group, those groups performed worse than either groups whose membership was stable or groups whose membership changed totally. The advantages conferred on decentralized groups by their strong TMSs when membership is stable are potentially undermined when turnover occurs. Because TMS is a cognitive division of labor, the group's implicit coordination logic is not easily observed by the new member (Wegner, 1987). Hence, for decentralized groups, a new member would have difficulty contributing because he or she would not understand how the group communicates or organizes its activities. When groups have strong TMS, the incumbent members of groups tend to ignore the contributions of a new member and expect him or her to fill the role of the departing member (Lewis et al., 2007). Taken together, decentralized groups fail to integrate a new member into the group due to their strong TMS prior to turnover.

The features that undermine TMS formation in centralized groups with stable membership—limited communication pathways and mandated coordination logic—instead aid in the integration of new members. New members in centralized groups can easily discern the simple organizing principle, where all members contribute their information and views to the central member, who then integrates the information and activities for the group (Guetzkow & Simon, 1955). In turn, understanding the group's coordination logic helps new members to work effectively with the other members, which is critical to group integration (Chao, O'Leary-Kelly, Wolf, & Klein, 1994; Morrison, 1993; Morrison, 2002; Ostroff & Kozlowski, 1992). Moreover,

the limited connectivity of centralized groups also requires greater reliance on the extant pathways for the members to communicate. Frequent communication improves the new member's knowledge of how to perform his or her tasks and provides clarity in terms of the responsibilities associated with the position, which expedites the new member's ability to contribute to the group (Morrison, 2002). Overall centralized groups are better able to integrate new members than decentralized groups because new members are more likely to contribute and have their contributions encouraged and acknowledged.

The introduction of a new member, even novices with little experience, into an existing group can enhance the group's performance (Ferriani, Cattani, & Baden-Fuller, 2009; Uzzi & Spiro, 2005). When the group incorporates the new member's ideas and perspectives, the group is able to perform its task more effectively (Levine, Choi, & Moreland, 2003; Levine & Moreland, 1985). In addition to increasing the creative problem solving of incumbent members (Choi & Thompson, 2005), new members can also introduce new insights that improve group performance (Levine, Moreland, & Choi, 2001). Integrating a new member often leads incumbent members to reflect on and discuss members' expertise and the group's division of labor, which serves to stimulate TMS development (Choi & Levine, 2004). We anticipate that the communication network of centralized groups enables them to better integrate the new member and thereby, to improve their TMS and performance; however, the network of decentralized groups promotes the establishment of a strong TMS under stable membership, which subsequently undermines their ability to integrate a new member. Thus, we predict:

Hypothesis 1: Communication network and turnover interact to affect group performance: decentralized groups perform better when group membership is stable than

when turnover occurs, while centralized groups perform better when turnover occurs than when group membership is stable.

Hypothesis 2: Communication networks and turnover interact to affect transactive memory systems: decentralized networks have stronger transactive memory systems when group membership is stable than when turnover occurs, while centralized groups have stronger transactive memory systems when turnover occurs than when membership is stable.

Communication Per Path

Communication networks not only influence the flow of communication but also the amount of communication that occurs between members. In decentralized groups, members share communication pathways to all other group members. The greater number of communication pathways increase the demands on members' time and attention and reduce the attention and time the member has to communicate along any one pathway (Brooks, 1975). As opposed to decentralized groups, centralized groups must rely on fewer pathways to communicate, which increases the group member's dependence on each individual pathway. Restricting the communication pathways of a member increases their saliency and importance in completing the group task. For example, in the centralized network in Figure 3, the majority of the members have only one communication pathway, which means all information and coordination to and from that member must be conveyed along that pathway. Thus, the communication constraints of the centralized groups increase members' reliance on the available communication pathways and result in greater communication per pathway than in the less restricted decentralized groups.

In addition to direct communication, frequent communication between members also encourages the development of transactive memory systems (Lewis, 2004). Communication per path represents the frequency of communication that occurs in a group relative to the number of available communication paths in the group. When turnover occurs in groups with a strong TMS, incumbent members neglect to communicate with the new member (Lewis et al., 2007), which reduces the amount of communication per path and weakens the group's TMS. In contrast, the fewer paths available to centralized groups make each connection more salient to the group members. Therefore, centralized groups will be more likely to communicate with a new member than decentralized groups. The greater amount of communication per path allows members to update the group's knowledge of who knows what. In addition, the act of integrating the new member creates an opportunity for the incumbent members to reflect on and discuss group members' expertise as well as the group's coordination logic, which strengthens the group's TMS. Formally, we predict:

Hypothesis 3: Communication per path mediates or explains the effect of the interaction between the communication network and turnover on transactive memory systems and the mediation is stronger when turnover occurs than when group membership is stable.

In addition to testing these hypotheses, we expect to replicate past work showing that transactive memory systems improve group performance (for a review see Ren & Argote, 2011). We go beyond past work by showing that transactive memory systems and the amount of communication per path explain or mediate the effect of communication networks on performance and that their mediation is conditioned by turnover.

Scope Conditions

Because we are interested in communication networks, we selected interdependent tasks that require cooperation so that we could observe how information was shared in the group. Also, our focus is on non-routine, complex tasks. Our theory, therefore, applies to complex problem-solving tasks that require coordination and creativity. Examples of such tasks include product design, proto-type development, engineering design processes, and software engineering. Moreover, both centralized and decentralized communication networks are commonly implemented for such tasks. For example, both communication networks can be found in the software development industry, where programmers must coordinate as a group to create and optimize software. In many cases, software development groups are distributed globally and directives from the organization and/or time zones determine their communication networks. Decentralized communications networks are used in many open source software development groups where every member can coordinate using direct communications with all other members (Tsay, Dabbish, & Herbsleb, 2014). Alternatively and analogous to the centralized groups, software groups often designate the role of a ‘software architect’ who coordinates their activities and all communications flow through this member (Kruchten, 2008; Bosch & Bosch-Sijtsema, 2010). In addition to the software domain, one sees both decentralized and centralized groups in other domains, such as the military.

Because our tasks involve creative problem solving, we expect that the contributions of the new member have the potential to improve group performance (e.g., see Choi & Thompson, 2005). New members in our study receive the same training and information as the members whom they replace. New members have not worked with the group previously so they are not knowledgeable about other group members or aware of the group’s coordination logic. We have

hypothesized that whether the group benefits from the new member depends on the group's communication network. We turn now to the methods we used to test this hypothesis.

Methods

Participants, Task and Procedures

One hundred and nine four-person groups composed of 503 individuals (49% female) were recruited from a mid-Atlantic American university participant pool and through advertisements online.⁶ Participants received \$20 or course credit for their participation and there was an additional reward of \$20 per person given to the members of the best performing group in each condition. The ages of participants ranged from 18 to 37 with an average age of 22.0 years. Forty-nine percent of the participants were Asian or Indian, 37% were Caucasian, and 14% were of other ethnicities.

Tasks

Because we are interested in interdependent problem-solving tasks, we used two tasks that fell in the conceptual cooperative quadrant of McGrath's (1984) circumplex model. Both tasks required creative problem solving. The first task was a programming task with the possibility of errors; the second was an idea-generating task. Both tasks were based on an online graphical programming interface. This interface allowed participants to design programs, called pipes, that collect, manipulate, organize, and filter information from the Internet to create a desired output. Although conceptual and language similarities exist between Yahoo! Pipes and other programming languages, knowledge of other programming languages would not provide direct benefits to working in Yahoo! Pipes because of its unique graphical programming interface. We anticipated that many participants would be unfamiliar with Yahoo! Pipes.

⁶ Data from seven groups were dropped from the analysis. Two groups failed to follow the experiment's instructions, and five groups contained members who had previously participated in the experiment.

Nonetheless, participants were asked at the end of the study if they had experience with Yahoo! Pipes. The average familiarity with the programming interface was very low with 94.2 percent of the participants rating themselves as unfamiliar or very unfamiliar with Yahoo! Pipes.

The programming task required each group to work together to create a pipe that 1) sorted selected news items by publication date, 2) removed any repeated articles, and 3) allowed a user to specify a search keyword. The task required the use of five specific modules. Although working on separate computers, participants had access to a virtual work environment allowing them to contribute and to see the contributions of their group mates simultaneously. All members could access and make changes to the Yahoo! Pipe. In the idea-generating task participants were asked to collectively generate as many new features or functional improvements as possible to enhance the program pipe that they had created in the programming task. Participants worked in the same environment that they used in the programming task. The new features had to be both novel and feasible to implement within the Yahoo! Pipes interface and therefore, required the module expertise of all of the members. For both tasks, group members never interacted face-to-face and communicated only through an instant messaging client.

Manipulations

We manipulated two variables in the experiment: communication network and turnover. We manipulated the communication network by controlling who could communicate with whom through an instant messaging client. In the centralized condition, three peripheral members could only contact one central member who could communicate with all the peripheral members. In the decentralized condition, all members could communicate with all other members (see Figure 3). Throughout both tasks, the communication network remained unchanged.

We manipulated turnover by replacing a randomly selected member from each group after the practice task with another participant who acquired the network position of the departing member. Participants were not warned that their group might experience turnover. The new member received the same training materials as the departing member, but had not previously worked with a group. In decentralized groups that experienced turnover, a randomly chosen member was selected to be replaced. Centralized groups that experienced turnover experienced change of either a peripheral member or a central member. For example, in the centralized peripheral turnover condition (see Figure 3 part B), a peripheral member (A, B, or D) was randomly selected and replaced. In centralized central turnover condition, the central member, C, was replaced. Although we did not make predictions that turnover of the central member would have a significantly different effect than turnover of peripheral members, we allow for the possibility in our design and subsequent tests by including both types of centralized turnover. At the conclusion of the results section we report comparisons between groups that were in either of these centralized turnover conditions.

Procedures

After arriving at the laboratory, participants were randomly assigned to one of four isolated rooms, each associated with a member ID and a position within the network. We only allowed members to communicate using an instant text messenger and limited their opportunities to see one another. The participants then began a training phase where they received basic information about the programming task as well as instructions for the experiment. The materials explained how to communicate with the other members through the instant messenger, directed the participants to a short video demonstrating the creation of a sample program within Yahoo! Pipes, and provided detailed information about the programming modules available.

Additionally, we provided each group member with different specialized information about one of the modules necessary for completing the task. The different module-specific information was randomly distributed to each of the four members. We assigned this specialized information to ensure that group members were interdependent. For groups experiencing turnover, the new member received the same specialized information as the member whom he or she replaced.

Once all the participants had read the training materials, they were given thirty minutes to practice the task together. After they finished the practice task, group members completed the first survey. At this point, for groups in the turnover condition, a randomly chosen group member was removed from the communication network and dismissed from the experiment and a new member was introduced to the group. The new member occupied the same position in the communication network as the departing member and received the same specialized information during training. Groups were then given instructions for the programming task, which they had thirty minutes to complete. The programming task was followed by the five-minute feature-generating task.⁷ Group members then completed the second survey. Finally, we debriefed and thanked participants.

Measures

Several variables in this study were behavioral measures, including our two dependent measures: the number of errors in the programming task and the number of functional improvements in the feature-generating task. The communication per path between group members was also a behavioral measure based on the messages sent on the instant message client. The remaining measures were collected from a survey, which measured the group's

⁷ Eleven groups were inadvertently given 10 minutes instead of 5. There was no main effect of this on new features but a control variable was included in all predictions of new features, see note in Table 2.

transactive memory system, the perceptions of the communication network, and group member demographics and experience, such as their familiarity with Yahoo! Pipes.

Errors

We calculated the number of errors in the Yahoo! Pipes program that each group submitted. Errors included both cases when group used incorrect modules or when the group omitted modules required for the program to function properly. In order to calculate the errors, we categorized errors into four comprehensive categories: missing modules, incorrect settings, incorrect modules, or unconnected modules. The number of errors for a module was based on the number of settings in that module. For example, if a group did not include a particular module in their program and that module had three required settings, three errors would be recorded for the group. If a module was included but one of the settings was wrong, the group was coded as having one error. These errors were summed into a single measure for each group. To ensure that the categorization scheme was comprehensive and objective, a portion of the groups had their errors assessed by two coders ($n = 70$). The Cohen's Kappa of .72 ($p < .001$) indicated good agreement between coders (Cohen, 1960). A single coder then coded errors for the remaining groups.

New Features

During the feature-generating task, participants responded to the question: "Think of any ways that you think the pipe you just built could be improved by creating new features. What other ways could this pipe be more helpful to an end user, be more simply designed, etc.?" Two coders coded a subset of the groups ($n = 40$), assessing the new features on whether it introduced novel functionality and was feasible to implement. Two coders attained very good reliability, as

indicated by the Cohen's Kappa of .88 ($p < .001$). Any disagreements between coders were addressed and resolved. A single coder then coded the new features for the rest of the groups.

Transactive Memory Systems

Lewis's (2003) 15-item survey measure was used to measure the groups' transactive memory system. The survey instrument was administered at the end of the study, after groups had completed both tasks. The overall reliability was acceptable (Cronbach's alpha = .82). The average intergroup reliability (rwg) was .95, indicating that it is appropriate to aggregate the individual-level measures to the group level. The ICC(2) value was .61, indicating acceptable reliability of the measure. These reliability statistics provide evidence for general agreement among group members and the appropriateness of aggregating to the group level (LeBreton & Senter, 2008). The ICC(1) value, which indicates the extent to which the variability in individual responses can be predicted by group membership, was .28. Values of .25 or higher are considered to be large effects (Murphy & Myors, 1998).

Communication Per Path

We calculated the communication per path based on group members' instant text messages. Communication per path is the sum of all group messages exchanged between members during the task performance period divided by the total available communication paths in the group (three for centralized and six for decentralized). This value was then divided by the time to task completion to account for variation in the group's completion time. We calculated this variable for both the programming task and the feature-generating task. Analyses predicting errors used the communication per path during the programming task and analyses predicting new features used communication per path during the feature-generation task. For table 4, we

used cumulative communication per path, the combination of communication per path for both task periods, to predict the effect of the network on communication or on TMS (Models 6 and 7).

Results

We begin this section by discussing the effectiveness of the communication network manipulation. We then present results for errors and new features. Next, we discuss results indicating that transactive memory systems and communication per path explain the effects of the communication networks and turnover on group performance. The section concludes with a discussion of robustness checks.

Communication Network Manipulation Checks

First, we determined whether members correctly assessed their group's communication network. Each group member was asked which communication pathways existed among members of the group. Group members correctly identified the group's communication pathways 86% of the time. Decentralized groups were slightly more accurate (88%) than centralized groups (84%) in identifying communication pathways ($p < .1$). These results suggest that group members were aware of the pattern of their available communication pathways in both the centralized and decentralized conditions.

Second, to determine if the communication network manipulations shaped the communication among group members to be either decentralized or centralized, we analyzed the messages sent between each of the members. Although it was not possible for the centralized groups to send messages in a decentralized pattern, it was possible for the decentralized groups to send messages in a centralized pattern. To explore this possibility, we calculated Freeman's (1979) degree centralization measure based on the communication messages shared within each group. Degree centralization is a group-level measure of the dispersion of group members'

degree centrality scores. Given that degree centralization can only be calculated for dichotomous networks, we only included a communication pathway if two members communicated over a certain threshold. The threshold for inclusion was one standard deviation below the group's mean level of messages shared.⁸ Using a threshold for tie inclusion is common in network research, and the threshold we applied provides a reasonable distribution of degree centralization values within the sample (Borgatti, Everett, & Johnson, 2013). The degree centralization measure was highly correlated with the manipulation of communication network ($r = .81, p < .001$), which suggests that our communication manipulation influenced the pattern of messages exchanged among group members, as expected.⁹

Performance

We predicted that the communication network and turnover would interact to affect group performance (Hypothesis 1) such that decentralized groups would perform better when there was no turnover than when there was, and centralized groups would perform better when turnover occurred than when membership was stable. Next, we hypothesized that the communication network and turnover would interact to predict transactive memory systems such that decentralized groups would have stronger TMS when membership was stable than when turnover occurred and centralized networks would have stronger TMS when turnover occurred than when membership was stable (Hypothesis 2). Finally, we proposed that communication would mediate the interaction between communication network and turnover in predicting TMS

⁸ We converted the weighted networks to dichotomous networks using the R (version 3.1.3) package `tnet` (Opsahl, 2012, version 3.011) and calculated Freeman's (1979) graph-level degree centrality using the R package `igraph` (Csardi & Nepusz, 2006, version 0.7.1)

⁹ We also analyzed the manipulation using betweenness centralization. Betweenness centralization indicates the variation of group member's betweenness centrality, how often a member resides on the shortest communication path between all possible pairs in the group. Betweenness centralization is then the level of dispersion of these values. Similar to degree centralization, betweenness centralization also has a positive correlation with the communication network manipulation ($.79, p < .001$).

and that the mediation would be stronger when turnover occurred than when it did not (Hypothesis 3). We anticipated that centralized groups would have more communication per pathway than decentralized groups and that this difference would be larger when groups experienced turnover than when membership was stable.

We present descriptive statistics and correlations in Table 3. Table 4 presents the ordinary least squares estimates predicting errors based on the communication network, turnover and their interaction.¹⁰ In Model 1 of Table 4, the interaction of communication network and turnover was negative and significant ($B = -2.31, p < .05$), as predicted by Hypothesis 1. Model 3 predicts the number of new features. In this model, communication network was negative and significant ($B = -1.76, p < .05$) indicating that centralized groups generated fewer new features than decentralized groups. As predicted by Hypothesis 1, we found a significant positive interaction between communication network and turnover ($B = 2.64, p < .05$). For both errors and new features, decentralized groups performed better when group membership was stable while centralized groups performed better when turnover occurred.

Figure 4 depicts the mean numbers of errors (left side) and new features (right side) as a function of communication networks and turnover. As can be seen from the figure, decentralized groups made fewer errors and generated more new features when they did not experience turnover than when they did. By contrast, centralized groups made fewer errors and generated more new features when they experienced turnover than when they did not. Thus, the pattern of results supports Hypothesis 1.

¹⁰ To aid in interpretation, we report coefficients for ordinary least squares models; however, all analyses were repeated with Poisson regressions, a version of the generalized linear model appropriate for a dependent variable that is a count measure, because both of our outcome variables are count variables. These Poisson regressions produced very similar results to those presented here.

We turn now to a test of Hypothesis 2. As can be seen from Model 5 of Table 4, the centralized network negatively affected TMS ($B = -4.24, p < .01$), turnover had a marginal negative effect on TMS ($B = -2.68, p < .10$) and the interaction of the network and turnover was positive and significant ($B = 4.71, p < .05$). The significant positive interaction is consistent with Hypothesis 2. Decentralized groups developed a stronger TMS when membership was stable than when turnover occurred (55.1 vs. 52.4), and centralized groups developed stronger TMS when turnover occurred than when membership was stable (50.9 vs. 52.9). Thus, the pattern of results for transactive memory parallels results shown in Figure 4 for new features generated.

While not explicitly hypothesized, we examined whether transactive memory systems mediated the effect of communication networks on performance. As can be seen from Table 4, when TMS was included as a predictor of errors in Model 2, it was negative and significant. Further, the comparison of results between Model 1 and Model 2 reveals that the interaction of communication network and structure was no longer significant when TMS was included, suggesting that TMS accounted for the effect of the interaction on performance. Similarly, when TMS was included as a predictor of new features (see Model 4), it was positive and marginally significant. As we see in Table 4, when TMS was added in Model 4, the effect of communication network was no longer significant and the interaction of network structure and turnover became less informative ($p < .05$ to $p < .1$).

Next, we investigated the role of communication per path in explaining TMS and performance. We first analyzed how the communication networks and turnover affected the amount of communication per path. As can be seen from Model 6 of Table 4, the main effect of communication network ($B = .33, p < .1$) and its interaction with turnover in predicting communication per path ($B = .48, p < .1$) were both marginally significant and positive.

Centralized groups had more communication per path than decentralized groups. The mean levels of communication per path as a function of communication network and turnover can be seen in Figure 5. Decentralized groups had somewhat more communication per path when they did not experience turnover than when they did while centralized groups had more communication per path when they did experience turnover than when they did not. These results indicate that turnover increased communication per path for centralized groups whereas the opposite was true for decentralized groups.

Figure 5 also shows the proportion of communication that was directed to the new member (see the darker bands in the turnover condition bars). As can be seen from the figure, the proportion of communication directed to the new member was much higher in centralized than in decentralized groups. The difference in these proportions was significant using planned contrasts ($p < .001$), indicating that centralized groups communicated more to their new members than decentralized groups. We also replaced the proportion of communication directed *to* the new member with the communication *from* the new member and found a very similar pattern: the new member communicated more in centralized than decentralized groups ($p < .001$).

As a supplement to our quantitative results, we provide examples from groups' transcripts to illustrate the differences in how decentralized and centralized groups integrated the new member. The first quote illustrates that the incumbent group members in the decentralized groups did not directly communicate with the new member, whom they seemed to ignore and assume would not contribute.

Decentralized Turnover (Group 55):

Incumbent Member C to Incumbent Member D: “are you working on it? Just checking”

Incumbent Member D to Incumbent Member C: “I think (New Member) E is doing random shit, (Incumbent Member) B and me are not”

The following quotations from two centralized groups demonstrate how the incumbent members communicated directly with the new member. In the first quote from a group with central turnover, an incumbent member informed the new member of the role in which he or she had been placed. In the second quote from a group with peripheral turnover, the incumbent member encouraged and applauded the contributions of the new member.

