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**"THE INFLUENCE OF COMMUNICATION NETWORKS AND
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THE INFLUENCE OF COMMUNICATION NETWORKS AND TURNOVER ON

TRANSACTIVE MEMORY SYSTEMS AND TEAM PERFORMANCE

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

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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 denser 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

expected 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

In this paper (coauthored with Linda Argote and Brandy Aven), we 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 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

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formally defined these differences as role equivalent classes, the number of categories of

members who have the same relative connections (Hanneman & Riddle, 2005). [1] As this number

increases, the group members will feel less like a group and, therefore, have higher shared social

identity. In this paper, I argued 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 e al., 2012). Finally,

I proposed 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 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

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[1] Note that role equivalence is determined by the types of connections an individual has in a network. This is related but different from roles as described in Chapter 2 which is the unique task divisions within a group.

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. This 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.[2] 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, Lange & Gillis, 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 &

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[2] 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;

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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. Siegel Christian, Pearsall, Christian & Ellis (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, so 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,

and those recruited through the credit pool received 1 hour of course credit.[3] There was an

additional $10 per member incentive for the groups that performed best in each experimental

condition.

Design

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[3] 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.[4] 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 1-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

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[4] Random numbers were generated using random.org for assigning groups to condition.

remember all of the parts of the task. Correct assembly of the circuit produced identifiable 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 10-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, so this individual was in a position synonymous to those in the lower TMS condition. After 10 minutes, each participant received a diagram of the circuit for an additional 3 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 2 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 10-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 10-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 &

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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 10-

minute performance period. Fifty percent of the groups submitted their circuit within the 10-

minute performance period and the other half did not turn in their circuit (whether complete or

not) within the 10-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 5 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 who 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 zero and three. Groups that experienced turnover could have a maximum of two 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; as a result, 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 5-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 10 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 ($B = 3.22$, $p < .05$).[5] 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

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[5] 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.[6]

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% CI [-1.10, .11]) but is for groups that experienced turnover ($B = -.55$, $p < .05$, 95% 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

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[6] 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.

not vary based on turnover. Thus, I found no support for Hypothesis 1. I was surprised not to find 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 three 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

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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).

Although 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

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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, whereas 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, whereas 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.[7] 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

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[7] 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.

interface. We anticipated that many participants would be unfamiliar with Yahoo! Pipes. 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 30 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 30 minutes to complete. The programming task was followed by the 5-minute feature-generating task.[8] 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

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[8] 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.[9] 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.[10]

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

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[9] 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)

[10] 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, $p < .001$).

predicting TMS 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.[11] 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, whereas 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.

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[11] 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.

Although 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 communization per path when they did not experience turnover than when they did, whereas 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). [12]

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[12] In order to determine the robustness of these findings, we repeated these analyses using just communication per path that occurred within the first 6 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 6 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

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

per path per minute. The serial pathway in the moderated serial mediation predicting 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).

($B = .02$, 95% CI: -.04, .16) but was positive and significant for groups that experienced turnover ($B = .09$, 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).[13] 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)

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[13] These analyses were repeated using only communications from the first 5 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).

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 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

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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

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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, Kronenfeld, & 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

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challenge of integration and coordination among groups with specialized members. Group members also communicated through computers located in separate rooms and so 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. Though 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 as useful for innovation, because their limited pathways reduce the interconnectedness and, in turn, 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 together and ties that tear apart: The influence of network centralization and density on shared social identity and group performance

Abstract

I theorize that the structure of a group's communication network can increase perceived differences between group members, which will in turn inhibit the development of positive group processes. Two unique, but difficult to empirically separate, dimensions 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 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. I 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 a group's level of TMS. TMS mediated the effect of centralization on performance. These results suggest that structural effects alone are not sufficient to understand group outcomes. This work serves as a bridge between the study of group performance from a networks perspective and a group psychological perspective.