Centralized Central Turnover (Group 60):

Incumbent Member D to New Member E: “could you speak with A and B???”

New Member E to Incumbent Member D: “yeah [I] think so. I can talk to B and B said he/she can only talk to me”

Incumbent Member D to E: “ok, and you can talk to A?”

New Member E to Incumbent Member D: “yea”

Incumbent Member D to New Member E: “because you [perform] as a communicator for the group”

Centralized Peripheral Turnover (Group 70):

Incumbent Member C to New Member E: “We figured out up to part c, [but] we can’t figure that out.”

Incumbent Member C then proceeds to explain to New Member E what Incumbent Member B’s ideas were.

New Member E to Incumbent Member C: “[That] should be the title we let people allow”

Incumbent Member C to New Member E: “mmm...let me ask the others....you are amazin [sic]”

These quotes reinforce the quantitative results indicating that centralized groups communicated more with their new members than decentralized groups. Centralized groups integrated their new members and incorporated their contributions better than decentralized groups.

Next, we examined how communication networks, turnover, their interaction and communication per path affected TMS. Model 7 in Table 4 adds communication per path as a predictor of TMS, and shows that communication per path had a significant and positive effect on TMS. Also, relative to Model 5, turnover became non-significant and the interaction between network structure and turnover became marginally significant when communication per path was included in Model 7. This result indicates that communication per path partially explained the effect of these variables on the development of TMS. Interestingly, the main effect of network structure remained significant when communication per path was included, indicating that network structure had an effect on TMS over and above its effect through communication per path.

Moderated Mediation Analyses

Next, we present a test of moderated mediation using PROCESS, a macro that tests for mediation and moderated mediation and uses bootstrap sampling to test for indirect effects (Hayes, 2013). The use of bootstrap sampling allows for tests of mediation and moderation that have more statistical power and violate fewer assumptions than other tests of mediation (Hayes, 2013). For all of these analyses, we used 50,000 bias-corrected bootstrap samples. The results of the PROCESS analysis indicated that communication per path mediated the relationship between the communication network and transactive memory systems, and that the relationship was stronger when turnover occurred ($B = 2.45$, 95% CI: 1.14, 4.28) than when group

membership was stable ($B = 1.02$, 95% CI: .01, 2.69). The index of moderated mediation test determines whether the size of mediations at the two levels of our moderator (2.45 vs. 1.02) were significantly different from one another (Hayes, 2015). This test was significant (95% CI: .20, 3.28), indicating that the strength of the mediation was stronger for the turnover groups as compared to the no turnover groups. Thus, we find support for Hypothesis 3.

Figure 6 provides an integrative model of our hypotheses. Each individual hypothesis is labeled in the framework of Figure 6. In the preceding sections, we provided support for Hypotheses 1, 2, and 3. We now turn to a test of the full “moderated serial mediation” model as presented in Figure 6 for our two dependent variables, errors and new features.

The analysis for errors indicated that for groups that did not experience turnover, the effect of communication network on errors was partially mediated by communication per path and TMS ($B = -.21$, 95% CI: $-.66, -.03$); however, the majority of the effect was accounted for by TMS alone in no turnover groups ($B = .98$, 95% CI: $.41, 1.92$). By contrast, for groups that experienced turnover, the strength of the effect of communication network through communication per path and TMS was larger in magnitude ($B = -.52$, 95% CI: $-1.08, -.21$) than the effect through TMS alone ($B = .44$, 95% CI: $.0002, 1.1386$). The index for moderated mediation (Hayes, 2015) indicated that the effect of having a centralized network on errors through communication per path and TMS was stronger in turnover vs. no turnover; 95% CI: $-.68, -.05$). The effect of having a centralized network on errors just through TMS did not differ in magnitude based on turnover; 95% CI: $-1.35, .16$).¹¹

¹¹ In order to determine the robustness of these findings, we repeated these analyses using just communication per path that occurred within the first six minutes of the programming task. Six minutes was the minimum time to completion amongst all the groups on the programming task. Focusing on the first six minutes allowed us to explore variations in communication per path without having to account for time to completion of the task. Results from these analyses were identical to those using communication per path per minute. The serial pathway in the moderated serial mediation predicting

Figure 6b provides a visualization of this mediation. These results indicated that for groups that did not experience turnover, TMS explained the majority of the effect of the communication network on errors: centralized groups performed worse because they had weaker TMS than decentralized groups. There was a countervailing effect of communication network—centralized groups communicated more than decentralized groups, which improved their TMS and thereby reduced errors—but this effect was smaller than the effect of the communication network on errors through TMS when group membership was stable. Hence, when there was no turnover, the net effect of having a centralized network increased errors ($-.21 + .98 = .67$).

When groups experienced turnover, however, the magnitudes of the effects changed (see Figure 6c). For groups that experienced turnover, the effect of the having a centralized network on communication per path was much stronger than for groups that did not experience turnover and the effect of communication per path on TMS was also stronger. When groups experienced turnover, the effect of centralized networks to reduce errors through their effect on communication per path and TMS exceeded the centralized network's effect to increase errors through TMS alone ($-.52 + .44 = -.08$). Taken together, the net effect was such that centralized groups performed worse than decentralized groups when they did not experience turnover but performed better than decentralized groups when they did, due to their increased communication per path improving the group's TMS.

We then tested the same moderated serial mediation with new features as the dependent variable. The serial pathway of the centralized network effect on new features through communication per path and TMS was not significant for groups with stable group membership ($B = .02$, 95% CI: $-.04, .16$) but was positive and significant for groups that experienced turnover

errors was smaller (no turnover: $B = -.13$, 95% CI: $-.48, .05$; turnover $B = -.41$, 95% CI: $-.89, -.16$) though still significantly moderated by turnover (95% CI: $-.71, -.01$).

($B = .09$, 95% CI: .01, .28). TMS by itself acted as a significant mediator of the effect of having a centralized network on new features for groups with stable membership ($B = -.55$, 95% CI: -1.34, -.09) but not for groups that experienced turnover ($B = -.03$, 95% CI: -.33, .26).¹² These results are very similar to results presented above for errors; however, neither of the mediations were moderated by turnover. As a whole, we have found general support for our hypotheses and for the overall model in Figure 6a. Results were stronger for errors than for new features.

Member Turnover for Centralized Groups Robustness Check

As described in the methods section, centralized groups could experience the loss of a member from either the central position or a peripheral position. Because the central and peripheral turnover conditions did not differ in their errors, new features or the strength of their transactive memory systems, these two centralized turnover conditions were combined into a single, centralized network turnover condition in the above analyses. In this section, we describe results of analysis that replicated those described above including one form of centralized turnover in the analysis at a time.

First, the difference in the number of errors between groups that experienced turnover of a central or peripheral member did not approach significance (1.22 and 1.23, respectively). When either of the centralized turnover conditions (central member or peripheral member turnover) were removed from model 1 in Table 4, the interaction of network structure and turnover was the same direction and marginally significant ($p < .1$). This reduction in significance is likely due to

¹² These analyses were repeated using only communications from the first five minutes of the task. Five minutes was the minimum time to completion for the feature-generating task. Results from these analyses are very similar to those reported in the manuscript, indicating that the results are robust. The serial pathway in the moderated serial mediation predicting new features was nearly identical to that presented in the manuscript. The serial pathway was significant only for groups that experienced turnover (no turnover: $B = .01$, 95% CI: -.06, .14; turnover $B = .09$, 95% CI: .01, .28) and TMS was a significant mediator only for groups that did not experience turnover (no turnover: $B = -.52$, 95% CI: -1.30, -.06; turnover $B = -.03$, 95% CI: -.33, .23). However, neither the serial mediation nor the mediation through TMS were significantly moderated by turnover (95% CI: -.03, .26 and 95% CI: -.04, 1.25).

a reduction in power. Similarly, there was no significant difference between the number of new features generated in either central member or peripheral member turnover groups (4.52 vs. 5.00, respectively). No differences were detected when Model 3 in Table 4 predicting new features was run with only one of the centralized turnover conditions included in the analysis at a time.

Next, we re-ran all moderated mediation analyses with data from only one of the two centralized turnover conditions included at a time. Results for the moderated mediation predicting TMS, the moderated serial mediation predicting errors, and the moderated serial mediation predicting new features produced the same results regardless of which centralized turnover condition was included. Thus, turnover in centralized groups appeared to have a similar effect regardless of whether the peripheral or central member left the group.

Discussion and Conclusion

Our results indicate that turnover reverses the effect of communication networks on group performance. Decentralized groups performed better when membership was stable than when turnover occurred. By contrast, centralized groups performed better when turnover occurred than when membership was stable. Transactive memory systems explained or mediated the effect of the communication network on group performance. Further, the amount of communication along each pathway explained how the strength of a group's TMS varied as a function of its communication network and turnover. When groups experienced membership turnover, centralized groups communicated more with their new members than decentralized groups, and this greater communication enabled centralized groups to both strengthen their TMSs and increase their performance. When decentralized groups experienced turnover, they communicated less with the new member, which reduced both their TMS and their performance.

Taken together, our results indicate that membership stability is an important factor that determines centralized and decentralized network performance. When membership was stable, decentralized groups developed a stronger TMS than centralized groups. Decentralized groups were able to implicitly coordinate members' contributions and tailor group processes to individual group members. When turnover occurred, however, the new member could not readily understand either the decentralized group's implicit coordination logic or his or her role within the group. By contrast, the explicit coordination logic of centralized groups enabled them to make better use of the contributions of new members than decentralized groups. Two features of the centralized communication networks helped groups integrate new members and benefit from their ideas and perspectives. First, in centralized groups the means of coordination, which were largely determined by the communication structure, were simple and explicit. Second, the greater communication per path in the centralized groups reduced the likelihood that the incumbent members would ignore the new member. The active integration of the new member not only encouraged the formation of a strong TMS but also improved the group's creativity and problem-solving capabilities. Thus, when group membership was stable, the implicit coordination and tailored roles in decentralized networks resulted in stronger TMS and higher performance than centralized groups. But when turnover occurred, the explicit coordination logic inherent in centralized networks enabled them to incorporate the new member, and this integration stimulated the development of TMS and improved performance.

The experimental manipulation of communication networks we use here provides two distinct methodological advantages. First, even though some research has ventured to understand how networks affect group performance, identifying the direct causal effects of networks has proven challenging in field settings, particularly because of endogeneity issues

(Ferriani et al., 2009; Lee et al., 2014; Rulke & Galaskiewicz, 2000; Uzzi & Spiro, 2005). Our study design provides insight into communication networks and group processes and is unhampered by endogeneity concerns (see Croson, Anand, & Agarwal, 2007, for a discussion of the advantages of experimental research). The experimental design and random assignment of participants to both communication networks and to positions in the networks also enabled us to attribute effects to the communication network rather than to conditions that led to the formation of the network or to qualities of individuals who might gravitate to certain positions in the network (Sasovova, Mehra, Borgatti, & Schippers, 2010). Thus, directly manipulating the communication network allows us to make causal claims about the effects of communication networks on group performance (Manski, 1993). Second, where possible we used behavioral measures such as the amount of communication, which are more objective than self-reported variables (Spector, 1994). In particular, self-reports of communication and social networks have been found to be heavily biased by social factors, such as individual status (Bernard, Killworth, & Sailor, 1976).

In addition to providing insights difficult to obtain by other methods, the design of our study maps well to organizational phenomena. The two tasks we used—the programming task and the idea-generating task—parallel many tasks found in organizational settings. Within organizations, groups often work on complex tasks, which involve both problem solving and creativity (Devine, Clayton, Phillips, Dunford, & Melner, 1999; Kozlowski & Ilgen, 2006). Thus, our realistic tasks provide external validity. In addition, we trained individuals on different information to increase task interdependence among the group members, which captures the challenge of integration and coordination among groups with specialized members. Group members also communicated through computers located in separate rooms and thus, operated as

a distributed group. This arrangement is analogous to contemporary project-based work conducted in organizations via email (Kleinbaum, Stuart, & Tushman, 2013; Aven, 2015). This feature of our experiment not only represents a condition under which many groups operate in organizations today but also allowed us to control the communication network and to capture all communication that occurred among group members. While the features of our experimental design were chosen to reflect characteristics of real organizations, these design features also present boundary conditions to which our findings are most likely to generalize. Therefore, we anticipate that our findings would generalize to groups in which members perform complex interdependent tasks and communicate in a distributed manner.

One limitation of our study was that the feature-generating task always followed the programming task. We thought that this was the most realistic sequence: it would be more natural for teams to identify “ways that the pipe you just built could be improved by creating new features” after rather than before they had built the pipe. The correlation between errors in the programming task and new features in the feature-generating task was $-.33$, which indicates a moderate relationship between the two tasks: as errors on the programming task decreased, the number of new features increased. Thus, performing well on the first task did not constrain members from being able to identify ways the pipe could be improved on the second task. Nonetheless, it would be useful in future work to develop an idea-generating task that could occur before or after the programming task and thus, allow the order of tasks to be counterbalanced.

This paper contributes to several literatures as well as highlights their intersections. In a review of the transactive memory literature, Ren and Argote (2011) recommended greater research on how social networks affect the development of transactive memory systems. Our

research shows that the communication network is an important predictor of transactive memory systems. In addition, our findings demonstrate turnover conditions the effect of the communication network on TMS development. Decentralized groups have stronger TMS when membership is stable than when turnover occurs. Within centralized groups, the event of turnover alters group processes to promote the development of TMS. Whereas prior work has primarily demonstrated negative effects of turnover on TMS and performance (Lewis et al., 2005; Lewis et al., 2007), our results indicate that turnover can stimulate the development of a strong TMS for centralized groups.

As has been called for, our findings also offer insights into the effects of the communication network structure on group-level outcomes, such group performance (Casciaro, Barsade, Edmondson, Gibson, Krackhardt, & Labianca, 2015). Although there is a robust literature on the effects of communication networks on individual outcomes (Ahuja, Galletta, & Carley, 2003; Borgatti & Cross, 2003; Cross & Sproull, 2004), our work provides new insights into the effects of network configurations on group-level outcomes. In this study, we empirically established that under stable membership a decentralized communication network enables the development of TMS, which in turn leads to positive performance. In addition, our findings begin to unpack how communication networks interact with membership change to affect group processes. Both the greater communication to the new member in the centralized groups and qualitative excerpts from the transcripts suggests that new members in centralized groups were incorporated into the group's communications more fully than new members of decentralized groups. In the turnover condition, the communication among the centralized groups was more likely to be balanced among all of the members and not simply restricted to just the incumbent members. Interestingly, research on the collective intelligence of groups has also found that less

variance in communication participation among group members (equal turn-taking) is associated with higher group performance (Woolley, Chabris, Pentland, Hashmi, & Malone, 2010).

Our results suggest that dynamic environments where member turnover commonly occurs might benefit from encouraging centralized communication. The results of our mediation analyses provide further insights into how groups might address membership turnover, such as promoting the communication to and from the new members. Just as assigning a facilitator in brainstorming sessions improves creativity and efficiency (Sutton & Hargadon, 1996), assigning an incumbent group member to communicate with new members and encouraging them to contribute might facilitate the integration of new members even in decentralized communication settings. Alternatively, structured processes or formal procedures that facilitate contributions from all members could also be effective in offsetting the negative effects of membership turnover. Future research should examine these mechanisms in enabling groups to integrate new members and perform effectively when membership change occurs.

Our results have implications for organizational design and contradict the classic advice in the literature (e.g., see Burns & Stalker, 1961) that organizations in dynamic environments should be organized in an organic manner. Instead, our study indicates that when dynamism is caused by changes in membership, centralized or hierarchical groups perform better than decentralized groups. Thus, our results suggest that taking a fine-grained approach to understanding the source of the dynamism will advance organization design research as well as contribute to a growing body of literature on the benefits of certain forms of bureaucracy (Adler, 2012; Bunderson & Boumgarden, 2010).

In their seminal work, Burns and Stalker (1961) argued that groups can cultivate either efficiency or control through constrained/formal/mandated structures or creativity and innovation

by permitting more autonomy and emergent coordination (Bunderson & Boumgarden, 2010). Centralized networks are rarely viewed to be useful for innovation as their limited pathways reduce the interconnectedness and thus interactions of unique idea holders, undermining innovation. However, limited structures may help provide the necessary communication arrangement to share ideas when the group's membership is not stable. Our findings suggest that turnover provides a means to introduce innovation and creativity into mandated structures or centralized networks. Thus organizations may be able to gain the benefits of efficiency while also increasing the innovation capabilities of their teams by adopting centralized structures coupled with the frequent rotation of team members.

CHAPTER 4 (Study 3): Ties that bind and ties that tear: The influence of network centralization and density on shared social identity and group performance

Abstract

I theorize that the structure of a group's network can affect performance when it inhibits positive group processes that are driven by low perceived differences between group members if the structure increases those perceived differences. Two unique but difficult to empirically separate measures of network structure are centralization and density. Centralization is the variance in an individual's structural relationships; density is the number of ties available to group members. I propose that both centralization and density have an interactive effect on the extent to which there are differences in how group members perceive their group. Shared social identity, the extent to which all group members see themselves as members of a group, will be reduced if differences between group members are evident. Shared social identity, in turn, increases the likelihood the group will develop a shared understanding of who knows what—also known as a transactive memory system (TMS)—which positively influences group performance. In a laboratory experiment, I manipulated the centralization and density of each groups' communication network separately, allowing their main and interactive effects to be isolated, and assessed TMS using both indirect and direct measures. As hypothesized, centralization and density interacted such that increasing density lowered the shared social identity of centralized but not decentralized groups. Shared social identity then increased group's level of TMS and both mediated the effect of centralization on performance. This work serves as a bridge between studying the structural effects of networks on group psychological phenomena and suggests that structural effects alone are not sufficient to understand group outcomes.

Ties that bind and ties that tear: The influence of network centralization and density on shared social identity and group performance

The structure of a group's communication network influences its performance due to both direct effects of the structure on performance and the structure's effects on psychological phenomena within the group. Differences in how individuals are connected can often lead to difficulty in individuals' ability to collaborate with their peers effectively (Ashforth & Mael, 1989). If we had a better understanding of which structural differences were the most damaging to group members' ability to collaborate, more effective decisions could be made in improving group performance. If the structure of the group members does not limit a group's desire or ability to collaborate, then groups will have more ability to develop positive group processes such as a shared social identity—the extent to which group members feel like members of a group—or a transactive memory system—the extent to which there is a shared understanding of who knows what in a group. Both of these processes help groups collaborate more effectively and perform better. A better understanding of the direct and interactive relationships of network structure on these aspects of group performance could allow for more effective decisions in structuring work groups.

Two important dimensions of overall network structure are centralization and density. Centralization is the extent to which certain members in the network act as communication bridges between other members (Freeman, 1979).¹³ Density is the proportion of possible communication paths that are used between given individuals within a group (Wasserman & Faust, 1994). These concepts are important as the communication networks of small groups are often differentiated based on their centralization and density (Katz, Lazer, Arrow, & Contractor,

¹³ Throughout this paper, centralization specifically refers to betweenness centralization (Freeman, 1979), however, in networks of small groups, the relative rankings of networks on other forms of centralization (e.g. degree or closeness) are very similar.

2004). Centralization in a network suggests that there is strong leadership (Cross & Prusak, 2002) or strategic actors (Burt, 1992). Density, conversely, suggests that members are close-knit (Barnes, 1969). Although centralization and density are conceptually distinct, it can be difficult to tease apart their effects because the two dimensions are often highly correlated in field settings. Understanding the influence of these network concepts in isolation can provide a better understanding of which network features should be encouraged within a given network. For example, if a manager is in a position to influence the communication structure of a group with the goal of improving overall performance, should the manager merely focus on increasing the number of ties (density) or changing the group's structure (centralization)? The manipulation of centralization and density in the laboratory allows us to create networks in which density and centralization are relatively uncorrelated with one another to help better answer this question.

The centralization and density of a group each influence the extent to which group members have similar connections to others in the group. If group members occupy similar positions in a network, they are likely to perceive that they are similar to each other (Michaelson & Contractor, 1992) and belong to the same group. If members do not perceive their coworkers as similar to themselves, their motivation to work with them may be reduced (Ellemers, Gilder, & Haslam, 2004).

When members feel that they are all part of a group, they share a social identity (Tajfel & Turner, 1985). Social identity is the psychological process whereby individuals place themselves and others into categories based on perceived areas of similarity. When group members identify with their group, they are more committed (Jehn & Shah, 1997) and motivated to perform well (van Knippenberg, 2000). The extent to which a group has a shared social identity also increases

a group's transactive memory system (Liao, Jimmieson, O'Brien, & Restubog, 2012), which increases its performance (Ren & Argote, 2011).

I argue that centralization and density interact with one another to influence the extent to which members are similarly connected to the other members in the group, and thus the extent to which they share an identity. Increasing density through adding ties will make decentralized group members more similarly connected and centralized groups less similarly connected. Thus, as networks become denser, perceptions of a shared social identity decrease for centralized groups and increase for decentralized ones. Adding a tie to centralized groups decreases members' sense of a shared identity and weakens the groups' TMS, which in turn decreases its performance. By contrast, adding a tie to decentralized groups can increase members' perceptions of sharing an identity, strengthen their TMS and increase their performance. Thus, the interactive effect of network centralization and density on group performance is mediated by the effect of the structure on shared social identity and TMS. These relationships between the network and group psychological factors explain the effects of the network on group performance.

In the sections that follow, I develop the rationale for these hypotheses. I then describe the methods for the experiment in which the hypotheses are tested. I used an experimental design to randomly assign groups to predetermined networks and individuals to positions within those networks. Results from the experiment are presented and interpreted. The paper concludes with a discussion of the implications of the findings for theory and for practice as well as directions for future work.

Communication Network Centralization

The concept of network centralization as currently used was first formalized in Freeman (1979) after having been proposed by Bavelas (1948). Individual-level centrality metrics measure features such as the number of shortest paths between others on which an individual lies—an example of betweenness centrality—to determine the relative difference of an individual's position in the network compared to that of other individuals.¹⁴ The network-level centralization measures that Freeman (1979) developed assess the extent to which there is variance in the levels of centralization for the individuals in the network. If large differences exist in individual-level centrality, the network is centralized.

Besides the overall influence of network centralization on the ability of the group to coordinate, the centralization of the network also influences the extent to which members are similarly or dissimilarly connected with one another. If members are unequally connected to one another, they may feel like they, or other members, are being excluded from the group. Network density, the extent to which there are many or a few connections in the network, also influences the extent to which members recognize differences between themselves and other team members.

Network Density

Density, in network terminology, is the number of ties that exist divided by the number of possible ties (Wasserman & Faust, 1994). Dense networks distribute information among group members quickly because few steps are required to get from one person to another (Friedkin, 1981). Network density has been found to increase information sharing and collaboration within groups (Reagans, Zuckerman, & McEvily, 2004; Balkundi & Harrison, 2006). Reagans et al.

¹⁴ There are many ways centrality can be calculated but in team networks of my interest, the comparative rankings of these networks are practically identical. See Table 5a for a comparison of centralization values for four networks of four members.

(2004) found that group members who were more similar to one another were more likely to form a dense network. Individuals were more likely to interact with those who were similar to themselves. Though in Reagans et al. (2004) the individual's behaviors led to the network formation, it is possible that an individual will believe that the members of their group are more similar if their network is densely connected. To the extent that dense connections lead to a reduction in differences in members' connections density may lead members to identify more with their peers.

I propose that that centralization and density interact to affect group processes and outcomes. Centralization influences the extent to which group members vary in the connections that they have. Groups that have high levels of centralization have individuals who are more highly interconnected or who are keeping individuals separated. Centralization, therefore, increases the extent to which members perceive differences between group members due to their unequal connections. More central members, for example, are differently connected to the group than peripheral members. When centralized groups increase in density, these perceived differences do not necessarily diminish. When more ties are added to a group but the centralization remains high, these additional ties may not serve to reduce the inequality in connections. Within decentralized groups, however, becoming denser leads to group members being more equally connected with one another as ties must be spread out among members.

Relationship of the Network to Group Psychological Phenomena

Though network researchers often study the interactions within dyads and small groups, psychological phenomena are infrequently studied when researching networks. This has been changing, however, with recent research in group-level networks which have investigated psychological mediators to explain the influence of network features on group performance (see

Rulke & Galaskiewicz, 2000; Lee, Bachrach, & Lewis, 2014; Troster, Mehra, & van Knippenberg, 2014). Interactions between individuals, which can be measured or manipulated through the group's network, often build the relationships and psychological states on which group researchers focus. Focusing on the relationship of the network to the group allows us to leverage research in both areas to increase understanding. One concept that promises to increase understanding of how members respond to differences in how they are connected to their network is shared social identity.

Shared Social Identity

Social identity theory proposes that individuals categorize themselves and others into groupings that help individuals make sense of social relationships (Tajfel & Turner, 1985; Turner, 1982). A shared social identity—the extent to which group members classify themselves as being part of a group—influences the feelings and behavior of group members (Doosje, Ellemers, & Spears, 1995; Ashforth & Mael, 1989). For example, individuals perceive other individuals with whom they share an identity more positively and as more likely to cooperate with them than with individuals with whom they do not share an identity. Social identity is not a new concept in the study of networks. Homophily, that members who are similar to one another are more likely to interact (McPherson, Smith-Lovin, and Cook, 2001), is an outcome of individual social identity decisions and is frequently found in social networks. In addition to influencing network formation, the group's network structure can be influenced by the extent of shared social identity within a group.

Shared social identity increases within a group as individuals recognize factors about themselves that are similar. Absent other information, individuals might use their own position or the positions of their peers within the group's communication network to determine who is

classified into which categories. If individuals see two individuals who are similarly connected, they are more likely to think those individuals are similar to one another (Michaelson & Contractor, 1992). Thus, if individuals see others who have the same kinds of connections as themselves, they infer that those others are similar to themselves. If there are few categories or if all members are in the same category, the average level of shared social identity within the group is likely to be high. Thus, the communication network within a group can be the basis through which individuals make social identity judgments. The network of the group as a whole would therefore influence the extent to which the group members have a shared social identity.

Imagine a globally distributed team with four, interdependent members who are each at a different office: Alice, Bob, Candace, and David. All team members primarily communicate with Alice and not directly with each other. Bob, Candace, and David may recognize that they all share the same relationship to Alice and feel similarly about their relationship to their peers. If, however, Bob and Candace begin communicating with each other, David who is primarily communicating only with Alice, might feel left out. Bob and Candace might also feel that the group is now less of a group as they feel closer to each other than their peers. This change in how members feel about their membership is driven by how differences in their communication network influence their group psychological states. These network differences change how the group members experience the group and the extent to which they share an identity.

Role equivalence is a form of general equivalence that measures the extent to which individuals would look the same in a network map if there were no labels (Winship, 1988; Pattison, 1994).¹⁵ A role equivalent class is the subset within a network where all members within the subset share the same kinds of connections (e.g., tied to an individual who is tied to two others). The more unique classes there are within a network, the more differences there are

¹⁵ I am using the automorphic equivalence definition of role equivalence (Hanneman & Riddle, 2005).

between the average two individuals in the group, as more members have different sets of connections. Thus, as the number of role equivalent classes increases, the less likely a member will be connected to peers who are role equivalent to themselves. This makes it less likely for a given member to see him or herself as having a similar network to the network of his or her peers. That is, the more classes there are, the less chance a member recognizes another member who is role equivalent to him or herself. When a member recognizes that another member has a different set of connections, he or she will feel less like a part of the group.

Figure 7 and Table 5a describe a set of networks where there is an interactive relationship between density and centralization such that density increases the number of classes in centralized groups and reduces the number of classes in decentralized groups. Table 5a provides various network-level metrics of comparison including three centralization values, average path length, and the number of role equivalent classes. In these networks, we see that for centralized networks, having dense connections increased the number of role equivalent classes compared to centralized networks that were sparsely connected. This effect is reversed for decentralized groups where the dense network has fewer role equivalent classes than sparse groups. I propose that increases in the number of role equivalent classes will increase feelings of isolation by leading members to feel different from one another. Thus, within centralized networks, dense networks will have lower shared social identity than sparse groups and these effects will be opposite for decentralized groups. Thus, increased density negatively affects shared social identity for centralized groups but positively affects shared social identity for decentralized groups.

Hypothesis 1: Density negatively moderates the effect of centralization on shared social identity such that centralized groups have lower shared social identity when they are

dense versus sparse and decentralized groups have higher shared social identity when they are dense versus sparse.

Transactive Memory Systems

A transactive memory system is the shared division of memory and cognition within a group such that information about who knows what is encoded, stored, and made available for retrieval (Wegner, 1987; Lewis & Herndon, 2011). When individuals work closely with one another, they learn each other's skills and areas of expertise (Liang, Moreland & Argote, 1995). Lewis and Herndon (2011) described how TMS differs from other socially shared cognitions, in that there is differentiated knowledge. TMS assists group performance by providing a basis for group members to make decisions about who should perform which tasks or who should be asked for advice. TMS typically improves group performance in terms of increased production, reduced errors, and increased creativity (see Ren & Argote, 2011, for a review).

Transactive memory systems form over time as individuals closely interact with one another (Wegner, 1987; Liang, et al., 1995). Recent work, suggests that group shared social identity also leads to a more developed TMS (Liao, Jimmieson, O'Brien, & Restubog, 2012). Liao and colleagues (2012) proposed that shared social identity would increase TMS through motivating group members to invest resources in developing a TMS. When group members share a social identity, they are more willing to trust their teammates and be interdependent with one another. It can be risky to rely on a teammate's areas of expertise instead of one's own. If members have a shared social identity, however, the development of a transactive memory system will be a natural extension of their work together. Additionally, individuals who share a social identity are more likely to engage in knowledge transfer and typically perform better as a group than those lacking a shared identity (Kane, Argote, & Levine, 2005). Increased knowledge

transfer between group members provides more access to information about individuals' areas of expertise, and, thereby, more opportunities to increase the group's TMS. In a subsequent field study, Liao, O'Brien, Jimmieson, and Restubog (2015) found evidence that shared social identification increased group TMS giving some empirical support for this hypothesis.

Hypothesis 2: Shared identity increases the strength of a group's TMS.

Lastly, I hypothesize that the majority of the effects of network centralization and density on group performance will be explained by social shared identity and TMS. Prior research has found that centralization's effects on performance are in part due to centralization's effect on group TMS (Argote, Aven, & Kush, under review). These researchers focused on communication as central members can become overwhelmed if there is need for a lot of discussion (Guetzkow & Simon, 1955). Members becoming overwhelmed is in part due to centralized groups having difficulty knowing of effective ways to collaborate (Burgess, 1968). As the development of a transactive memory systems are, in large part, a means by which members learn to collaborate (Lewis & Herndon, 2011) the network's influence on TMS should help explain performance impacts due to poor ability to collaborate due either to centralization, density, or their interaction. Thus, the effects of the network structure on performance will be due primarily to the network's effects on the group processes of interest: shared social identity and TMS.

Hypothesis 3: Shared social identity and TMS will mediate the effects of network structure (centralization and density) on group performance.

Scope Conditions

Prior researchers have studied the effects of density and centralization on group performance, initially using simple information aggregation tasks (Bavelas, 1950; Leavitt, 1951;

Guetzkow & Simon, 1955) and later in more complicated or difficult tasks (Shaw, 1964; Faucheux & Mackenzie, 1966). Centralized groups typically perform better on simpler tasks, but decentralized groups are often better on more complicated tasks because centralized members can become overwhelmed (Cross & Prusak, 2002). I am interested in complex tasks that require coordination and the combination of unique areas of expertise. I am also primarily interested in teams whose work is internal to the group, with few external parties involved. Examples of such complex tasks abound in organizations and include tasks such as computer programming, strategic planning and medical diagnoses. In order for members to recognize their network, I hope to relate these findings to groups that are fairly small with no more than 5 or 6 members. Groups with larger sizes may have different relationships as the complexity of their networks become exponentially larger. I test this possibility with a simulation at the conclusion of the results. Table 5b provides examples of teams that fit within the scope of this study, separated by how their communication structures would often be categorized.

Methods

Participants

Four-person groups were recruited through a public participant pool at a mid-Atlantic university and randomly assigned to one of the four different experimental conditions. Data were collected from fifty-four groups for a total of 216 participants. Participants received either \$15 or course credit for their participation.¹⁶ There was an additional incentive of \$60 for the best performing group in each condition. Four such rewards, one per condition, were given. Fifty-four percent of the participants were female. Fifty-five percent of the participants were Asian or

¹⁶ No significant difference was found on any of the dependent variables on whether the participants received cash or course credit. Thus, this control was not included in any analyses.

Asian American, 30% were Caucasian, 8% African American, and 7% reported other ethnicities. The average age of the participant population was 24.8 years with a standard deviation of 7.5.

Tasks

Participants completed a programming task and an innovation task. In the programming task, participants used Yahoo! Pipes—a graphical programming tool—to create a program that would allow a user to search Flickr¹⁷ for pictures using a keyword and a location. To ensure the task was interdependent, each participant received unique information about one of four specialized modules needed to complete the task. The task was impossible to complete successfully without all group members sharing their unique information. Each participant sat in a separate cubicle from the other participants. Participants collaborated through an instant messenger and through a shared virtual workspace. On this workspace, all members were able to see and contribute to the task. Participants were given 15 minutes to complete this task.

In the innovation task, participants used the shared virtual workspace to generate ideas for new programs that could be made using Yahoo! Pipes. In addition to ideas for products, the group members also ranked their ideas from most to least useful as well as their perceptions of how difficult it would be to create a program that accomplished those goals. The groups were told that their performance would be judged based on both the number and quality of their submissions. This task involved idea evaluation and some amount of assessment and implementation, making it similar to the kind of innovation tasks done by organizational teams (Parnes, 1975). The groups were given 15 minutes to work on the innovation task.

Manipulations

This experiment was a 2 (Density) X 2 (Centralization) between-subjects design. The total number of bidirectional ties possible in a group of four individuals is six. The assigned

¹⁷ Flickr is a popular photo sharing website.

networks contained either three or four bidirectional ties made available to the participants. The overall network density for these structures was, therefore, .5 or .67, respectively—density is the number of ties divided by the number of possible ties. The centralization of the group was manipulated by changing the interconnections between the four members to create networks that were relatively high (.80) or low (.22) in betweenness centralization. Representations of the structures used in the experiment can be found in Figure 7. In Table 5a, the number of ties between the individuals is the number of communication channels open within the group. All other values in this table are the theoretical values for this structure, and the ties are unweighted. The three centralization values were calculated using the formula in Freeman (1979) and are essentially the extent to which the individual with the highest individual level centrality differs from the average group member. Degree centrality is the number of ties for each individual. Betweenness centrality is the extent to which an individual bridges between other members in the group. Closeness centrality is the distance an individual is from other members on average. Role equivalent classes are determined using automorphic equivalence as defined by Hanneman and Riddle (2005). This is the number of individuals or sets of individuals that have the same basic tie structure in their local group. Average path length is the average number of steps from one individual to any other individual in the group.

Procedures

Participants were randomly assigned to cubicles isolated from the other participants as they arrived in the laboratory. After all of the group members had arrived, the participants individually watched a short training video to introduce them to the Yahoo! Pipes programming tool. The group members then began the 15-minute practice period where they worked on a Yahoo! Pipe collaboratively, communicating using an instant messenger. The instant messenger

only allowed communication between members based on the structure to which they were assigned.

After the practice task, the group members either completed the programming task or the innovation task. The order of the two tasks was randomly determined and counterbalanced to counteract any order effects.¹⁸ Each group completed a short survey in between the two tasks and after the second of the two tasks. The group members were then debriefed, thanked, and compensated for their participation.

Measures

Transactive memory systems (indirect measure). An indirect measure of transactive memory systems was assessed using Lewis's (2003) 15-item survey measure, which is the most commonly used measure and generally has acceptable psychometric properties. This survey instrument contains measures of three indicators of a developed transactive memory system: specialization, coordination, and expertise credibility. I included this measure in the survey between the two tasks and at the end of the experiment. The second measure of TMS was used in this paper as this would be measure of the strength of the group's final TMS. The average $Rwg(j)$, which measures within-group agreement, was large suggesting that group members generally agreed on the group's TMS (.91). The ICC values [$ICC(1) = .29$, $ICC(2) = .62$, $p < .001$] and Cronbach's alpha (.87) were also acceptable.

Transactive memory systems (direct measure). In addition to the indirect measure of TMS mentioned above (Lewis, 2003), I also included a direct measure of TMS based on Austin's (2003) measure. Austin (2003) proposed that TMS itself could be directly measured through measuring the structure of members' areas of knowledge and their understanding of their

¹⁸ Small differences in the effect of the order of the task were recognized—groups performed slightly better on tasks that they completed second but these differences were not statistically significant. Groups made 11.1% more errors if they did the programming task first and 9.7% fewer innovative ideas if they did the innovation task first.

peers' knowledge. Austin (2003) proposed measuring the total amount of knowledge in the group (knowledge stock), the amount of individual-level specialization, the amount of agreement about who has what knowledge, and the extent to which group members come to consensus about who the experts are. I modified the Austin (2003) measures slightly to better accommodate the tasks in the present study. Due to an oversight, 8 groups did not receive the battery of questions used to derive the Austin-style questions. These 8 groups did not significantly differ from the 46 groups that received these questions on their scores on any mediator or dependent variable. Thus, all Austin-style measures created will be for the smaller sample of 46. There do not appear to be any differences between these groups and groups not included.

Participants were asked about their own and other's level of knowledge on a 5 point scale from 1 "strongly disagree" to 5 "strongly agree" with the option of saying "I don't know" for 12 areas of knowledge. These 12 areas were developed during pre-testing and pertain to specific modules in Yahoo! Pipes, actions that need to be done during Yahoo! Pipes development (e.g. linking modules) and about the steps in the innovation task. Exploratory factor analysis with varimax rotation confirmed that the 9 questions related to the programming task loaded on one factor and the 3 questions related to the innovation task loaded on a separate factor. These two factors explained 44.1% and 21.3% of the variance in these 12 items, respectively. Knowledge stock variables were created for each task with the 9 items for the programming task and the 3 items for the innovation task summed separately and then averaged at the group level.

Individual-level and group-level specialization scores were calculated using standard deviations. For the individual-level measure, the standard deviation of self-reported knowledge across all 12 areas of knowledge was calculated. For the group-level measure, the standard deviation was calculated across all members for each 12 areas of specialization separately. Thus

there were 12 values, each representing the extent to which there was variance in how much knowledge each individual reported having in the group. These values were then averaged.

Accuracy in members assessing the other members in their team was calculated by first calculating inaccuracy with the following formula:

$$InaccuracyAssessingMembers = \sum_{X=1}^t \sum_{i=1}^n |MemberX_i - GroupAverageX_i|$$

Where t = is each of the four members of the group and n = each of the 12 knowledge categories. Thus, four inaccuracy values are created, one for each member and then these four calculations were summed to provide a group-level member inaccuracy value. This value was then subtracted from the maximum value in the sample to transform the inaccuracy score into an accuracy score. The lower this value, the more the average of the group's perceptions of each member's area of knowledge differed from the average member's self-reported knowledge. The higher this value, the more accurate the group's perceptions were.

Austin (2003) calculated consensus based on the number of members that agreed that a given individual was the most expert in a knowledge area. This was possible because the knowledge questions forced members to rank their peers. I calculated a consensus measure as the extent to which there was variation around individual's ratings of a peer's level of knowledge. I calculated the standard deviation of all ratings of individual X's ability in knowledge area I for all member knowledge pairs, this created 48 variables. These were then averaged within an individual and then within the group. This value was subtracted from the maximum value within the sample to create a measure of consensus. This consensus variable was the extent to which members agreed about the ratings of members on knowledge in the group.

Shared social identity. Social identity was measured using three survey instruments developed by Luhtanen and Crocker (1992), Doosje, Ellemers, and Spears (1995), and Hinds and

Mortensen (2005). The first two measures use surveys to assess group members' feelings of connectedness and oneness with the group. The third measure asks participants to look at two circles that vary from being totally separate to mostly overlapping. One circle is labelled "self" and the other circle is labelled "other." The participants then choose the level of circle overlap that represents how they felt about being part of this group. The Luhtanen and Crocker (1992) measure had acceptable reliability and agreement among the group members [Cronbach's alpha = .77, rwg(j) = .75, ICC(1) = .12, ICC(2) = .34, $p < .05$]. The group members did not have acceptable agreement on the Doosje, Ellemers, and Spears (1995) scale [rwg(j) = .76, ICC(1) = .01, ICC(2) = .06, *n.s.*] or the Hinds and Mortensen (2005) measure [ICC(1) = -.05, ICC(2) = -.23, $p = n.s.$]. Thus, only the Luhtanen and Crocker (1992) measure was used in the analyses.

Errors. The measure of Errors was calculated based on the Yahoo! Pipes that the groups submitted. Errors were differences between the program the group built and a correct pipe. Errors were typically due to missing important modules, missing or wrong settings within modules, or incorrect modules being present. All individual errors were based on the number of settings that the missing module contained or the number of settings that needed to be changed. This provided an objective criterion to weight different errors that is approximately the number of steps the group would need to take to make their program work. Two coders assessed all errors, and had good agreement (Cohen's Kappa = .74, $p < .001$). Coders met to discuss any disagreements and corrected the final coding used.

Innovative ideas. The list of innovative ideas from the innovation task was assessed by two coders to determine the number of innovative ideas each group generated. Ideas were assessed on the extent to which they were coherent and responsive to the prompt. Ideas only had to be present, they did not have to have a ranking or a rating. These two coders reached

substantial agreement (Landis & Koch, 1977) with a Cohen's Kappa of .64 ($p < .001$). An average of the two coders ratings was used in analyses. An additional, more restrictive assessment of innovative ideas was also created for a robustness check. In order for an idea to count it had to also have a rating and a ranking.

Network manipulation checks. Group members responded to a series of general descriptions of the qualities and structures of their communication network. First, I asked participants to report their perception of the group's communication network by responding to the questions such as "Can A communicate with B". Participants were also given descriptions of the actual network or qualities such as: "One member could communicate with everyone" "Each member could communicate to one or two members on either side so we formed a chain" and responded on a 5-point scale strongly agree to strongly disagree scale.

Results

Manipulation checks

Though experimental manipulations were used to enforce a particular communication network structure, groups could have been differently affected by the network structure or could have not used the entirety of the available network structure. In order to determine the effectiveness of the manipulations, two types of manipulation checks were used. The structure of the actual communication network was assessed based on how the group used the connections available to them. Second, groups answered survey items asking about the structure of their network. Questions either provided written descriptions of networks or described qualities of networks that centralized or dense networks would be more or less likely to have than decentralized or sparse networks.