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 difficulties in their ability to collaborate effectively with peers (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 communication within a group can increase a group's 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. Shared social identity, in turn, will increase the strength of a group's 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 effectively and perform well.

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).[14] 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, 2004). Centralization in a network suggests that there is strong leadership (Cross & Prusak,

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[14] 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.

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 negatively 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 focus merely 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 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. In this paper, I will demonstrate that 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 their 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 interaction 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 current concept of network centralization 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.[15] 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 many connections exist 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. (2004) found that group members who were more similar to one another were more likely to form a dense network. Further, 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 his or her group are more similar if their network is densely connected. To the extent that dense

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[15] Centrality can be calculated in many ways, but in networks of my interest, the comparative rankings are practically identical. See Table 5a for a comparison of centralization values for four networks of four members.

connections lead to a reduction in differences in members' connections, density may lead

members to identify more with their peers.

I propose that centralization and density interact to affect group processes and outcomes.

Centralization influences the extent to which group members vary in the connections they have.

Groups that have high levels of centralization comprise 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 reduce the inequality in connections. Within decentralized

groups, however, becoming denser leads to group members becoming 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,

they infrequently study psychological phenomena when researching networks. This has been

changing, however, with recent research in group-level networks that has 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 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 are individuals with whom they do not share an identity. Social identity is not a new concept in the study of networks. Homophily, the concept 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

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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 communicate primarily 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 to 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 measures the extent to which individuals would look the same in a network map if there were no labels (Winship, 1988; Pattison, 1994). [16] 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 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 it is that members will be connected to peers who are role equivalent to themselves. This makes it less likely for a given member to see herself as having a network similar to the network of her peers. That is, the more classes there are, the less

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

chance she will recognize another member who is role equivalent to herself. When a member recognizes that another member has a different set of connections, she will feel less like a part of the group. This recognition would lead to decreased feelings of identity with or positivity toward 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, 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 lead members to feel different from one another, which in turn leads members to identify less with the group and feel less positively about their group membership. 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 on 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 become overwhelmed due in part to centralized groups having difficulty knowing effective ways to collaborate (Burgess, 1968). As the development of a transactive memory systems is a means by which members learn to collaborate (Lewis & Herndon, 2011), the network's influence on TMS should help explain performance. Thus, the effects of the network structure on performance will be primarily a result of 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

Other scholars have studied the effects of structure, primarily just centralization, on group performance, initially using simple information aggregation tasks (Bavelas, 1950; Leavitt, 1951; Guetzkow & Simon, 1955) and later using 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 interested primarily in teams whose work is carried out by the group members themselves, 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. Groups that are fairly small with no more than five or six members will be reasonably able to recognize their networks. The findings in this study may not be as applicable to groups of larger sizes, as their networks become exponentially more complex. 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 the ways 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 54 groups for a total of 216 participants. Participants received either $15 or course credit for their participation.[17] 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 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

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[17] No significant difference was observed on any of the dependent variables on the basis of whether the participants received cash or course credit. Thus, this control was not included in any analyses.

would allow a user to search Flickr[18] 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 generating 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

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

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[18] Flickr is a popular photo sharing website.

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 who 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 at 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 completed either the programming task or the innovation task. The order of the two tasks was randomly determined and counterbalanced to

counteract any order effects.[19] 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 which 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 a 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) method. Austin (2003) proposed that TMS itself could be directly measured through calculating the structure of members' areas of knowledge and their understanding of their 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

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[19] 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 had 9.7% fewer innovative ideas if they did the innovation task first.

about who the experts are. I modified the four measured proposed in the Austin (2003) method slightly to better accommodate the tasks in the present study. Due to an oversight, eight groups did not receive the battery of questions used to derive the Austin-style questions. These eight 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. The omitted groups were fairly evenly distributed across the conditions. Using Figure 7 as a guide, three groups were in structure A, one in structure C, and two in each in structure B and D. There were no statistical differences between these eight groups that did not receive the Austin-style measures and the 46 groups that did on their shared social identity, TMS, errors, or innovative ideas.