Weighted, directed networks were created for each group based on their communications through the instant messenger. As network-level effects of interest (centralization and density) are primarily available only for unweighted networks, ties in the network were dichotomized at the mean minus one standard deviation. This means that only ties that contained at least the mean minus one standard deviation of communications within that group were present in the networks, all other ties were not.¹⁹ Network-level analyses were then performed on these emergent communication networks. Centralized group's emergent communication networks were more centralized—determined using Freeman's (1979) measure of degree centralization—than decentralized groups (.47 vs. .26, $p < .001$). I also calculated the density of these emergent networks and found again that groups in the high density condition enacted denser networks than those in low density conditions (.56 vs. .47, $p < .01$)

A series of survey-based manipulation checks were also used. First, we asked each participant “Can member X speak to member Y” for all 6 relationships that can exist within the group and members responded yes, no, or “I don't know”. Group members were 82% accurate in identifying the correct connections within their networks. This level of accuracy suggested that, on average, group members were correct on five ties and wrong on one or correct on four and reported not knowing for two. Additionally, no network condition was significantly more accurate than the others in knowing their network structure. Members in centralized groups reported that their structure isolated members more than in decentralized groups (4.0 vs. 3.6, $p < .05$), and members in dense groups reported that their structure allowed for more coordination than members in sparse groups (3.2 vs. 2.8, $p < .05$). I also included literal written descriptions of

¹⁹ Previous analyses on similar groups found robust effects for similar cutoff points. The betweenness centralization is similar with centralized groups having more betweenness centralization (.66 vs. .44, $p < .01$). Dichotomising at mean minus two standard deviations also results in statistically different degree centralization for the centralized vs. decentralized groups (.51 vs. .16, $p < .001$). Dichotomizing at the median lead to a similar mean difference (.35 vs. .28, $p < .1$).

the structure of connections within the networks that group members could agree or disagree with. Some examples can be found in the measures section of the paper. Groups in the described structure were always more likely to agree to the description of their structure compared to groups that were not in that structure.

Each participant received one of four pieces of unique information about modules used in the programming task: Count, Flickr, Sort, and Text/Location Input. Five questions captured individual's perspectives about their own and other's knowledge on each of these four areas [the first three pieces of unique information were captured in three knowledge questions (Count, Flickr, and Sort) and one was captured in two questions which were then averaged (Text Input and Location Input)]. Members that received more information about the Count or Flickr modules reported higher levels of knowledge on those than other members in their group (4.00 vs. 3.36, $p < .01$ and 4.16 vs. 3.65, $p < .01$, respectively). There was no evidence, however, that members assigned knowledge about the Sort module or the Text / Location Inputs reported being more knowledgeable about them than their peers (3.91 vs. 3.94, *n.s.* and 3.56 vs. 3.72, *n.s.* respectively). There were also small mean differences such that the individual assigned with knowledge about the Count, Flickr, or Sort modules were seen as having more of that knowledge than members without that knowledge (3.66 vs. 3.64, *n.s.*; 3.88 vs. 3.80; *n.s.*; 3.92 vs. 3.87, *n.s.* respectively). For the Inputs, however, the members who were assigned expertise were seen as having somewhat less knowledge in that area (3.60 vs. 3.72, *n.s.*). Thus, there is some limited evidence that members assigned with unique areas of knowledge reported more knowledge and were seen as having more of that knowledge than others in the group. The Sort and Inputs knowledge were somewhat simpler information, which may have been easier to transfer to peers, thus leading all members to have similar levels of knowledge.

Hypotheses Tests

Means, standard deviations and correlations are provided in Table 6. Hypotheses one and two were tested using linear regressions. As errors and innovative ideas are count variables, additional Poisson regressions were used to confirm effects but are only reported here when their results differed from the linear regressions. Hypothesis 3, the moderated serial mediation, was tested using PROCESS (Hayes, 2013; 2015), an OLS-based plugin for SPSS that allows for indirect effects tests to be performed using bootstrap sampling. All confidence intervals in mediation analyses are 95% percentile-based bootstrap confidence intervals. Analyses will first be done using Lewis's indirect measure of transactive memory systems with a subsequent analysis testing hypotheses using the direct measure of TMS.

The model proposed in hypothesis 3 of this paper is a serial moderated mediation where centralization's effect on performance through shared social identity and TMS is moderated by network density. The effect between centralization and shared social identity is moderated by density such that centralization decreases shared social identity more when the network is dense than when it is sparse, hypothesis 1. Then shared social identity increases TMS—hypothesis 2—which subsequently increases performance. See Figure 8 for a visual representation of this statistical framework.

In order to test whether the model as proposed was supported, I first ran a moderated serial mediation analysis using PROCESS (Hayes, 2013) as described in Hayes (2015). I will first report the results for errors and then for innovative ideas. For low density groups, the indirect effect of centralization on errors through identity and TMS was not significantly different from zero (0 was included in the 95% confidence interval: -2.329, .702). For high density groups, however, the indirect effect of centralization on errors through identity and TMS

was significant and positive (95% CI: .031, 3.114). The index of moderated mediation, which tests if the prior two effects have different magnitudes, was significant (95% CI: .009, 4.664). This suggests that the size of the indirect effect of centralization on errors that goes through shared social identity and TMS differs for groups that are low in density versus high in density, as predicted.

For innovative ideas, the results were very similar. There was no significant indirect effect of centralization on innovative ideas through shared social identity and TMS for groups that were low in density (95% CI: -.399, 1.427) but there was for groups high in density (95% CI: -1.919, -.033). The index of moderated mediation was significant, suggesting that the two above effects significantly differed from one another (95% CI: -2.915, -.023). This same effect is consistent using the more rigorous definition of an innovative idea: that the idea must have also had its difficulty to be created rated and ranked by usefulness compared to the group's other ideas. Again, no significant indirect effect of centralization on ranked and rated ideas through shared social identity and TMS for groups in low density (95% CI: -.518, 1.550) but there was for groups that were dense: (95% CI: -2.544, -.030). The significant index of moderated mediation indicates that the indirect effect is much larger in magnitude for dense groups compared to sparse groups (95% CI: -3.576, -.026).

These two sets of analyses support the overall model that the effects of centralization and density on performance depend on their influence on shared social identity and TMS. Within all groups, shared social identity led to stronger TMS and TMS led to better performance. For groups that were sparse, centralized and decentralized groups did not significantly differ on their shared social identity, TMS, or performance on either task. Thus, there was no significant mediation of a centralization effect on performance for sparse groups. Adding a tie to centralized

groups to make them denser, however, led those groups to have less shared social identity than dense, decentralized groups and sparse, centralized groups. Thus, a negative effect of centralization on errors, within dense groups, was due to centralized groups having lower shared social identity than dense decentralized groups, which had a subsequent negative effect on their TMS.

In order to give more clarity, I now present individual regressions to demonstrate the effects of centralization and density on errors through shared social identity and TMS, see Table 7. From Model 1 in Table 7, we see that there was a significant interaction between density and centralization in predicting shared social identity. This interaction was such that shared social identity increased slightly with density in decentralized groups (3.30 to 3.46) but decreased with density in centralized groups (3.45 to 3.10), see Figure 9. The difference between low and high density groups within the centralized condition on shared social identity was statistically significant using a planned contrast ($p < .05$). These results provide support for hypothesis 1, that centralization's effect on shared social identity is more negative when groups are dense than when they are sparse. It should be noted that group members generally agreed on their level of shared social identity. The central member within centralized groups did report slightly higher group shared identity (3.48 vs. 3.20, *n.s.*). The isolated member in the dense centralized groups did not report different levels of shared social identity than his or her peers (3.05 vs. 3.06).

Shared social identity increases the strength of TMS within groups, see model 2 in Table 7, supporting hypothesis 2. A scatter plot of this relationship is presented in Figure 10 to demonstrate the strength of this effect. Model 3 in Table 7 demonstrates that the relationship of shared social identity on TMS is also present in the subsample that also received the Austin-style measures. Lastly, both shared social identity and TMS reduced errors, see models 1 and 2 in

Table 8.²⁰ Figure 11 presents a scatter plot of TMS and Errors. Unexpectedly, some of shared social identity's effect on errors was independent of its effect through TMS. An additional analysis supported that shared social identity mediated an additional effect of centralization on errors for groups that were dense (95% CI: .143, 4.249) but not for those that were sparse (95% CI: -2.604, .909). The index for moderated mediation was significant, suggesting that significantly more of the effect of centralization on errors was due to shared social identity in dense groups than in sparse groups (95% CI: .134, 5.817).

Results are similar in predicting innovative ideas, see model 5 in Table 8, except that shared social identity did not carry an independent effect of centralization on innovative ideas. All of the effect of centralization on innovative ideas going through the serial pathway from shared social identity to TMS. I created a more restrictive measure of innovative ideas where ideas were only counted if there were indicators that the groups had assessed the idea after it was generated by assigning a rank of usefulness and rating of difficulty. The regressions (see model 9 of Table 8) and mediation analyses are practically identical using this modified dependent variable. With support from the indirect effects tests above, the overall moderated serial mediation model is supported and the directions of the relationships are as predicted in the third hypothesis.²¹

Direct Measure of TMS

One goal of this project was to test if direct and indirect measures of TMS are related and if each predict group outcomes. First, I calculated bivariate correlations between the Lewis

²⁰ Models 1 and 2 were repeated using over-dispersed Poisson regressions. The only difference with the linear regressions were in model 2: TMS is somewhat less significant in this model with $p = .054$.

²¹ In line with my hypothesized mechanism, if centralization, density, and their interaction are replaced with the number of role equivalent classes in the network, all analyses are identical with full support for a serial mediation model where the number of classes decreases shared social identity, which increases TMS, which increases performance on either task. The same additional mediation effect through just identity when predicting errors is still present.

measure of TMS and the 4 variables that were used to directly assess the group's TMS, see Table 6. Lewis's measure was positively correlated with both knowledge stock variables ($r = .591, p < .001$ for the programming knowledge and $r = .456, p < .01$ for the innovation task). Interestingly, the individual-level specialization variable was negatively related to the Lewis measure of TMS ($r = -.246, p < .1$). The group-level specialization variable was not correlated with Lewis's measure ($r = -.052, p = .732$). Member-knowledge accuracy measure was positively related to Lewis's measure ($r = .285, p < .1$). Consensus was not significantly related to Lewis's measure of TMS ($r = .209, n.s.$). Though consensus was intended to measure a unique concept, it was highly correlated with accuracy ($r = .899, p < .001$) leading to collinearity in the following regressions and was dropped from the analysis. Thus, many of the components of the Austin measure were correlated with the Lewis (2003) measure but the specialization measure appeared to be negatively related.

One of Lewis's sub scales is intended to measure specialization and it is often assumed that one benefit of the development of a TMS is the group members' ability to develop unique areas of specialization.²² It is possible that the amount of time group members worked together was not sufficient for them to develop unique areas of specialization or that, if they had, they would not have been investing sufficient effort toward coordinating with their peers. This led to a reconsideration of the role of individual-level specialization in group TMS. Though groups are often considered to leverage an existing TMS to develop specializations, this requires for a TMS to exist before specialization can occur. Therefore, individual-specialization, though it is often considered an important component of an existent TMS, may not be helpful in a direct measure of TMS. Individual-level specialization is not included in any subsequent analyses.

²² Correlations of the specialization value with the Lewis (2003) subscale for TMS find that they are practically uncorrelated ($r = -.076, p = .616$). There are marginal negative correlations between specialization and the other two subscales which drives the overall negative correlations (coordination $r = -.274, p < .1$; credibility $r = -.246, p < .1$).

In prior analyses, all of the network manipulations' effects on the indirect measure of TMS were due to the interaction of centralization and density on shared social identity. I performed analyses predicting each component of the Austin measure to determine if the network has direct or indirect effects on their development. Both the network manipulations and shared social identity have effects on the Austin components but shared social identity does not mediate the effects of the network on any of these components. Refer to Table 7, models 4 through 8 for the analyses of the direct effects of the network on all TMS measures. The network manipulations had an interactive effect on programming knowledge such that decentralized groups reported having less knowledge overall when their network was dense versus sparse (28.32 vs. 31.25) whereas centralized groups had slightly more total knowledge when dense versus sparse (33.63 vs. 32.78). The network manipulations had an interactive effect on innovation knowledge such that dense centralized networks had more knowledge about the innovation tasks than any of the other networks (12.13 vs. 10.70, $p < .05$). There was also an interactive effect of centralization and density on within-group specialization such that decentralized groups had much more within-group specialization when they were dense versus sparse (1.11 vs. .72, $p < .01$). Centralized groups had similar levels of within-group specialization, regardless of density. Lastly, there was a main effect of density on member-knowledge accuracy such that groups were less accurate when they were in dense versus sparse networks (2.15 vs. 3.07, $p < .001$). These results suggest that, unlike the Lewis measure of TMS, the network itself seems to have had an effect directly on the Austin measures of TMS.

When taken in aggregate, a pattern appears to emerge. Centralized groups reported having more knowledge when they were dense than sparse; whereas, decentralized groups reported more individual-level and group-level specialization when dense versus sparse. Within

decentralized groups, however, members are also less accurate in knowing who has what knowledge, when sparse versus when dense. This could suggest a few things, dense, decentralized groups may prioritize specialization, even if it means the group has less knowledge overall, because all members are accessible but not central. Centralized groups are particularly good at information aggregation (Leavitt, 1951; Schilling and Fang, 2013) thus these groups may have been better able to share their knowledge with one another leading to more reported knowledge and more knowledge of who had what knowledge.

I then proceeded to reproduce the models predicting errors, see Table 8, using the four variables based on Austin (2003). The VIF index did not suggest that any models suffered from multicollinearity. In model 3, all four variables are included in predicting errors. Knowledge of the programming task ($B = -.652, p < .001$) was significant at the 95% level in predicting errors. The within group knowledge distribution variable ($B = -5.278, p < .1$) and member-knowledge accuracy ($B = -1.891, p < .1$) were significant at the 90% level. These analyses suggest that groups who have more knowledge make fewer errors, and there is some evidence that high variance in the group's knowledge distribution or accurate perceptions of who knows what led groups to make fewer errors. Shared social identity also remained significant in the model ($B = -4.535, p < .05$). The adjusted R^2 for this model is nearly .09 larger than when errors is predicted by shared social identity and the Lewis measure of TMS (adj. $R^2 = .583$ vs. adj. $R^2 = .494$) suggesting that the Austin measure of TMS may explain more about group performance than the Lewis measure.²³

In order to determine if Austin and Lewis explained unique or different variance, I added the Lewis measure to this model predicting errors, see Model 4. When the Lewis measure is

²³ In order to ensure the effects are robust, I included the individual-level specialization to the regressions. Specialization based on the average standard deviation of scores within individual in the group is not significant and no significance levels change for the other variables.

added, the adj. R^2 increases (.611) and the change in the R^2 value was marginally significant (R^2 change = .031, $p < .1$). This suggests that only a small amount of variance in errors is being explained by the indirect measure of TMS over and above the direct measure of TMS. In this model, the Lewis measure is marginally significant ($B = -.283$, $p < .1$). Programming knowledge remains significant but within-group specialization and member-knowledge accuracy both become non-significant. This would seem to suggest that Austin and Lewis's measure of TMS are getting at a similar underlying construct and that Lewis's measure of this construct—TMS—explains additional variance, even controlling for the direct measure. The indirect and direct measures of TMS, since they each explain some unique part of errors, must then be tapping into unique and only partially overlapping elements of the underlying construct of TMS.

Analyses predicting ideas generated in the innovative task were intriguing. The Lewis measures of TMS had been significantly related to innovative ideas produced. None of the Austin-style measures were significant predictors of creative ideas nor did the R^2 increase when they were added into the model, see Models 7 and 8. As footnoted above, I also used a more rigorous definition of innovative ideas as the dependent variable—ideas had to also have a rating and a ranking. Using this variable as the dependent variable, knowledge of the innovation task was significantly, positively related to the number of innovative ideas the group members ranked and rated ($B = 1.786$, $p < .001$) as was member-knowledge accuracy ($B = 1.969$, $p < .01$), see model 11. The Austin-style measures are much more predictive of innovative idea production than the Lewis measure, model 10 vs. model 11. When the Lewis measure is added in model 12, it is not a significant predictor of innovative ideas that were ranked and rated. Thus, I found evidence that two components of the Austin-style measure, knowledge about the innovation task,

and accuracy in recognizing peers' areas of expertise significantly increased group's number of innovative ideas.

Generalizability of Structure to Role Equivalence Relationship

This paper proposed that centralization would interact with density leading to lower shared social identity due to the interaction having an influence on the number of role equivalent classes in the network. This interaction was such that centralized groups become denser, they have more role equivalent classes whereas decentralized groups had fewer. An assumption was made that this theoretical relationship would remain stable in other networks within small groups. Simulated data were generated to test if the interactive effects between centralization and density on group outcomes due to the number of role equivalent classes would extend to networks of other sizes, centralizations, or densities. In order to test this assumption, I generated a total of 7000 networks that varied in their number of members (4, 5, or 6) and their density (between .375 and .667). Parameters were chosen based on creating networks with the following characteristics. For groups of 4 members, networks were created where 3 or 4 ties are present. For groups of 5 members, networks were created where 4, 5, or 6 ties were present. For groups of 6 members, networks were created where 6 or 7 ties were present. These values were chosen to give a broad range of reasonably connected groups. From these random networks, I measured their density, degree centralization, and the number of role equivalent classes.²⁴

First, I predicted the number of role equivalent classes based on the group's centralization, density, and dummy variables for whether there were 5 or 6 members in the group, 4 member groups serving as the reference category. In this model, all variables are significant and positive, suggesting that as both density and centralization increase, so does the

²⁴ These analyses were done in UCINET 6.601 using the Erdos-Renyi model to generate random networks. Degree centralization and automorphic role equivalence were also calculated in UCINET. These analyses were repeated using networks generated using the Bernoulli distribution and the same main findings were found.

number of role equivalent classes, and that there are more role equivalent classes in groups of 5 and 6 versus groups of 4. Next, I added the interaction of centralization and density to the model to determine if it explains additional variance in the number of role equivalent classes in these networks. The interaction is significant ($B = 5.14, p < .001$) as is the R^2 change score (.01, $p < .0001$).²⁵ The interaction suggests that centralization increases the number of different role equivalent classes in a network and density exaggerates that effect, as predicted. This interaction is present controlling for the number of members in the network or not. Thus, the proposed relationship between the interaction of centralization and density on the number of role equivalent classes appears to be consistent with other networks of small groups.

Effect of Communication Per Path

As discussed in more depth in Chapter 3, communication can help increase the strength of a group's transactive memory system (Hollingshead & Brandon, 2003). In this chapter, density was manipulated separately, thus the ability for members to communicate was more directly manipulated and controlled for. Groups could, however, communicate as much or as little as they were willing or able to during the task which could explain some portion of the effect of the network on shared social identity, TMS, or group performance. Communication within the group was captured through instant messages, identically to chapter 3, and were divided by the amount of time the group took and the number of paths available within the group. Centralization, density, and their interaction were unrelated to either communication during the programming task, innovation task, or the combination of the two. The following analyses will all use cumulative communication unless otherwise noted.

Cumulative communication was positively related to shared social identity ($B = .278, p < .001$) but, the interaction of centralization only became stronger ($B = -.600, p < .01$), compare to

²⁵ These analyses are identical using negative binomial regressions as role equivalent classes is a count.

Table 7 Model 1. Cumulative communication was related to TMS ($B = 3.305, p < .01$) when replacing shared social identity in Table 7 Model 2 but becomes non-significant when shared social identity is added to the model. Communication does not change the significance level of any other variable, when added to Table 7 Model 2. Neither cumulative communication nor communication during the programming period significantly predicted Errors or changed the significance of any other variable, when added to Table 8 Model 2. Similarly, neither cumulative communication nor communication during the innovative task significantly predicted or changed the significance level of another variable in predicting innovative ideas, when added to Table 8 Model 5, or innovative ideas that had been ranked and rated, Table 8 Model 9. Adding either cumulative communication or communication during the innovative task did lower the significance level of Member Accuracy in Table 8 Model 11 but did not affect Table 8 model 7 where traditional innovative ideas was the dependent variable. These analyses suggest that though communication predicted TMS, shared social identity was a better predictor, and communication did not explain any additional variance in any of the additional analyses.

Discussion

I used a laboratory experiment to investigate the effects of centralization and density of a group's communication network on their performance. In addition, I investigated how the centralization and density of a group's communication network affected two group psychological phenomena: shared social identity and TMS. As hypothesized, I found evidence for an indirect effect of centralization on performance is moderated by density and mediated by shared social identity and its effect on TMS. These results suggest that the total influence of the network on the group was due in part to the network's effect on these group-level psychological phenomena. Interestingly, I found evidence that shared social identity carried a unique effect on errors which

was distinct from its effect on errors through TMS. This finding could suggest that shared social identity is a particularly important mediator when considering the effects of the network on group performance. However, shared social identity is not often measured in network studies, thus studies of the effects of the network on outcomes might miss important effects if—as in the present study—a significant portion of the effect of the network was through shared social identity. In a set of additional analyses, I also demonstrated that a direct measure of TMS appears to capture somewhat more variance in errors to the popular indirect measure of TMS developed by Lewis (2003). This measure outperformed the Lewis (2003) scale in predicting innovative ideas. Thus, though the Lewis (2003) measure may be preferred in many circumstances due to its relative ease of calculation and the reduced number of questions for participants, an Austin-style measure is also valuable.