Participants were asked whether they agreed or disagreed that a member had a particular knowledge on a 5-point scale from 1 "strongly disagree" to 5 "strongly agree" with the option of saying "I don't know." They assessed themselves and the other three members for 12unique areas of task 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 the steps in the innovation task. Exploratory factor analysis with varimax rotation confirmed that the nine questions related to the programming task loaded onto one factor and the three questions related to the innovation task loaded onto 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 of 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 were 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 who 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 peer's ratings of an individual's level of knowledge. I calculated the standard deviation of all ratings of member X's ability in knowledge area i for all member knowledge pairs. This calculation created 48 variables. These were then averaged within an individual and within the group to determine the extent to which members had variance in the

ratings of an individual's knowledge. The standard deviation value was then subtracted from the maximum value within the sample to create a measure of consensus. This consensus variable was thus the extent to which members agreed about the ratings of members on knowledge in the group.

Shared social identity. Shared social identity was measured using three survey instruments developed by Luhtanen and Crocker (1992), Doosje, Ellemers, and Spears (1995), and Hinds and Mortensen (2005). These measures were chosen to cover several aspects of group members' perceptions of belonging and positive associations with their group. The Luhtanen and Crocker (1992) measure assesses the extent to which group members feel positively about their group and their group members' interactions with each other. The Dossje et al. (1995) scale assesses the extent to which group members feel that they are part of their group. The third measure asked 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 of collective self-esteem was modified to contain the 5 items that were most relevant to work groups. See the appendix for all the items included. The items in this scale measure the extent to which group members feel positively about their membership in the group. This scale 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 other two scales were intended to assess the extent to which individuals see themselves as a member of the group. 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.]. As neither of

these scales had acceptable reliability, only the Luhtanen and Crocker (1992) measure was used

in the analyses. I explored why groups disagreed on these measures. Within the two

decentralized structures, members did not disagree about their level of reported identity using the

Doosje et al. (1995) measure. Within the centralized sparse structure (C in Figure 7), central

members typically reported higher levels of identity than the peripheral members (3.46 vs. 2.95,

$t(47) = -2.33$, $p = .024$). This same difference was marginally significant (3.39 vs. 2.90, $t(52) = -$

1.86, $p = .069$) in the centralized dense structure (D in Figure 7). The Hinds and Mortensen

(2005) also had similar results, where central members in centralized structures reported more

overlap between the group and themselves than the peripheral members. Thus, there was some

evidence in these analyses that group disagreement on two measures of identity was driven by

members' structural positions influencing the extent to which they saw themselves as members

of the group. Members agreed, however, on the group's level of shared social identity on the

Luhtanen and Crocker (1992) scale, as detailed later in the paper.

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 the presence of incorrect modules. 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 its 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.

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 needed

only 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 this assessment, an

idea also had to have a rating and a ranking in order to count.

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 perceptions 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" and

"Each member could communicate to one or two members on either side so we formed a chain,"

and responded on a 5-point strongly agree to strongly disagree scale. Due to the same oversight

mentioned in the description of the Austin-style measure of TMS, 46 of the 54 groups received

all measures. There was no evidence that these 46 groups differed from the rest of the sample.

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 available connections. Second, groups answered survey items about the structure of their network. Questions either provided written descriptions of networks or described network qualities 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 its 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.[20] Network-level analyses were then performed on these emergent communication networks. Centralized groups' emergent communication networks were more centralized—determined using Freeman's (1979) measure of degree centralization—than those of decentralized groups (.47 vs. .26, $t(52) = -4.516$, $p < .001$). 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, $t(52) = -3.039$, $p = .004$)

A series of survey-based manipulation checks was also used. First, we asked each participant, "Can member X speak to member Y?" for all six relationships that could 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

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[20] 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, $t(52) = -2.734$, $p = .009$). Dichotomising at mean minus two standard deviations also results in statistically different degree centralization for the centralized vs. decentralized groups (.51 vs. .16, $t(52) = -7.461$, $p < .001$). Dichotomizing at the median led to a similar mean difference (.35 vs. .28, $t(52) = -1.996$), $p = .051$).