The present experiment advances knowledge about networks and group outcomes. More specifically, I demonstrated that the network's effects on performance were due entirely to the network's effects on two group phenomena: shared social identity and TMS. There have recently been calls for additional research that bridges the social network literature and the organizational psychology literature (Casciaro, Barsade, Edmondson, Gibson, Krackhardt, & Labianca, 2015). Research combining the network and organizational perspective can help develop an understanding of the micro underpinnings of macro behavior. The present study demonstrates that knowledge of the network alone may not be sufficient to understand the effect of the network on group outcomes. It is also important to understand the effect of the network on the group's psychology. The interaction between centralization and density is important in understanding the development of a shared social identity in a team.

Lee, Bachrach, and Lewis (2014) performed a field study that has some similarities with the present study. Generally, these researchers found a more robust positive effect of the number of transitive triads within a group on TMS than of density or centralization. These researchers proposed that transitive triads allowed the group members to verify the expertise of their peers more effectively, helping to develop TMS. In the present study, only one network contains a transitive triad, as these networks are less dense than the average network Lee et al. (2014) used (.58 vs. .78). There may be some benefit of the triad within the one network that has a triad (D in Figure 7), but I expected that this benefit will be overwhelmed by the negative effects of a lack of shared identity. Additionally, this project was about the effects of communication ties, whereas Lee et al. (2014) investigated the effect of advice ties on TMS. Communication ties contain both expressive and instrumental ties, whereas advice ties contain only instrumental ties (Podolny & Baron, 1997; Umphress, Labianca, Brass, Kass, & Scholten, 2003).

The use of random assignment of individuals to networks and network positions allows me to make causal statements about the effects of the network dimensions on the outcome variables without endogeneity concerns. This type of study has the advantage of being high in internal validity and has the ability to make causal claims about the effect of the network on group outcomes. Thus, this experiment complements field studies of networks, which are high in external validity. Further, the use of realistic tasks and the inclusion of two task types (production and innovation) increases the external validity of the experiment.

This experiment distinguishes itself from other network studies in two primary ways. First, this study addresses the group-level network centralization and density as predictors of group performance. Though other studies have considered centralization, more work has instead examined nodal centrality and not the centralization of the whole team. Second, the present

experiment adds additional value by being high in internal validity through an experimental manipulation of network centralization and density. Other work that has addressed the first contribution (e.g. Lee et al., 2014; Troster et al., 2014) used the emergent centralization and density of the group which introduces concerns about endogeneity (Manski, 1993). The present experiment, therefore, complements these prior studies by demonstrating a causal effect of the network on group processes and performance.

Though transactive memory systems have now been studied for a number of years, no prior work (to the author's knowledge) has directly compared indirect and direct measures of a group's TMS. The popular Lewis (2003) measure is an indirect assessment of a group's TMS that measures the presence of three indicators of a group's TMS. The Austin (2003) measure is a direct measure of TMS that uses a combination of the knowledge about the task within a group, the variety of that knowledge, and the group member's agreement on who has what knowledge as a more direct assessment of the group's transactive memory system. The analyses in this paper found a strong relationship between both measures of TMS, the indirect and the direct measures. The Lewis measure is highly related to several components of the Austin-style measure and both are similarly predictive of group programming errors. It is also validating that two vastly different approaches to measuring TMS appear to be picking up the same underlying construct. Thus, though the Lewis and Austin measures are quite different in their implementation, they appear to cover a large overlapping amount of variance.

Limitations

A key assumption in this experiment was that individuals would be able to recognize the structure of their group and their place within that larger structure. In large networks, this type of accurate understanding becomes less likely with individuals much more prone to make errors,

especially about the connections of individuals several steps away from themselves (Krackhardt & Kilduff, 1999). In this sample, however, members were relatively accurate in recognizing the structure of their network. Thus, for other networks of this relative size, 4-6 individuals, members may be relatively good in recognizing their networks or at least the extent to which members are similarly or dissimilarly connected.

The tasks used in this study both fall in the same quadrant of McGrath's (1984) circumplex model—conceptual-cooperative—though both tasks were somewhat different from one another. We found similar results for both tasks which reinforces my proposal that these results are likely to extend to other groups also engaged in similar types of tasks. In addition to this dimension, the tasks involved in this experiment had many steps and components. Similar prior research has found very different network effects for simple vs. complex tasks (Faucheux and Mackenzie, 1966; Burgess, 1968). Thus, the findings from this study may be most relevant to groups doing conceptual and cooperative tasks that have a level of complexity or difficulty. Though this is a limitation of the study, many groups in modern organizations, primarily complete difficult and interdependent tasks.

Groups in this experiment worked together for about 45 minutes. If groups had been given longer or shorter amounts of time, different effects may have been present. Giving groups more time may have allowed the effects of the network to diminish. Burgess (1968) found some evidence that groups can determine efficient strategies to improve performance even within inefficient networks, given enough time. Even if more time can increase group efficiency, however, the network centralization may still have a negative effect on groups' shared social identity. During pre-testing, a shorter time period was used such that 12 groups across the 4 conditions only worked together for 30 minutes. In these groups, the same pattern of effects was

visible with dense decentralized groups having the highest shared social identity and dense centralized groups the lowest. When these groups are added to the rest of the sample, all hypotheses remain supported. Thus, giving groups 50% less time did not appear to have drastic effects on the results.

Future Directions

Though this paper serves as a step forward, the study of networks in small groups and the relationship of network phenomena to group and psychological phenomena has significant room to grow. Though many network phenomena and measures are well established, there are unique opportunities to understand the relationship of these network phenomena on group-level phenomena that are also well-established in the psychological and management areas. In the current experiment, I focused primarily on shared social identity and transactive memory systems and their relationship to network centralization and density. Though this study has compelling results, many work groups are much larger than the groups of four in this study. Future work should look at larger groups, and potentially those where centralization and density are correlated as this is typical in many networks studied in the field. Additionally, there are future opportunities to study these network phenomena on other organizational phenomena. For example, faultlines within groups, where individuals form subgroups based on shared characteristics (Polzer, Crisp, Jarvenpaa, & Kim, 2006; O’Leary & Mortensen, 2010), could also help explain the results found in this study, but studies with larger varieties of networks would be necessary to answer this question.

One relationship that could be particularly important would be to examine the network underpinning of the development of a group’s shared mental model vs. a transactive memory system. Though related, these two forms of cognitive interdependence are distinguishable from

one another. A shared mental model is the shared representation of how a task should be completed (Canon-Bowers, Salas, and Converse, 1993; see DeChurch and Messmer-Magnus, 2010 for a review). Both shared mental models and TMS have positive effects on group performance, though they appear to vary in their usefulness based on the type of task and interdependence of the task. In order to develop a shared mental model, individuals must only agree on the procedure around task completion whereas a transactive memory system involves the aggregation of multiple perspectives of who has what expertise in the group. Thus a shared mental model may be easier for groups in sparse or centralized networks to develop than a transactive memory system. With this in mind, future work could benefit our understanding of the development of these two forms of cognitive interdependence by creating networks that are likely to be conducive to one form of cognitive interdependence but not the other. Dense networks or those low in centralization that allow for individuals to cross-check individual's areas of expertise are likely to be beneficial in their ability to build a transactive memory system. However, more sparsely connected groups may be able to develop a shared mental model to improve their performance without needing the additional connections. Groups in these network structures, may implicitly pursue one form of cognitive interdependence and not the other, to increase their performance. Greater development of theory and empirical work around these concepts may allow researchers to make better recommendations to teams based on their task, network, and limitations as to what cognitive interdependence strategy to pursue.

Lastly, the innovative task in this study provides much additional information that could be used in future analyses. In future analyses, the novelty of the proposed ideas will be assessed using Amabile's (1983) consensual assessment technique. In this task, participants not only were asked to create new ideas but they also had to assess the difficulty of implementing that idea and

the idea's usefulness. Using human raters, the group's accuracy in their perception of the idea difficulty or idea usefulness can be assessed. These additional assessments would serve to increase the precision of the measure of innovativeness, and they could serve as additional dependent variables to assess.

Practical Implications

Using the findings from this study, managers and group leaders may be better equipped to take action to improve group performance by changing the structure of a group to one that is most conducive to high group performance. A manager might identify an underperforming group and, using social network analysis, determine that it has a sparse, centralized network. A reasonable conclusion may be that lack of communication or information sharing within this group led to the group's poor performance. This conclusion could lead the manager to add ties to the network. The findings from this experiment suggest, however, that increasing the number of communication ties within a group may not be effective in improving performance if the additional ties reduce the group's shared social identity. Ties that increase feelings of a shared social identity are more likely to improve group outcomes than ties that decrease feelings of a shared social identity. Thus, before adding a tie to a communication network, a group should assess if the tie is likely to bind them together (as in the example of B in Figure 7) or tear them apart (as in the example of D in Figure 7).

CHAPTER 5: General Discussion

These three studies examined the effects of communication networks and turnover on shared social identity, transactive memory systems and team performance. These papers add to the literature on TMS by increasing our understanding of the predictors of TMS. We also add to the literature on networks by determining the effects of network characteristics on communication, shared social identity, TMS and team performance in two experiments. Due to the experimental designs of the studies, we were able to determine causal effects of the communication networks on groups.

One of the goals of this dissertation was to advance understanding of how turnover influences both TMS and TMS's ability to improve performance. Both Study 1 and 2 examined the influence of turnover on TMS and performance. In Study 1 there was no direct effect of turnover on TMS or performance. In Study 2, however, turnover influenced both TMS and performance through an interaction with the group's communication structure. In both studies, there was evidence that individuals' actions after the new member joined the group affected the group's ability to manage turnover. In the first study, groups that engaged in role change could perform well if they experienced turnover. In the second study, groups were able to develop a strong TMS after turnover if they communicated sufficiently, especially if that communication was with the new member.

The research presented in this dissertation is particularly novel in regards to findings about the effects of turnover. In both studies 1 and 2, there was evidence that some groups performed better after experiencing turnover than groups that had stable membership. In Study 1, groups that engaged in role change after experiencing turnover performed better than many groups that did not experience turnover. Similarly, in Study 2, centralized groups had the fewest

errors and performed well on the creative task when they experienced turnover. In both of these studies, there was some evidence that groups were able to benefit from turnover by engaging with the new member. In study one, the members' engagement in role change could have been due to attempting to accommodate for the new member. In study two, communication—which could allow for the integration of perspectives from the new member—drove centralized groups to perform well. Thus, in both Study 1 and 2, there was some evidence that groups could benefit from the new member if they engaged in integrative processes.

Studies 2 and 3 determined the effect of the communication network on groups' transactive memory systems. In both experiments, we found that the network affected processes that led to the formation of transactive memory systems. In Study 2, communication helped explain the relationship of the group's network structure on their TMS. Centralized groups communicated less than decentralized groups when membership was stable. Thus, centralized groups developed weaker TMS than decentralized groups. Interestingly, we found that these effects reversed for groups that experienced turnover, due in part to centralized groups communicating more with their new members than decentralized groups. In Study 3, communication was less important, but instead the network's effect on shared social identity helped explain TMS. Increasing density decreased shared social identity for centralized but not for decentralized groups. I argued that this effect was due to density increasing differences in centralized groups in the number of role equivalent classes, whereas increasing density decreased those differences in decentralized groups.

Study 3 used an Austin-style direct measure of TMS (2003) in addition to the Lewis (2003) indirect measure. Comparing these two measures provided a way to validate that both measures are tapping the same underlying group characteristic, which we call a transactive

memory system. Interestingly, the predictors of the Lewis (2003) measure of TMS and the four components of the Austin (2003) measure were not the same. Thus, though both appear to explain the same kind and amount of variance in group performance, the measures related differently to centralization, density, and their interaction. For example, dense, centralized groups had higher levels of overall knowledge but lower levels of group-level specialization compared to dense, decentralized groups. Thus, groups with high TMS according to the indirect measure may actually have high levels of one sub-component of TMS (e.g. knowledge) but low levels of another (e.g. specialization). These differences could be due to the group's structure affecting the aspects of TMS that its members prioritize, leading to variance in the areas to which groups develop their TMS.

All of these experiments used random assignment to condition and to position within the networks, which makes them high in internal validity. The experiments also used reasonable and realistic tasks, which adds to their external validity. Where possible, I used the same measurements and manipulations across the studies to aid in the comparison of these papers to one another.

Implications for Theory

Though much research has explored what leads to turnover, less research has examined the effects of turnover on group's processes and performance. Though turnover has typically been seen as generally negative, Studies 1 and 2 in this dissertation demonstrate situations in which turnover can be beneficial to groups. In both of these experiments, proxies for engagement with the new member (role change and communication with the new member) helped explain group performance or TMS development after turnover. This research builds on prior work (primarily Lewis et al., 2005, 2007) that suggests that group performance and/or re-encoding of

TMS can occur more rapidly if group members engage with new members to determine the ways in which they can benefit the group.

Study 2 integrates social networks into the discussion of the effects of turnover on group performance. The study manipulated the communication network (decentralized or centralized) and turnover. Members of decentralized groups could all speak to the new member but results indicated that they did not speak to the new member nearly as much as members in centralized groups. This effect is similar to the classic diffusion of responsibility findings (Latane & Nida, 1981). The structure of centralized groups directed members toward actions that were productive to the integration of a new member. Our study advances knowledge by determining how turnover influences the effect of a group's social network on group performance and contributes to a growing body of literature on dynamic networks (see Steglich, Snijders, and Pearson, 2010, and Kleinbaum, 2012, for examples). Study 2 contributes to advancing understanding of the micro-foundations of the network-level effects.

A major finding of the third study was the relationship of the network on group shared social identity. The effects of the network on shared social identity and group outcomes—both TMS and performance—were quite large. Shared social identity has rarely been studied in the context of social networks. This research demonstrates that some of the influence of the group's communication structure is better explained as an effect on the group member's feelings of belongingness to the group. Social identity is different from cohesion, which is sometimes discussed in the network literature, in that cohesion is more to related stickiness of group membership (Festinger, Schachter, & Back, 1950; Carron & Brawley, 2000). Network density is often seen as a measure of group cohesion (Reagans & McEvily, 2003) whereas this experiment demonstrated that shared social identity is predicted by an interaction of centralization and

density. Study 3 suggests that recognition of a group's communication network on intragroup phenomena such as shared social identity can help explain group outcomes.

Lastly, this study makes significant strides toward validating the typical metrics that are used to measure a group's transactive memory system. It is occasionally confusing to those not familiar with the research on TMS why the most common measure of TMS (Lewis, 2003) measures coordination, credibility, and specialization, but we describe a TMS as a shared understanding of the members who have knowledge within a group. In study three, I have presented a comparison between a direct measure of TMS and the more common indirect measure (Lewis, 2003). Though these measures are different, they seem to have similar predictive ability of group performance. Thus, Study 3 serves to help validate Lewis (2003) as an acceptable measure of TMS.

Implications for Practice

Chapters 2 and 3 highlight that the integration of new members is beneficial to groups, leading some groups that experience turnover to outperform their more stable peer groups. Results from chapter 3 suggest that centralized groups are better suited to integrate new members than decentralized groups. Thus, groups that expect group membership to be unstable may benefit from opting for a more centralized structure. The benefits from centralized groups in chapter 3, were partially due to their increased communication to the new member, relative to decentralized groups. Thus, encouraging more communication to the new member, regardless of group structure, could allow the group to develop a stronger TMS or to engage in effective role change behaviors. Groups that expect to experience turnover, therefore, should ensure that their structure is centralized or that there are processes in place to integrate new members as turnover occurs.

Chapter four highlighted the benefits of groups developing a shared social identity. Group structure affected shared social identity, which led groups to have stronger TMS and make fewer errors. This study demonstrated a causal relationship of the network on the group such that density led centralized groups to have much lower shared social identity. If leaders are in a position to affect the communication structures of groups that will be collaborating on a task, encouraging group members to form decentralized networks or reducing the number of role equivalent classes in the group's network could improve the group's level of shared social identity. For groups that have already been formed, leaders could assess the group's structure to determine if they want to engage in an intervention. Helpfully, there are many tools available to do these analyses, and there are often behavioral data such as email networks that can be used to assess problems. Though chapter four focused on the effect of the network on shared social identity, groups can encourage identity to develop in other ways such as focusing on a superordinate identity (Kane et al., 2005). Shared social identity is also a relatively easy concept to measure within groups, allowing group leaders to easily assess their group's level of shared identity and take action to help improve it if necessary.

Future Directions

The work done in this dissertation opens several additional streams of research that could advance these research areas. First, the results from Study 3 have helped us understand one component of the network, role equivalence, which affects a group's likelihood of developing a TMS. Based on the findings from Study 2, however, we might expect that turnover may have differing effects on groups that have various numbers of role equivalent classes. In Study 2, we hypothesized that the reason turnover was beneficial for these groups was that members knew that they had a role to play within the structure. Thus, if everyone has the same type of

connection to the group, it may increase the group's TMS, but it could also make members less likely to integrate the new member into their group.

In Study 3, a direct measure of TMS was developed and worked as a good predictor of group performance. Additional research on the development of the components of a group's TMS over time or in different kinds of tasks could be helpful in understanding whether groups make tradeoffs in their development of TMS (e.g., between knowledge and specialization). Data were collected in all three experiments related to some or all of the components of a direct measure of TMS (Austin, 2003) but has only been presented for the data collected in Study 3. The author hopes to integrate these data into developing a better understanding of the development of TMS and the relationship between this direct measure of TMS and other indirect measures (Lewis, 2003; Richter, Hirst, van Knippenberg, & Baer, 2012).

I chose to complete this research in the laboratory for a variety of reasons, one of which was the control of the communication network that the laboratory provides. Interesting work could be done, however, using archival data from the field, where data about the communication between a team is used to create a communication network. This type of work would be high in external validity and thus complement my laboratory research.

References

- Adler, P. S. (2012). Perspective—the sociological ambivalence of bureaucracy: from Weber via Gouldner to Marx. *Organization Science*, 23(1), 244-266.
- Ahuja, M. K., Galletta, D. F., & Carley, K. M. (2003). Individual centrality and performance in virtual R&D groups: An empirical study. *Management Science*, 49(1), 21-38.
- Amabile, T. M. (1983). Social psychology of creativity: a consensual assessment technique. *Journal of Personality and Social Psychology*, 43, 997–1013.
- Argote, L. (2012). *Organizational learning: Creating, retaining and transferring knowledge*. Norwell, MA: Kluwer Academic Publishers.
- Arrow, H., & McGrath, J. E. (1993). Membership matters how member change and continuity affect small group structure, process, and performance. *Small Group Research*, 24(3), 334-361.
- Arrow, H., & McGrath, J. E. (1995). Membership dynamics in groups at work: A theoretical framework. *Research in Organizational Behavior*, 17, 373-373.
- Ashforth, B. E., & Mael, F. (1989). Social identity theory and the organization. *Academy of Management Review*, 14(1), 20-39.
- Austin, J. R. (2003). Transactive memory in organizational groups: the effects of content, consensus, specialization, and accuracy on group performance. *Journal of Applied Psychology*, 88(5), 866-878.
- Aven, B. L. (2015). The Paradox of Corrupt Networks : An Analysis of Organizational Crime at Enron. *Organization Science*, 26(4), 980–996.

- Balkundi, P., & Harrison, D. A. (2006). Ties, leaders, and time in teams: Strong inference about network structure's effects on team viability and performance. *Academy of Management Journal*, 49(1), 49-68.
- Barnes, J. A. (1969). Networks and political processes. In J. C. Mitchell (Ed.), *Social networks in urban situations* (pp. 51-76). Manchester: Manchester University Press.
- Baumann, M. R. (2001). The effects of manipulating salience of expertise and membership change on transactive memory. (Unpublished doctoral dissertation). University of Illinois, Urbana-Champaign.
- Bavelas, A. (1948). A mathematical model for group structures. *Applied Anthropology*, 7, 16-30.
- Bavelas, A. (1950). Communication patterns in task-oriented groups. *The Journal of the Acoustical Society of America*, 22(6), 725-730.
- Bernard, H. R., Killworth, P., Kronenfeld, D., & Sailer, L. (1984). The problem of informant accuracy: The validity of retrospective data. *Annual Review of Anthropology*, 13, 495-517.
- Blau, P. M. (1974). Parameters of social structure. *American Sociological Review*, 39, 615-635.
- Borgatti, S. P., & Cross, R. (2003). A relational view of information seeking and learning in social networks. *Management Science*, 49(4), 432-445.
- Borgatti, S. P., & Foster, P. C. (2003). The network paradigm in organizational research: A review and typology. *Journal of Management*, 29(6), 991-1013.
- Borgatti, M. G., Everett, J. C., & Johnson (2013). *Analyzing social networks*. SAGE Publications Limited.

- Bosch, J., & Bosch-Sijtsema, P. (2010). From integration to composition: On the impact of software product lines, global development and ecosystems. *Journal of Systems and Software, 83*(1), 67-76.
- Brandon, D. P., & Hollingshead, A. B. (2004). Transactive memory systems in organizations: Matching tasks, expertise, and people. *Organization Science, 15*(6), 633-644.
- Brooks, F. P. (1975). *The mythical man-month*. Reading, MA: Addison-Wesley.
- Bunderson, J. S. (2003). Recognizing and utilizing expertise in work groups: A status characteristics perspective. *Administrative Science Quarterly, 48*(4), 557-591.
- Bunderson, J. S., & Boumgarden, P. (2010). Structure and learning in self-managed teams: Why “bureaucratic” teams can be better learners. *Organization Science, 21*(3), 609-624.
- Burgess, R. L. (1968). Communication networks: An experimental reevaluation. *Journal of Experimental Social Psychology, 4*(3), 324-337.
- Burns, T. & Stalker, G. (1961). *The management of innovation*. London: Tavistock Press.
- Burt, R. (1992). *Structural Holes: The Social Structure of Competition*. Cambridge, MA: Harvard University Press.
- Cannon-Bowers, J.A., Salas, E., & Converse, S. (1993). Shared mental models in expert team decision making. In N.J. Castellan, Jr. (Ed.), *Individual and team decision making* (pp. 221–246). Mahwah, NJ: Erlbaum.
- Carron, A. V., & Brawley, L. R. (2000). Cohesion conceptual and measurement issues. *Small Group Research, 31*(1), 89-106.
- Casciaro, T., Barsade, S. G., Edmondson, A. C., Gibson, C. B., Krackhardt, D., & Labianca, G. (2015). The Integration of Psychological and Network Perspectives in Organizational Scholarship. *Organization Science, 26*(4), 1162-1176.

- Chao, G. T., O'Leary-Kelly, A. M., Wolf, S., Klein, H. J., & Gardner, P. D. (1994). Organizational socialization: Its content and consequences. *Journal of Applied Psychology, 79*(5), 730.
- Choi, H. S., & Levine, J. M. (2004). Minority influence in work teams: The impact of newcomers. *Journal of Experimental Social Psychology, 40*(2), 273-280.
- Choi, H., & Thompson, L. (2005). Old wine in a new bottle: Impact of membership change on group creativity. *Organizational Behavior and Human Decision Processes, 98*(2), 121-132.
- Cohen, J. (1960). A coefficient of agreement for nominal scales. *Educational and Psychological Measurement, 20*(1), 37-46.
- Coleman, J. S. (1988). Social capital in the creation of human capital. *American Journal of Sociology, 94*, S95-S120.
- Croson, R., Anand, J., & Agarwal, R. (2007). Using experiments in corporate strategy research. *European Management Review, 4*(3), 173-181.
- Cross, R., & Prusak, L. (2002). The people who make organizations go-or stop. *Harvard Business Review, 80*(6), 104-112.
- Cross, R., & Sproull, L. (2004). More than an answer: Information relationships for actionable knowledge. *Organization Science, 15*(4), 446-462.
- Csardi, G., & Nepusz, T. (2006). The igraph software package for complex network research. *InterJournal Vol. Complex Systems, 1695*(5), 1-9.
- DeChurch, L. A., & Mesmer-Magnus, J. R. (2010). The cognitive underpinnings of effective teamwork: a meta-analysis. *Journal of Applied Psychology, 95*(1), 32.

- Devine, D. J., Clayton, L. D., Philips, J. L., Dunford, B. B., & Melner, S. B. (1999). Teams in organizations prevalence, characteristics, and effectiveness. *Small Group Research, 30*(6), 678-711.
- Doosje, B., Ellemers, N., & Spears, R. (1995). Perceived intragroup variability as a function of group status and identification. *Journal of Experimental Social Psychology, 31*(5), 410-436.
- Ellemers, N., De Gilder, D., & Haslam, S. A. (2004). Motivating individuals and groups at work: A social identity perspective on leadership and group performance. *Academy of Management Review, 29*(3), 459-478.
- Faraj, S., & Sproull, L. (2000). Coordinating expertise in software development teams. *Management Science, 46*(12), 1554-1568.
- Faucheux, C., & Mackenzie, K. D. (1966). Task dependency of organizational centrality: Its behavioral consequences. *Journal of Experimental Social Psychology, 2*(4), 361-375.
- Ferriani, S., Cattani, G., & Baden-Fuller, C. (2009). The relational antecedents of project-entrepreneurship: Network centrality, team composition and project performance. *Research Policy, 38*(10), 1545-1558.
- Festinger, L., Schachter, S., & Back, K. (1950). *Social pressure in informal groups*. New York: Harper & Row.
- Freeman, L. C. (1979). Centrality in social networks conceptual clarification. *Social Networks, 1*(3), 215-239.
- Friedkin, N. E. (1981). The development of structure in random networks: an analysis of the effects of increasing network density on five measures of structure. *Social Networks, 3*(1), 41-52.

- Gino, F., Argote, L., Miron-Spektor, E., & Todorova, G. (2010). First, get your feet wet: The effects of learning from direct and indirect experience on team creativity. *Organizational Behavior and Human Decision Processes*, *111*(2), 102–115.
- Glebbeck, A. C. & Bax, E. H. (2004). Is high employee turnover really harmful? An empirical test using company records. *Academy of Management Journal*, *47*, 277-286.
- Goodman, P. S. & Leyden, D. P. (1991). Familiarity and group productivity. *Journal of Applied Psychology*, *76*(4), 578-586.
- Gouldner, A. W. (1954). *Patterns of industrial bureaucracy*. Free Press, New York, NY.
- Guetzkow, H., & Simon, H. (1955). The impact of certain communication nets upon organization and performance in task-oriented groups. *Management Science*, *1*(3), 233–250.
- Hackman, J. R., & Oldham, G. R. (1976). Motivation through the design of work: Test of a theory. *Organizational Behavior and Human Performance*, *16*(2), 250-279.
- Hall, R. (1999). *Organizations: Structures, processes, and outcomes*. Prentice Hall.
- Hancock, J. I., Allen, D. G., Bosco, F. A., McDaniel, K. R., & Pierce, C. A. (2011). Meta-analytic review of employee turnover as a predictor of firm performance. *Journal of Management*, *39*(3), 573–603.
- Hanneman, R. A., & Riddle, M. (2005). *Introduction to social network methods*. University of California, Riverside. Retrieved from <http://faculty.ucr.edu/~hanneman/>.
- Hansen, M. T. (1999). The search-transfer problem: The role of weak ties in sharing knowledge across organization subunits. *Administrative Science Quarterly*, *44*(1), 82-111.

- Hausknecht, J. P., & Holwerda, J. A. (2013). When does employee turnover matter? Dynamic member configurations, productive capacity, and collective performance. *Organization Science*, 24(1), 210-225.
- Hayes, A. F. (2013). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach*. New York, NY: Guilford Press.
- Hayes, A. F. (2015). An index and test of linear moderated mediation. *Multivariate Behavioral Research*, 50(1), 1-22.
- Hinds, P. J., & Mortensen, M. (2005). Understanding conflict in geographically distributed teams: The moderating effects of shared identity, shared context, and spontaneous communication. *Organization Science*, 16(3), 290-307.
- Hogg, M. A. (2006). Social identity theory. In P. J. Burke (Ed.), *Contemporary social psychological theories* (pp. 111-137). Stanford, CA: Stanford University Press.
- Hollingshead, A. B. (1998). Retrieval processes in transactive memory systems. *Journal of Personality and Social Psychology*, 74(3), 659.
- Hollingshead, A. B., & Brandon, D. P. (2003). Potential benefits of communication in transactive memory systems. *Human Communication Research*, 29(4), 607-615.
- Hollingshead, A. B., Brandon, D. P., Yoon, K., & Gupta, N. (2010). Communication and Knowledge-sharing Errors in Groups. *Communication and organizational knowledge: Contemporary issues for theory and practice* (pp. 133-150).
- James, L. R., Demaree, R. G., & Wolf, G. (1984). Estimating within-group interrater reliability with and without response bias. *Journal of Applied Psychology*, 69, 85-98.

- Jehn, K. A., & Shah, P. P. (1997). Interpersonal relationships and task performance: An examination of mediation processes in friendship and acquaintance groups. *Journal of Personality and Social Psychology*, 72(4), 775.
- Kanawattanachai, P., & Yoo, Y. (2007). The impact of knowledge coordination on virtual team performance over time. *MIS Quarterly*, 783-808.
- Kane, A. A., Argote, L. & Levine, J. M. (2005). Knowledge transfer between groups via personnel rotation: Effects of social identity and knowledge quality. *Organizational Behavior and Human Decision Processes*, 96, 56-71.
- Katz, D. & Kahn, R. L. (1966). *The social psychology of organizations*. New York: Wiley.
- Katz, N., Lazer, D., Arrow, H., & Contractor, N. (2004). Network theory and small groups. *Small Group Research*, 35(3), 307-332.
- Kleinbaum, A. M. (2012). Organizational misfits and the origins of brokerage in intrafirm networks. *Administrative Science Quarterly*, 57(3), 407-452.
- Kleinbaum, A. M., Stuart, T. E., & Tushman, M. L. (2013). Discretion within constraint: Homophily and structure in a formal organization. *Organization Science*, 24(5), 1316-1336.
- Kozlowski, S. W., & Ilgen, D. R. (2006). Enhancing the effectiveness of work groups and teams. *Psychological Science in the Public Interest*, 7(3), 77-124.
- Krackhardt, D., & Kilduff, M. (1999). Whether close or far: Social distance effects on perceived balance in friendship networks. *Journal of Personality and Social Psychology*, 76(5), 770-782.
- Kruchten, P. (2008). What do software architects do? *The Journal of Systems & Software*, 81(12), 2413-2416.

- Kush, J., Williamson, C., & Argote, L. (2012). Challenges and opportunities for group learning and group learning researchers. M. A. Neale, E. A. Mannix (Eds.), *Research on Managing Groups and Teams, Vol. 15: Looking Back, Moving Forward: A Review of Group and Team-Based Research* (pp. 209-243). Emerald Group Publishing Limited.
- Landis, J. R., & Koch, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics*, 159-174.
- Latané, B., & Nida, S. (1981). Ten years of research on group size and helping. *Psychological Bulletin*, 89(2), 308.
- Leavitt, H. J. (1951). Some effects of certain communication patterns on group performance. *The Journal of Abnormal and Social Psychology*, 46(1), 38.
- LeBreton, J. M. & Senter, J. L. (2008). Answers to 20 questions about interrater reliability and interrater agreement. *Organizational Research Methods*, 11(4), 815-852.
- Lee, J. Y., Bachrach, D. G., & Lewis, K. (2014). Social Network Ties, Transactive Memory, and Performance in Groups. *Organization Science*, 25(3), 951-967.
- Levine, J. M. & Choi, H. S. (2004). Impact of personnel turnover on team performance and cognition. In E. Salas & S. M. Fiore (Eds.), *Team cognition: Understanding the factors that drive process and performance* (pp. 202-224). New York: Oxford University Press.
- Levine, J. M., Choi, H. S., & Moreland R. L. (2003). Newcomer innovation in work teams. In P. Paulus & B. Nijstad (Eds.), *Group creativity: Innovation through collaboration* (pp. 202-224). New York: Oxford University Press.
- Levine, J. M. & Moreland, R. L. (1985). Innovation and socialization in small groups. In S. Moscovici, G. Mugny, & E. Van Abermaet (Eds.), *Perspectives on minority influence* (pp. 143-169). Cambridge, MA: Cambridge University Press.

- Levine, J. M., Moreland, R.L., & Choi, H. S. (2001). Group socialization and newcomer innovation. *Blackwell handbook of social psychology: Group processes*, 3, 86-106.
- Lewis, K. (2003). Measuring transactive memory systems in the field: Scale development and validation. *Journal of Applied Psychology*, 88(4), 587-604.
- Lewis, K. (2004). Knowledge and performance in knowledge-worker teams: A longitudinal study of transactive memory systems. *Management Science*, 50(11), 1519-1533.
- Lewis, K., Belliveau, M., Herndon, B., & Keller, J. (2007). Group cognition, membership change, and performance: Investigating the benefits and detriments of collective knowledge. *Organizational Behavior and Human Decision Processes*, 103(2), 159–178.
- Lewis, K., Lange, D., & Gillis, L. (2005). Transactive memory systems, learning, and learning transfer. *Organization Science*, 16(6), 581-598.
- Lewis, K., & Herndon, B. (2011). Transactive memory systems: Current issues and future research directions. *Organization Science*, 22(5), 1254-1265.
- Liang, D. W., Moreland, R. L., & Argote, L. (1995). Group versus individual training and group performance: The mediating role of transactive memory. *Personality and Social Psychology Bulletin*, 21, 384-393.
- Liao, J., Jimmieson, N. L., O'Brien, A. T., & Restubog, S. L. (2012). Developing transactive memory systems theoretical contributions from a social identity perspective. *Group & Organization Management*, 37(2), 204-240.
- Liao, J., O'Brien, A. T., Jimmieson, N. L., & Restubog, S. L. (2015). Predicting transactive memory system in multidisciplinary teams: The interplay between team and professional identities. *Journal of Business Research*, 68(5), 965-977.

- Luhtanen, R., & Crocker, J. (1992). A collective self-esteem scale: Self-evaluation of one's social identity. *Personality and Social Psychology Bulletin*, 18(3), 302-318.
- Manski, C. F. (1993). Identification of endogenous social effects: The reflection problem. *The review of economic studies*, 60(3), 531-542.
- McGrath, J. E. (1984). *Groups: Interaction and performance*. Englewood Cliffs, NJ: Prentice-Hall.
- McPherson, M., Smith-Lovin, L., & Cook, J. M. (2001). Birds of a feather: Homophily in social networks. *Annual Review of Sociology*, 27, 415-444.
- Michaelson, A., & Contractor, N. S. (1992). Structural position and perceived similarity. *Social Psychology Quarterly*, 55(3), 300-310.
- Moreland, R. L. (1999). Transactive memory: Learning who knows what in work groups and organizations. In L. Thompson, D. Messick, & J. Levine (Eds.), *Shared cognition in organizations: The management of knowledge* (pp. 3-31). Mahwah, N.J.: Erlbaum.
- Moreland, R. L., & Argote, L. (2003). Transactive memory in dynamic organizations. In R. Peterson & E. Mannix (Eds.), *Leading and managing people in the dynamic organization* (pp. 135-162). Mahwah, N.J.: Lawrence Erlbaum Associates, Publishers.
- Moreland, R. L., Argote, L., & Krishnan, R. (1996). Socially shared cognition at work: Transactive memory and group performance. In J. L. Nye, & A. M. Brower (Eds.), *What's so social about social cognition? Socially cognition research in small groups* (pp. 57-84). Thousand Oaks: Sage.
- Moreland, R. L., Argote, L., & Krishnan, R. (1998). Training people to work in groups. R. S. Tindale, L. Heath, J. Edwards, E. J. Posavac, F. B. Bryant, Y. Suarez- Balcazar (Eds.), *Theory and Research on Small Groups* (pp. 37-60). New York: Plenum.

- Moreland, R. L. & Myaskovsky, L. (2000). Exploring the performance benefits of group training: Transactive memory or improved communication? *Organizational Behavior and Human Decision Processes*, 82(1), 117-133.
- Morrison, E. W. (1993). Longitudinal study of the effects of information seeking on newcomer socialization. *Journal of Applied Psychology*, 78, 173-183.
- Morrison, E. W. (2002). Newcomers' relationships: The role of social network ties during socialization. *Academy of Management Journal*, 45(6), 1149-1160.
- Murphy, K. R. & Myors, B. (1998). *Statistical Power Analysis: A Simple and General Model for Traditional and Modern Hypothesis Tests*. Lawrence Erlbaum, Mahwah, NJ.
- O'Leary, M. B., & Mortensen, M. (2010). Go (con) figure: Subgroups, imbalance, and isolates in geographically dispersed teams. *Organization Science*, 21(1), 115-131.
- Opsahl, T. (2012). tnet: Software for Analysis of Weighted, Two-mode, and Longitudinal Networks. Available through the Comprehensive R Archive Network (CRAN).
- Ostroff, C. & Kozlowski, S. W. (1992). Organizational socialization as a learning process: The role of information acquisition. *Personnel Psychology*, 45(4), 849-874.
- Parnes, S. J. (1975). *Aha! Insights into creative behavior*. DOK Publishers.
- Pattison, P. (1994). Social cognition in context: Some applications of social network analysis. In S. Wasserman & J. Galaskieqicz (Eds.), *Advances in Social Network Analysis* (pp. 79-109). Thousand Oaks, CA: Sage.
- Podolny, J. M., & Baron, J. N. (1997). Resources and relationships: Social networks and mobility in the workplace. *American Sociological Review*, 673-693

- Polzer, J. T., Crisp, C. B., Jarvenpaa, S. L., & Kim, J. W. (2006). Extending the faultline model to geographically dispersed teams: How colocated subgroups can impair group functioning. *Academy of Management Journal*, 49(4), 679-692.
- Reagans, R., & McEvily, B. (2003). Network structure and knowledge transfer: The effects of cohesion and range. *Administrative Science Quarterly*, 48(2), 240-267.
- Reagans, R., Zuckerman, E., & McEvily, B. (2004). How to make the team: Social networks vs. demography as criteria for designing effective teams. *Administrative Science Quarterly*, 49(1), 101-133.
- Ren, Y. & Argote, L. (2011). Transactive memory systems 1985-2010: An integrative framework of key dimensions, antecedents, and consequences. *The Academy of Management Annals*, 5(1), 189-229.
- Richter, A. W., Hirst, G., Van Knippenberg, D., & Baer, M. (2012). Creative self-efficacy and individual creativity in team contexts: Cross-level interactions with team informational resources. *Journal of Applied Psychology*, 97(6), 1282-1290.
- Rink, F., Kane, A. A., Ellemers, N., & Van der Vegt, G. (2013). Team receptivity to newcomers: Five decades of evidence and future research themes. *The Academy of Management Annals*, 7(1), 247-293.
- Rulke, D. L., & Galaskiewicz, J. (2000). Distribution of knowledge, group network structure, and group performance. *Management Science*, 46(5), 612-625.
- Sasovova, Z., Mehra, A., Borgatti, S. P., & Schippers, M. C. (2010). Network churn: The effects of self-monitoring personality on brokerage dynamics. *Administrative Science Quarterly*, 55(4), 639-670.

- Schippers, M. C., Den Hartog, D. N., Koopman, P. L., & Wienk, J. A. (2003). Diversity and team outcomes: The moderating effects of outcome interdependence and group longevity and the mediating effect of reflexivity. *Journal of Organizational Behavior, 24*(6), 779-802.
- Scott, W. R. 1992. *Organizations: Rational, natural and open systems*. Englewood Cliffs, NJ: Prentice-Hall.
- Shaw, M. E. (1964). Communication networks. In L. Berkowitz (Ed.), *Advances in Experimental Social Psychology, Vol. 6* (pp. 111-147). New York, NY: Academic Press.
- Siegel Christian, J., Pearsall, M. J., Christian, M. S., & Ellis, A. P. (2014). Exploring the benefits and boundaries of transactive memory systems in adapting to team member loss. *Group Dynamics: Theory, Research, and Practice, 18*(1), 69.
- Spector, P. E. (1994). Using self-report questionnaires in OB research: A comment on the use of a controversial method. *Journal of Organizational Behavior, 15*(5), 385-392.
- Steglich, C., Snijders, T. A., & Pearson, M. (2010). Dynamic networks and behavior: Separating selection from influence. *Sociological Methodology, 40*(1), 329-393.
- Sutton, R. I., A. Hargadon. 1996. Brainstorming groups in context: Effectiveness in a product design firm. *Administrative Science Quarterly, 41*(4), 685-718.
- Tajfel, H., & Turner, J. C. (1985). The social identity theory of intergroup behavior. In S. Worchel & W.G. Austin (Eds.), *Psychology of intergroup relations* (2nd ed., pp. 7-24). Chicago: Nelson-Hall.
- Tröster, C., Mehra, A., & van Knippenberg, D. (2014). Structuring for team success: The interactive effects of network structure and cultural diversity on team potency and performance. *Organizational Behavior and Human Decision Processes, 124*, 245-255.

- Tsay, J., Dabbish, L., & Herbsleb, J. (2014). Let's talk about it: evaluating contributions through discussion in GitHub. In Proceedings of the 22nd ACM SIGSOFT International Symposium on Foundations of Software Engineering, 144-154.
- Turner, J. C. (1982). Towards a cognitive redefinition of the social group. In H. Tajfel (Ed.), *Social identity and intergroup behavior* (pp. 66-101). Chicago: University of Chicago Press.
- Umphress, E. E., Labianca, G., Brass, D. J., Kass, E., & Scholten, L. (2003). The role of instrumental and expressive social ties in employees' perceptions of organizational justice. *Organization Science*, *14*(6), 738-753.
- Uzzi, B., & Spiro, J. (2005). Collaboration and Creativity: The Small World Problem. *American Journal of Sociology*, *111*(2), 447-504.
- van Knippenberg, D. (2000). Work motivation and performance: A social identity perspective. *Applied Psychology*, *49*(3), 357-371.
- Wasserman, S., & Faust, K (1994). *Social network analysis: Methods and applications*. Cambridge University Press.
- Weber, M. (1947). *The theory of economic and social organization*. Trans. A. M. Henderson, T. Parsons. Oxford University Press, New York.
- Wegner, D. M. (1987). Transactive memory: A contemporary analysis of the group mind. In B. Mullen & G. R. Goethals (Eds.), *Theories of group behavior* (pp. 185-208). New York: Springer-Verlag.
- Wegner, D. M., Giuliano, T., & Hertel, P. T. (1985). Cognitive interdependence in close relationships. In *Compatible and incompatible relationships* (pp. 253-276). New York: Springer.