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 its network structure. Members in centralized groups reported that their structure isolated members more than in decentralized groups (4.00 vs. 3.56, $t(44) = -2.684$, $p < .010$), and members in dense groups reported that their structure allowed for more coordination than members in sparse groups (3.21 vs. 2.82, $t(44) = -2.18$, $p < .05$). I also included literal written descriptions of 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 the modules used in the programming task: Count, Flickr, Sort, and Text/Location Input. Five questions captured individuals' perspectives about their own and others' knowledge of 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 who received more information about the Count or Flickr modules reported higher levels of knowledge on those than did other members in their group (4.00 vs. 3.36, $t(160) = 2.827$, $p = .005$ and 4.16 vs. 3.65, $t(164) = 2.713$, $p = .007$, 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 did (3.91 vs. 3.94, $t(164) = -.842$, $p = .401$ and 3.56 vs. 3.72, $t(163) = -.810$, $p = .419$ respectively).

There were also mean differences, such that the individuals assigned knowledge about the Count and Flickr modules were seen as having more of that knowledge (4.00 vs. 3.36, $t(488)$

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= 4.938, $p < .001$ and 4.16 vs. 3.65, $t(500) = 4.738$, $p < .001$, respectively). Members assigned to

the Sort or Inputs were not seen as having a different amount of this knowledge than their peers

(3.91 vs. 3.84, $t(500) = -.288$, $p = .773$ and 3.56 vs. 3.72, $t(497) = -1.414$, $p = .158$, respectively).

Hence, 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, which led all members to have similar levels of knowledge.

Hypotheses Tests

Means, standard deviations and correlations are provided in Table 6. Hypotheses 1 and 2

were tested using linear regressions. As errors and innovative ideas are count variables,

additional Poisson regressions were used to confirm effects but are reported here only 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 reported 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 (zero 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 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). The moderated serial mediation analysis is consistent with these results if the more rigorous definition of an innovative idea (that the idea also received a rating of difficulty and was ranked by usefulness) is used. Again, there was 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 high in density: (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 and no different from sparse, decentralized groups, see Figure 9. This is density's moderation of centralization's effect on shared social identity. These different levels of shared social identity in the group help explain their TMS and subsequent performance. Thus, the poor performance of dense, centralized groups was shown to be due to these groups having low shared social identity which reduced 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 ($t(50)$= -2.107, p = .040). 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 using the Luhtanen and Crocker (1992) measure as discussed in the methods section. The central members within centralized groups did report slightly higher shared identity (3.48 vs. 3.20, $t(105) = 1.583$, $p = .116$), but this difference was not statistically significant. The isolated members in the dense centralized groups did not report different levels of shared social identity than their non-central peers (3.05 vs. 3.06, $t(207) = -.712$, $p = .477$).

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.[21] 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 effects of centralization on innovative ideas went through the serial pathway from shared social identity to TMS. I created a more restrictive measure of innovative ideas, where

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[21] 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 $p = .054$.

ideas were counted only 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 to the analyses presented above with the more lenient measure of innovative ideas when 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. [22]

Direct Measure of TMS

One goal of this project was to test if direct and indirect measures of TMS are related and if each predicts group outcomes. First, I calculated bivariate correlations between the Lewis measure of TMS and the four 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 ($r = -.052$, $p = .732$). The 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, several components of the Austin measure were positively correlated with the Lewis (2003) measure, but the individual

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[22] 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.

specialization measure appeared to be negatively related. Due to the high number of specialization categories compared to the number of members, my measure of specialization may not appropriately represent the extent to which members have unique knowledge they can contribute to the group, one driver of TMS's positive effect on performance (Ren & Argote, 2011). Instead, group-level specialization may better represent this idea; thus, the individual-level specialization is not included in any subsequent analyses predicting group performance.