- Wells, W. P. & Pelz, D. C. (1966). *Scientists in organizations*. New York, NY: Wiley.
- Winship, C. (1988). Thoughts about roles and relations: An old document revisited. *Social Networks*, 10(3), 209-231.
- Woolley, A. W., Chabris, C. F., Pentland, A., Hashmi, N., & Malone, T. W. (2010). Evidence for a collective intelligence factor in the performance of human groups. *Science*, 330(6004), 686-688.
- Yoon, K., & Hollingshead, A. B. (2010). Cultural stereotyping, convergent expectations, and performance in cross-cultural collaborations. *Social Psychological and Personality Science*, 1(2), 160-167.
- Yuan, Y. C., Fulk, J., Monge, P. R., & Contractor, N. (2010). Expertise directory development, shared task interdependence, and strength of communication network ties as multilevel predictors of expertise exchange in transactive memory work groups. *Communication Research*, 37(1), 20-47.

CHAPTER 2 - TABLES

Table 1

Means, Standard Deviations, and Correlations

	Mean	SD	1	2	3	4	5	6	7	8	9	10
1. Group Trained												
2. Turnover			.00									
3. Errors	5.51	5.38	-.26*	-.10								
4. Arbitrary Errors	2.75	2.17	-.12	-.01	.02							
5. Tests	3.85	3.14	-.02	-.10	.10	.40***						
6. Time to Completion	437.99	188.09	-.24*	.04	.59***	.32**	.42***					
7. TMS Before Performance	49.00	3.68	.38**	.11	-.41***	-.11	.04	-.38**				
8. TMS After Performance	51.19	5.87	.28*	-.04	-.66***	-.16	-.13	-.73***	.51***			
9. Role Change	.51	.70	-.19	-.19	-.09	.06	.05	-.21	-.03	.16		
10. Expertise	.63	.45	-.05	-.88***	.15	-.01	.04	.02	-.18	-.05	.18	
11. Replacement Member	2.87	3.35	-.10	.91***	-.07	.04	-.07	.09	.03	-.05	-.12	-.77***

* $p < .05$, ** $p < .01$, *** $p < .001$

Table 2

Linear Regressions Predicting TMS and Errors

Variable	Errors	Errors	Errors	Errors	Errors
	Model 1	Model 2	Model 3	Model 4	Model 5
Intercept	7.37*** (1.08)	7.00*** (1.25)	30.22* (14.23)	37.66*** (5.91)	26.46*** (7.00)
Training (Group Trained = 1)	-2.74* (1.27)	-2.00 (1.76)	-.34 (1.96)	.51 (1.43)	.07 (1.42)
Turnover	-1.03 (1.28)	-.25 (1.82)	3.28 (18.08)	-2.03 (8.91)	9.38 (9.92)
Training * Turnover		-1.56 (2.57)	-2.02 (2.69)	-2.74 (2.05)	-2.90 (2.02)
TMS Before Performance			-.49 (.30)		
Turnover * TMS Before Performance			-.06 (.38)		
TMS After Performance				-.62*** (.12)	-.41** (.14)
Turnover * TMS After Performance				.04 (.18)	-.15 (.20)
Role Change					25.80** (9.26)
Role Change * Turnover					-39.67* (17.58)
Role Change * TMS After Performance					-.47** (.17)
Role Change * Turnover * TMS After Performance					.70* (.33)
R ²	.07	.08	.19	.48	.56

Note 1: Values in parentheses are standard errors.

Note 2: Due to the count nature of errors, all analyses were repeated with an over-dispersed Poisson regression, a more conservative test. In Model 5, Role Change * Turnover and Role Change * Turnover * TMS After Performance both become $p < .1$.

* $p < .05$, ** $p < .01$, *** $p < .001$

CHAPTER 2 – FIGURES

Figure 1

Anticipated Model of Relationships for Hypothesis 2

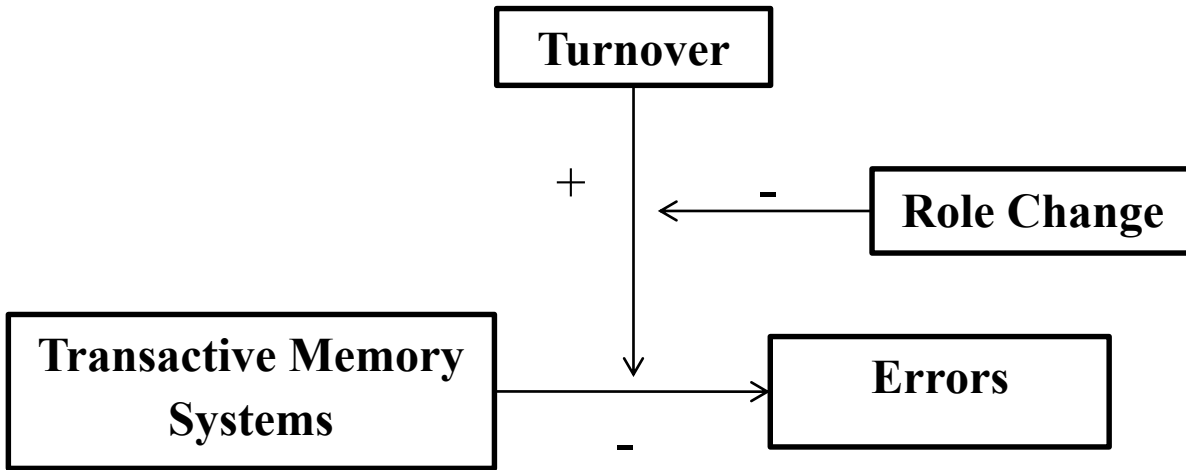
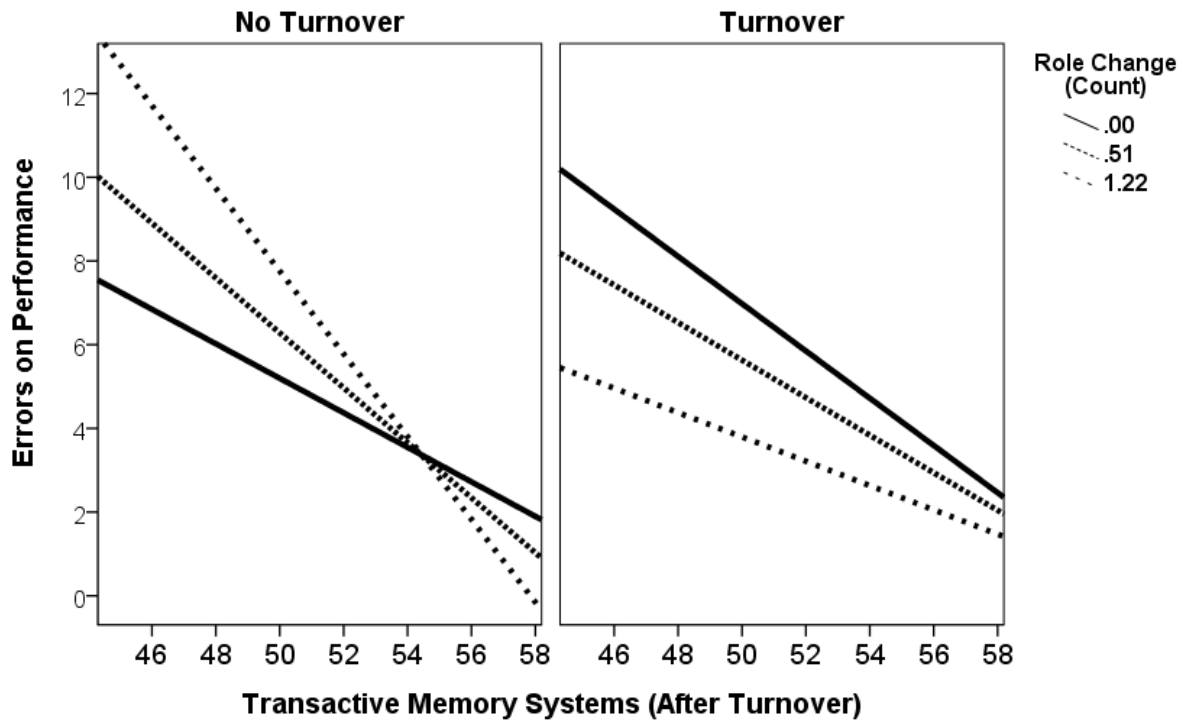


Figure 2

Moderation of TMS's Effect on Errors by Role Change and Turnover



CHAPTER 3 - TABLES

Table 3

Means and correlations

	Mean	SD	1	2	3	4
1. Errors	2.04	2.87				
2. New Features	4.39	2.63	-.33***			
3. TMS	52.84	5.17	-.34***	.19†		
4. Communication Per Path During Programming Task	1.53	.68	-.24*	.15	.26**	
5. Communication Per Path During Feature Generation Task	.87	.85	-.05	-.01	.26**	.63***

† $p < .1$, * $p < .05$, ** $p < .01$, *** $p < .001$

Table 4

Models of Errors, New Features, Communication Per Path, and Transactive Memory Systems

Variable	Errors	Errors	New Features	New Features	TMS	Communication Per Path	TMS
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Centralized Network	.67 (.87)	-.14 (.85)	-1.76* (.80)	-1.28 (.83)	-4.24** (1.56)	.33† (.18)	-5.26*** (1.49)
Turnover	.72 (.86)	.21 (.82)	-1.28 (.79)	-.98 (.79)	-2.68† (1.55)	-.17 (.18)	-2.15 (1.46)
Centralized * Turnover	-2.31* (1.13)	-1.42 (1.10)	2.64* (1.04)	2.09† (1.07)	4.71* (2.05)	.48† (.23)	3.28† (1.96)
TMS		-.19*** (.05)		.10† (.05)			
Communication Per Path							3.11*** (.80)
R ²	.06	.17	.08	.11	.07	.24	.18
N	109	109	109	109	109	109	109

Note 1. Values in parentheses are standard errors.

Note 2. Models 3-4 include a control for groups that inadvertently received additional time on the task, 1 = received 10 minutes, 0 = received 5 minutes. The results are consistent if the groups who received 10 minutes are removed from the analysis.

Note 3. Cumulative communication per path, which is used in Models 6 and 7 is the communication per path per minute for the combination of the programming task and the feature-generating task.

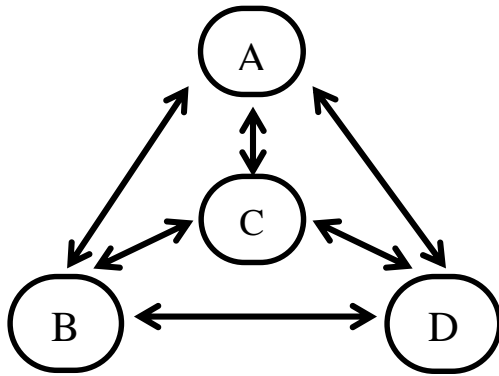
* $p < .05$, ** $p < .01$, *** $p < .001$

CHAPTER 3 – FIGURES

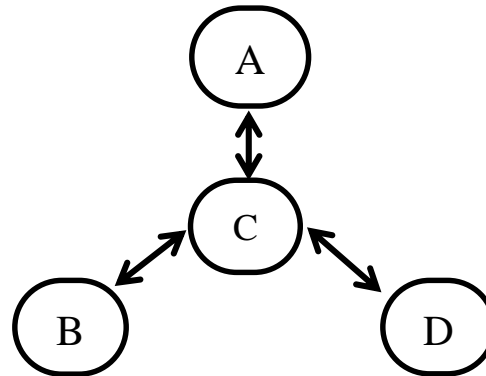
Figure 3

Decentralized and Centralized Communication Network

a.



b.

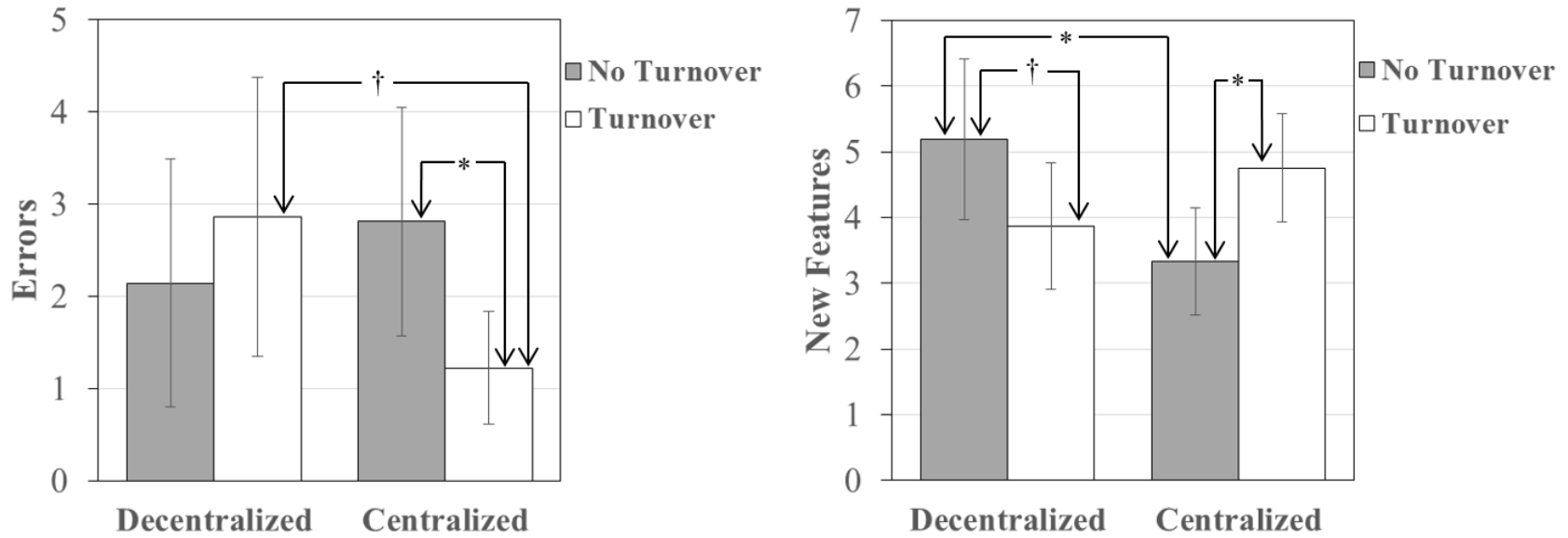


Note 1. Figure 3a represents the decentralized communication network.

Note 2. Figure 3b represents centralized communication network. C is the central member whereas A, B, and D are peripheral members.

Figure 4

Mean Errors and New Features as a Function of Communication Network and Turnover

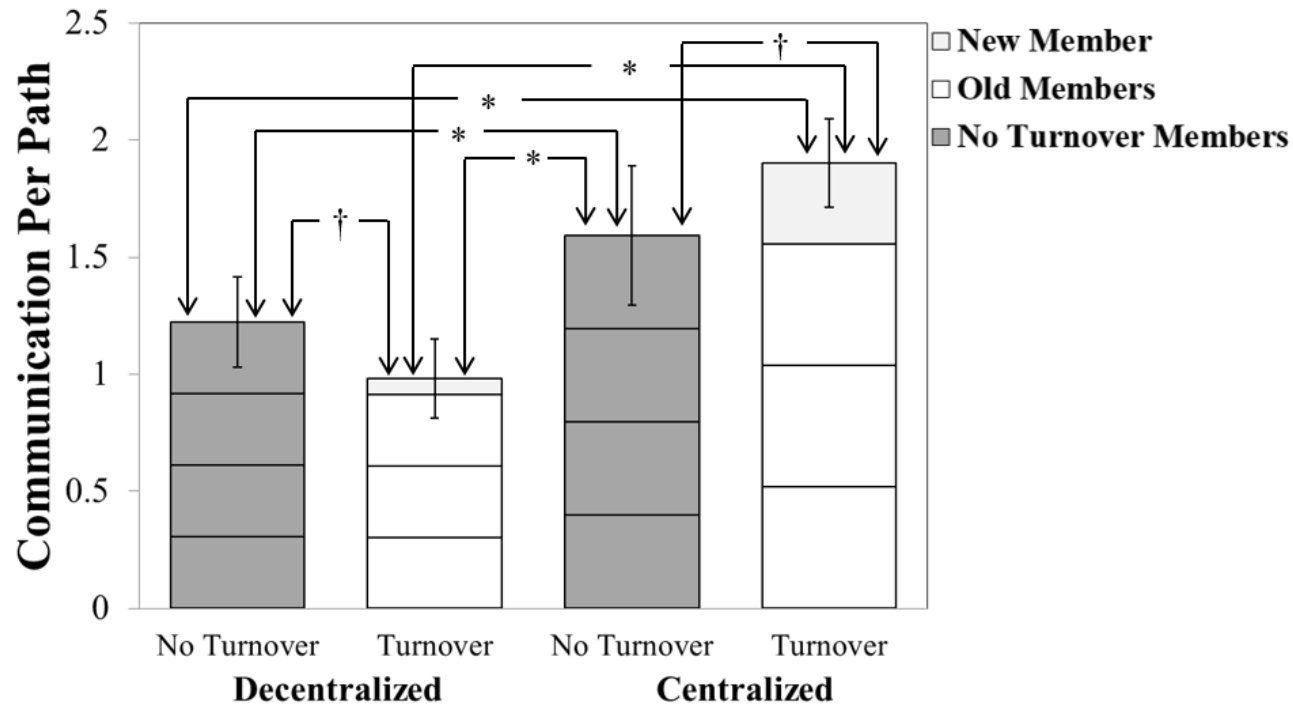


Note 1. Groups labeled with * are different at the $p < .05$ level, groups labeled with † are different at the $p < .1$ level.

Note 2. Error bars are 95% Confidence Intervals.

Figure 5

Communication Per Path by Network, Turnover, and Average Communication to Each Member During the Programming Task



Note 1. The portion of the communication sent to the average member in the group is represented by the subsections of the bar. Within groups that experienced turnover, the darker subsections are the portion of the communication within the group that went to the new member.

Note 2. Error bars are 95% confidence intervals on the whole amount of communication, not individual proportions.

Note 3. Planned contrasts are on the total amount of communication.

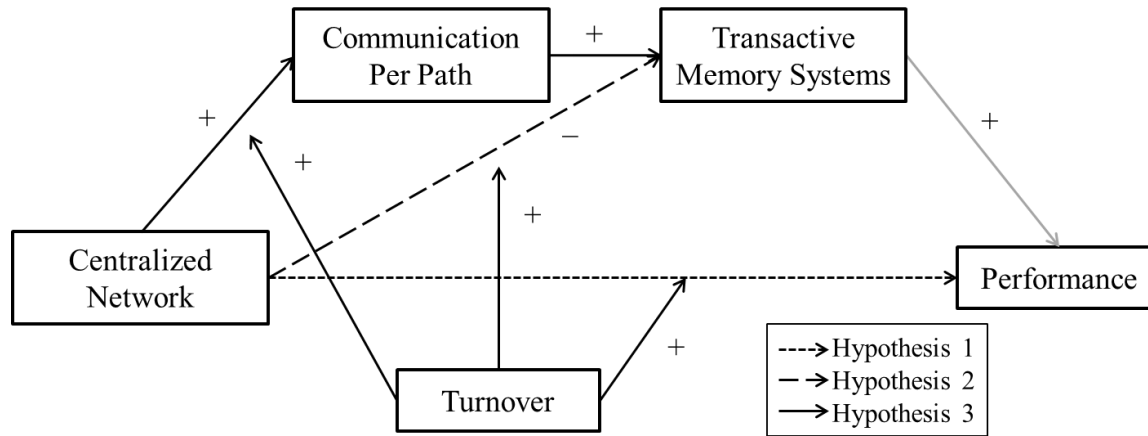
Note 4. Planned contrasts were also performed comparing the proportion of amount of communication to the new member. Centralized had significantly more communication to their new members than decentralized groups ($p < .001$).

† $p < .1$, * $p < .05$, ** $p < .01$, *** $p < .001$

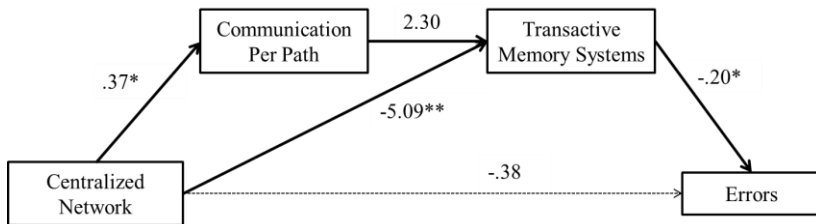
Figure 6

Statistical Framework and Models Predicting Errors by Turnover Condition

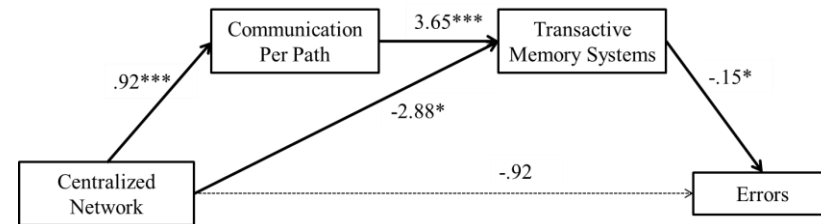
A.



B. Groups that did not experience turnover



C. Groups that experienced turnover



Note. Figure A shows the full statistical framework. Figure B shows coefficients for groups that did not experience turnover ($n = 42$) and C shows coefficients for groups that experienced turnover ($n = 67$) for errors.