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 on 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 emerges. Centralized groups reported having more

knowledge when they were dense versus sparse whereas decentralized groups reported having

somewhat less. Decentralized groups reported more specialization (individual-level and group-

level) when dense versus sparse whereas centralized groups that were dense and sparse scored

similarly on this measure. This could suggest that decentralized groups prioritize specialization

when they are dense versus sparse even if it means the group has less knowledge overall.

Centralized groups are particularly good at information aggregation (Leavitt, 1951; Schilling and

Fang, 2013); hence, these groups may have been better able to share their knowledge with one

another, leading to more reported knowledge but more of that knowledge may be overlapping

and non-unique.

I reproduced 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, $p < .05$).[23]

In order to determine if the Austin and Lewis measures explained unique or different variance, I added the Lewis measure to the model predicting errors; see Model 4. When the Lewis measure was added, the adj. R^2 increases (.611) and the coefficient on Lewis's measure of TMS was marginally significant (B = -.283, $p < .1$). Programming knowledge remained significant, but within-group specialization and member-knowledge accuracy both became non-significant. An F-test comparing the fit of Model 2 to 4 was significant ($F(4, 36) = 4.00$, $p = .009$), suggesting that the addition of the Austin-style measures explained a significant amount more variance than Model 2. An F-test comparing Model 4 to Model 3 was marginally significant ($F(1, 36) = 3.63$, $p = .065$) suggesting that the Lewis measure explains somewhat more variance over the Austin-style measures. This finding suggests that Austin's and Lewis's measures of TMS are tapping a similar underlying construct and that each explains some unique additional variance.

Analyses predicting ideas generated in the innovative task were intriguing. The Lewis measures of TMS was 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. 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. An F-

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[23] In order to ensure the effects are robust, I included the individual-level specialization to the regressions. Individual-level specialization was not significant, and no significance levels change for the other variables.

test comparing model 10 to 12 was significant ($F(4, 36) = 3.99$, $p = .009$), suggesting that the Austin-style measures explain a significant amount more variance in innovative ideas when added to the model. An F-test comparing model 11 to 12 was not significant meaning that the Lewis (2003) measure did not explain any additional variance over the Austin-style measures ($F(1, 36) = .08$, $p = .78$). 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 a group's number of innovative ideas when the measure of innovative ideas included a rating and ranking.

Generalizability of Structure to Role Equivalence Relationship

This paper proposed that centralization would interact with density and lead to lower shared social identity, due to the interaction's influence on the number of role equivalent classes in the network. This interaction was such that as centralized groups become denser, they have more role equivalent classes, whereas decentralized groups have 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 9000 networks that varied in their number of members (four, five, or six). Tie probability values were chosen to give a broad range of reasonably connected groups. From these random networks, I measured their density ($M = .55$, SD $= .20$), degree centralization ($M = .39$, SD $= .21$), and the number of role equivalent classes ($M = 3.14$, SD $= 1.21$). [24]

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[24] These simulations were created in UCINET 6.601 using the Bernoulli distribution to generate random networks. Degree centralization and automorphic role equivalence were also calculated in UCINET. These analyses were

First, I predicted the number of role equivalent classes based on the group's centralization, density, and dummy variables for whether there were five or six members in the group, four member groups serving as the reference category. In this model, all variables were significant and positive, suggesting that as both density and centralization increase, so does the number of role equivalent classes, and that there are more role equivalent classes in groups of five and six versus groups of four. Next, I added the interaction of centralization and density to the model to determine if it explained additional variance in the number of role equivalent classes in these networks. The interaction was significant and positive when added to the model $(B = 1.17, p < .001)$.[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. An F-test was also significant, suggesting that the inclusion of the interaction explains additional variance about the number of role equivalent classes in a network $(F(1, 8994) = 36.12, p < .001)$. Therefore, the proposed relationship between the interaction of centralization and density on the number of role equivalent classes appears is robust across the range of variables investigated in the simulations.