† $p < .1$, * $p < .05$, ** $p < .01$, *** $p < .001$

CHAPTER 4 – TABLES

Table 5a
Network Descriptive Statistics of Structures

Structure	Number of ties	Degree Centralization	Betweenness Centralization	Closeness Centralization	Role Equivalent Classes	Average Path Length
A: Low Density, Low Centralization	3	.33	.44	.42	2	1.25
B: High Density, Low Centralization	4	.00	.00	.00	1	1
C: Low Density, High Centralization	3	1	1	1	2	1.13
D: High Density, High Centralization	4	.67	.67	.75	3	1

Note: See text for a detailed description of each measure.

Table 5b
Examples of teams by their common communication network

	Low Density	High Density
Low Centralization	Product development teams	Wikipedia editors (breaking news) ²⁷ Medical diagnostic teams Marketing Teams
High Centralization	Open Source Software developers ²⁶ Wikipedia editors (non-breaking news) ²⁷ Strategic planning teams Covert or corrupt operations teams ²⁸	Lawyer teams Some sports teams

²⁶ Tsay, Dabbish, and Herbsleb (2010)

²⁷ Keegan, Gergle, Contractor (2013)

²⁸ Baker and Faulkner (1993) and Aven (2012)

Table 6
Means and Correlations

	Mean	SD	1	2	3	4	5	6	7	8	9	10	11	12
1. Centralized Structure														
2. Dense Structure			.04											
3. Shared Social Identity	3.32	.44	-.12	-.11										
4. TMS (Lewis)	52.11	6.22	-.08	-.04	.68***									
5. Errors	7.04	5.97	.13	.06	-.62***	-.62***								
6. Innovative Ideas	7.07	2.92	.00	.03	.12	.32*	-.21							
7. Innovative Ideas w/ ranks and ratings	5.81	3.55	.01	-.10	.14	.34*	-.19	.75***						
8. Programming Knowledge	31.57	5.25	.33*	-.09	.51***	.59***	-.61***	.23	.22					
9. Innovation Knowledge	11.07	1.26	.25†	.19	.22	.46**	-.20	.26†	.42**	.55***				
10. Individual-level Specialization	.70	.21	-.27†	.22	-.33*	-.25†	.32*	-.07	-.13	-.54***	-.25†			
11. Group-level Specialization	.90	.31	-.06	.32*	-.05	-.05	.00	-.16	-.19	-.23	-.19	.31*		
12. Member-knowledge Accuracy	2.61	.97	.13	-.48***	.20	.29†	-.32*	.27†	.38**	.40**	.14	-.32*	-.64***	
13. Consensus	.63	.21	-.04	-.43**	.20	.21	-.31*	.26†	.33*	.36*	.09	-.40**	-.67***	.90***

* $p < .05$, ** $p < .01$, *** $p < .001$

Table 7
Predicting mediating variables

	Shared Social Identity	TMS (Lewis)	TMS (Lewis)	Production Knowledge	Innovation Knowledge	Individual-level Specialization	Group-level Specialization	Member Knowledge Accuracy
Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Centralization	.15 (.16)	-1.32 (1.83)	-.63 (2.03)	.78 (1.67)	-.55 (.43)	-.04 (.08)	.16 (.12)	-.18 (.35)
Density	.16 (.16)	-.97 (1.83)	-1.26 (2.07)	-3.67* (1.71)	-.77† (.44)	.17* (.08)	.40** (.12)	-1.37*** (.36)
Centralization * Density	-.50* (.23)	2.83 (2.69)	2.94 (2.91)	6.11* (2.40)	2.49*** (.62)	-.17 (.11)	-.40* (.17)	.92† (.50)
Shared Social Identity		10.16*** (1.57)	9.63*** (1.78)	7.38*** (1.47)	1.06** (.38)	-.19** (.07)	-.07 (.11)	.52† (.31)
R ²	.11	.47	.42	.47	.40	.27	.21	.33
N	54	54	46	46	46	46	46	46

Note 1: The sample size for groups that received the direct measures of TMS was 46 instead of the 54 in the full sample. There were no detectable differences between the two samples.

Note 2: values in parentheses are standard errors.

* $p < .05$, ** $p < .01$, *** $p < .001$

Table 8
Predicting dependent variables

Variable	Errors	Errors	Errors	Errors	Innovative Ideas	Innovative Ideas	Innovative Ideas	Innovative Ideas	Innovative Ideas	Innovative Ideas	Innovative Ideas	Innovative Ideas
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
Centralized network	1.09 (1.88)	.61 (1.79)	2.70 (1.78)	2.61 (1.73)	.26 (1.12)	.21 (1.26)	.59 (1.33)	.63 (1.33)	.22 (1.35)	.19 (1.51)	1.18 (1.37)	1.19 (1.39)
Dense network	.28 (1.89)	-.07 (1.79)	-1.64 (2.10)	-1.24 (2.04)	.37 (1.12)	.25 (1.29)	2.14 (1.57)	1.95 (1.57)	-.66 (1.35)	-.88 (1.54)	1.94 (1.61)	1.89 (1.64)
Centralized *Dense	-.91 (2.76)	.11 (2.65)	2.24 (3.00)	1.57 (2.92)	-.39 (1.66)	-.22 (1.83)	-2.61 (2.24)	-2.29 (2.25)	-.10 (1.99)	.58 (2.19)	-3.89† (2.30)	-3.81 (2.35)
Shared Social Identity	-8.55*** (1.62)	-4.89* (2.08)	-4.54* (1.91)	-2.97 (2.02)	-1.26 (1.30)	-1.40 (1.45)	-1.07 (1.43)	-1.79 (1.56)	-1.45 (1.57)	-1.85 (1.73)	-1.90 (1.47)	-2.08 (1.63)
TMS (Lewis)		-.36* (.14)		-.28† (.15)	.21* (.09)	.21* (.10)		.13 (.11)	.26* (.10)	.23† (.12)		.03 (.12)
Production Knowledge			-.65*** (.18)	-.58*** (.18)			.06 (.13)	.02 (.14)			-.07 (.14)	-.08 (.14)
Innovation Knowledge			.22 (.67)	.65 (.69)			.69 (.50)	.49 (.53)			1.79*** (.52)	1.73** (.55)
Group Level Specialization			-5.28† (2.64)	-4.22 (2.61)			.08 (1.97)	-.41 (2.01)			1.70 (2.03)	1.57 (2.10)
Member Accuracy			-1.89† (.94)	-1.47 (.93)			1.06 (.70)	.87 (.72)			1.97** (.72)	1.92* (.75)
R ²	.39	.46	.66	.69	.12	.11	.17	.20	.14	.11	.38	.38
N	54	54	46	46	54	46	46	46	54	46	46	46

Note 1: Models 1-4 were replicated using poisson regression. In model 3, Centralized was significant at $p < .05$. In Model 4, Centralized was significant at $p < .05$. Identity and group-level specialization were significant at $p < .1$.

Note: values in parentheses are standard errors.

† $p < .1$, * $p < .05$, ** $p < .01$, *** $p < .001$

CHAPTER 4 – FIGURES

Figure 7

Communication Networks

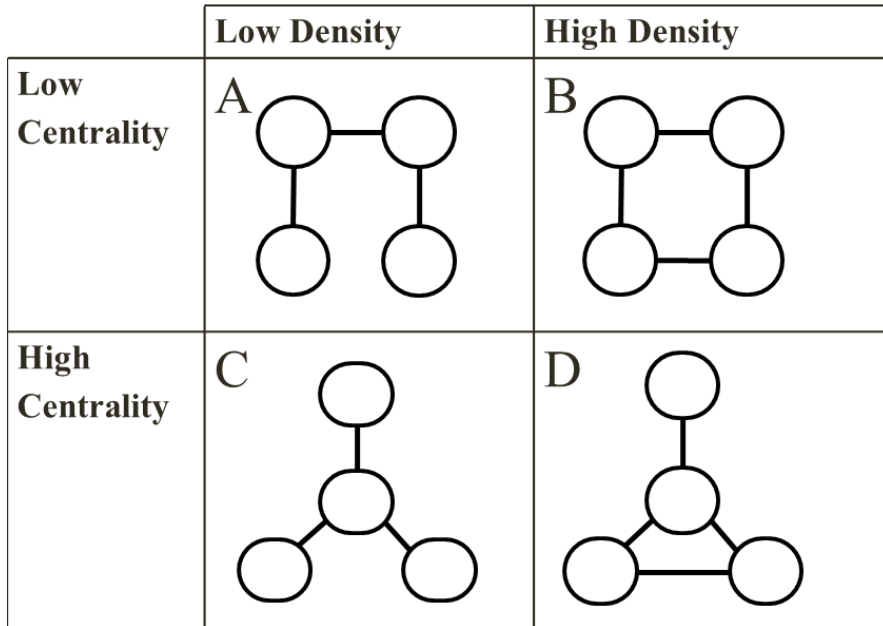


Figure 8

Statistical Framework for Moderated Serial Mediation

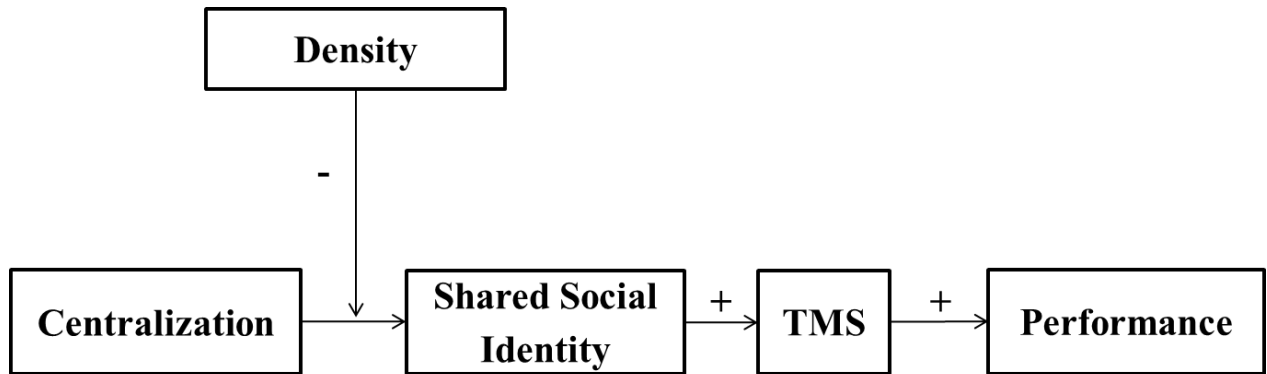
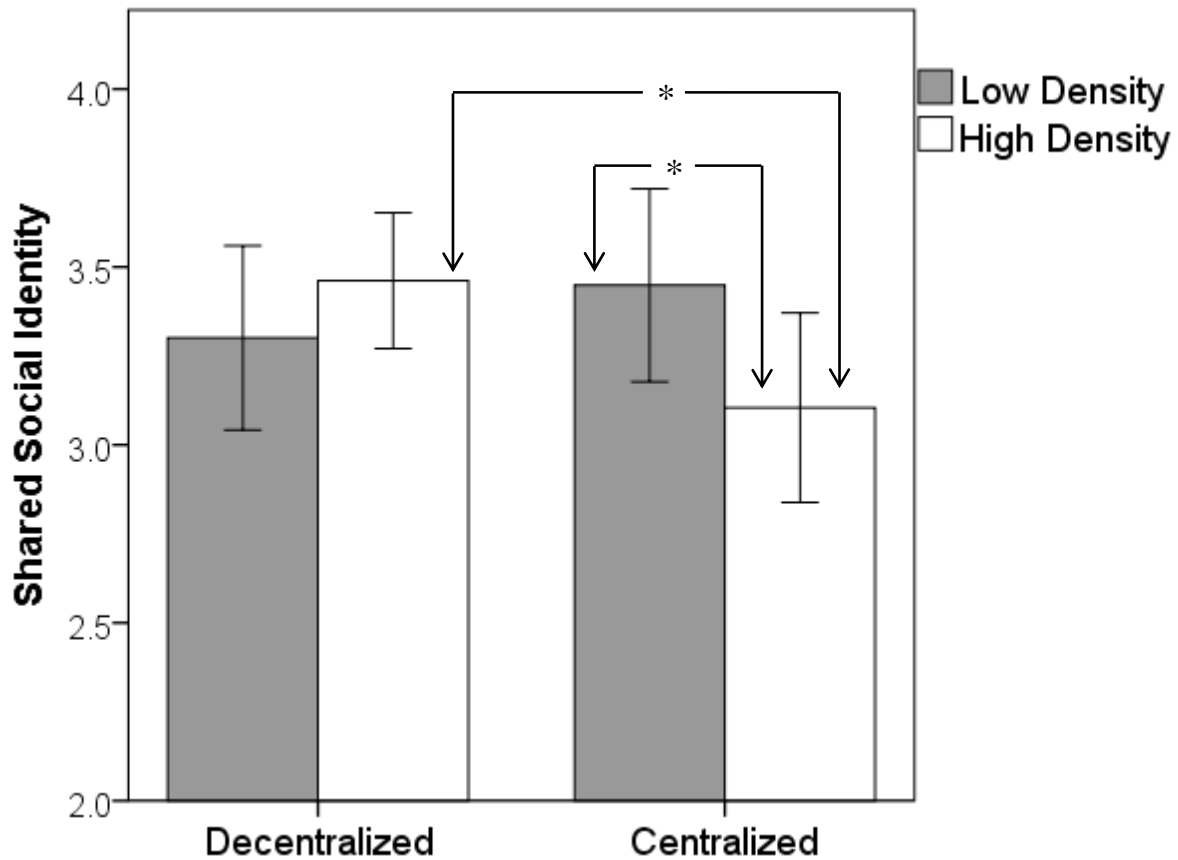


Figure 9

Interaction of Centralization and Density on Shared Social Identity

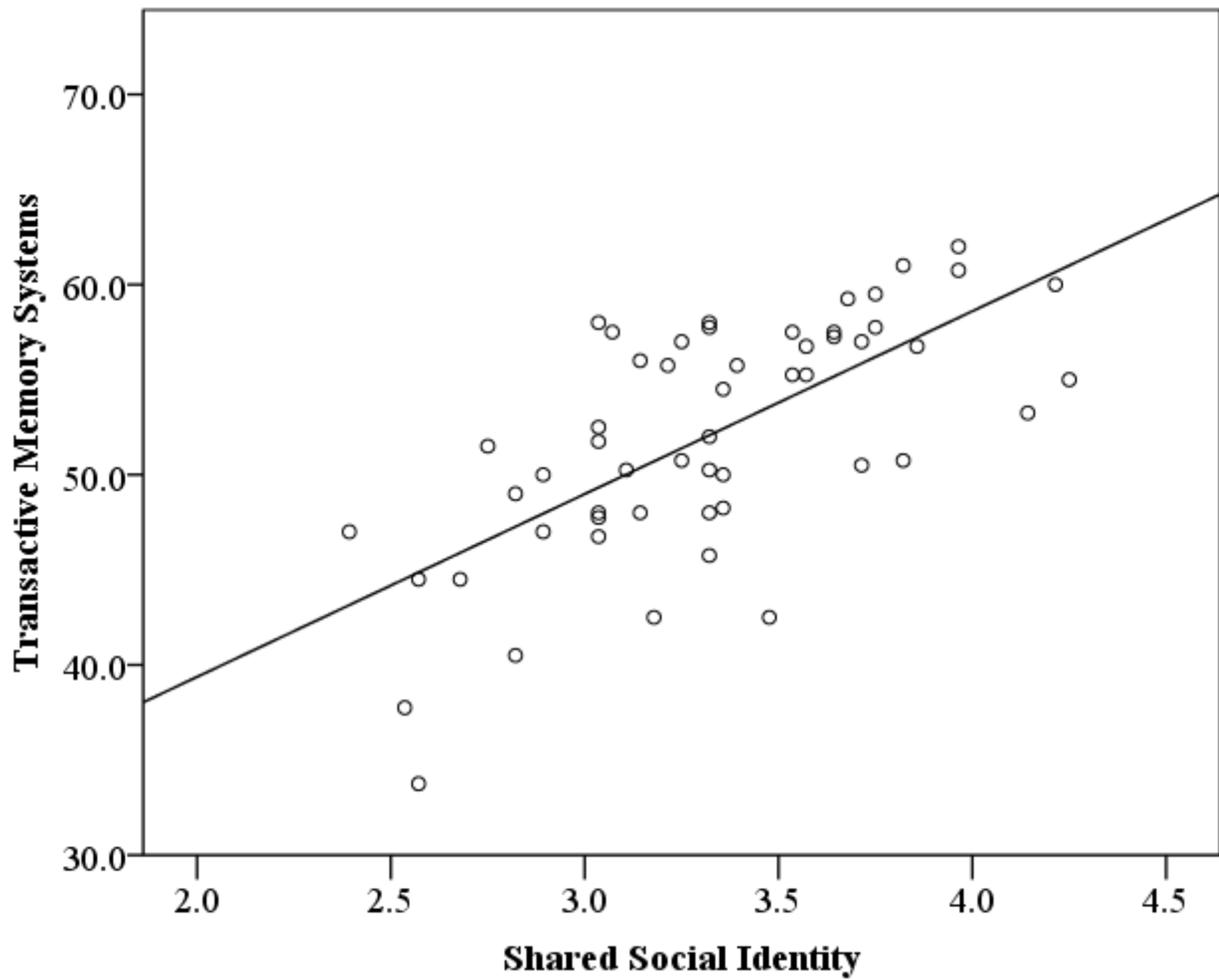


Note 1: Differences between bars were tested using planned contrasts. Significant at the $p < .05$ level.

Note 2: Error bars are 95% percentile-based confidence intervals.

Figure 10

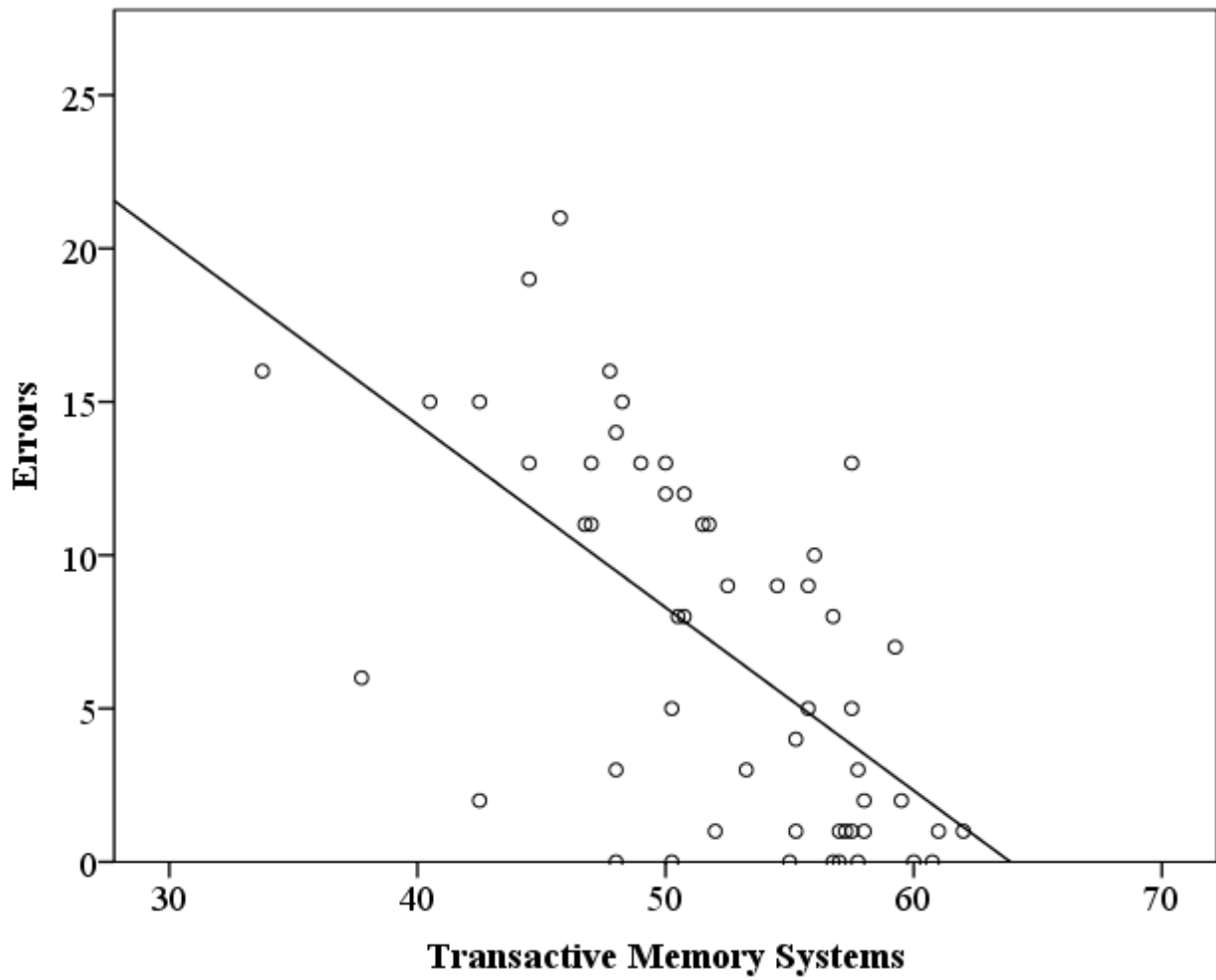
Relationship between Shared Social Identity and TMS



Note: The measure of transactive memory systems on the y-axis is the Lewis (2003) measure.

Figure 11

Relationship between TMS and Errors



Note: The measure of transactive memory systems on the x-axis is the Lewis (2003) measure.