Effect of Communication Per Path

As discussed in more depth in Chapter 3, communication can help strengthen 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

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repeated using networks generated using the Erdos-Renyi algorithm to generate random network, and the same main conclusions were found.

[25] These analyses are identical when repeated using negative binomial regressions.

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. The amount of communication was 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 communication during the programming task, innovation task, or the combination of the two. The following analyses will 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 ($B = -.600$, $p < .01$); compared to 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 re-added to the model. Communication did 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 lowered 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 its 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 that 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 than 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 because of 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 been

recent 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 shares 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 related to several components of the Austin-style measure and both measures 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 order for the structure to have an effect on their shared social identity. In large networks, this type of accurate understanding becomes less likely, and individuals are 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, four to six individuals, members may be relatively good at 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. I 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 boundary condition of the study, many groups in modern organizations primarily complete difficult and interdependent tasks.

Groups in this experiment worked together for about 45 minutes. 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 could 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 four 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. 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 is 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 individuals' 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 were asked not only to create new ideas but also to assess the difficulty of implementing those ideas and the ideas' 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 increase the precision of the measure of innovativeness and 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 whether 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. Hence, 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 4 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 4 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. I hope 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.

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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***	7.00***	30.22*	37.66***	26.46***
	(1.08)	(1.25)	(14.23)	(5.91)	(7.00)
Training (Group Trained = 1)	-2.74*	-2.00	-.34	.51	.07
	(1.27)	(1.76)	(1.96)	(1.43)	(1.42)
Turnover	-1.03	-.25	3.28	-2.03	9.38
	(1.28)	(1.82)	(18.08)	(8.91)	(9.92)
Training * Turnover		-1.56	-2.02	-2.74	-2.90
		(2.57)	(2.69)	(2.05)	(2.02)
TMS Before Performance			-.49		
			(.30)		
Turnover * TMS Before Performance			-.06		
			(.38)		
TMS After Performance				-.62***	-.41**
				(.12)	(.14)
Turnover * TMS After Performance				.04	-.15
				(.18)	(.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 $p < .1$.
* $p < .05$, ** $p < .01$, *** $p < .001$

Figure 1

Anticipated Model of Relationships for Hypothesis 2

Figure 2

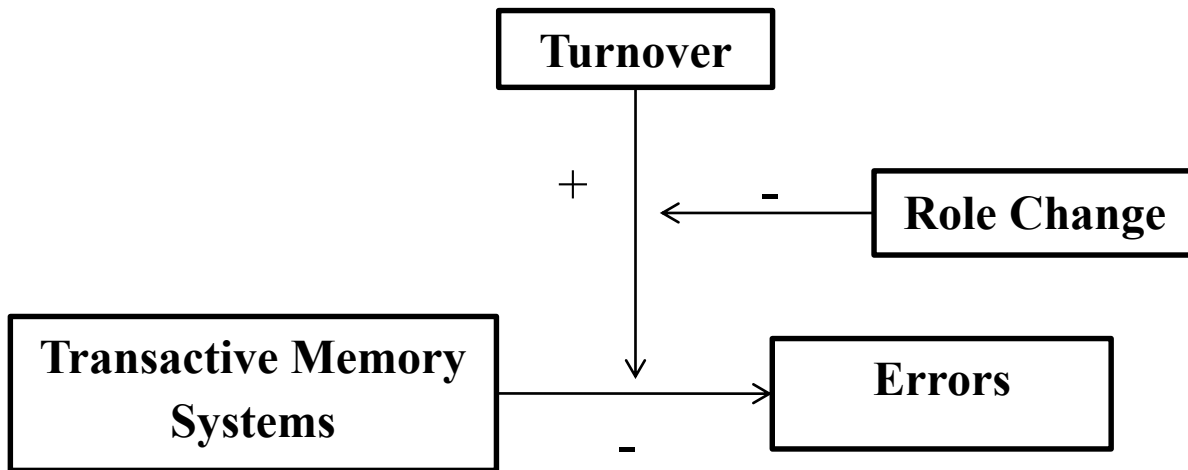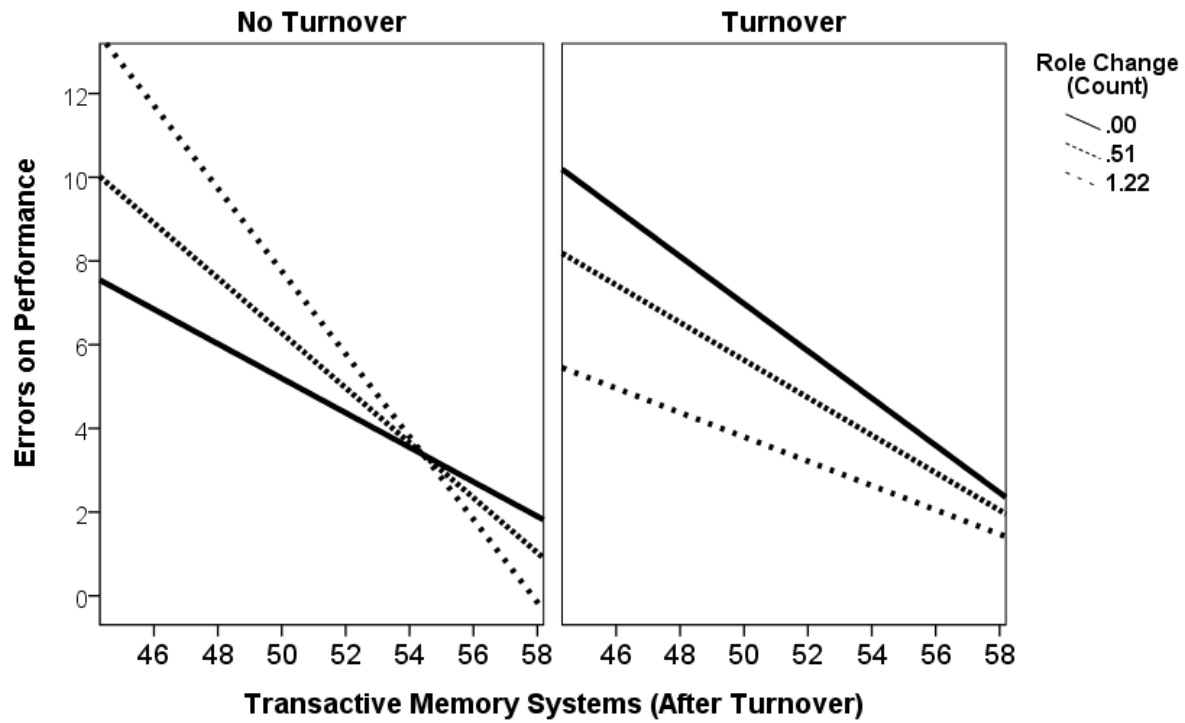*Moderation of TMS's Effect on Errors by Role Change and Turnover*

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	-.14	-1.76*	-1.28	-4.24**	.33†	-5.26***
	(.87)	(.85)	(.80)	(.83)	(1.56)	(.18)	(1.49)
Turnover	.72	.21	-1.28	-.98	-2.68†	-.17	-2.15
	(.86)	(.82)	(.79)	(.79)	(1.55)	(.18)	(1.46)
Centralized * Turnover	-2.31*	-1.42	2.64*	2.09†	4.71*	.48†	3.28†
	(1.13)	(1.10)	(1.04)	(1.07)	(2.05)	(.23)	(1.96)
TMS		-.19***		.10†			
		(.05)		(.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.
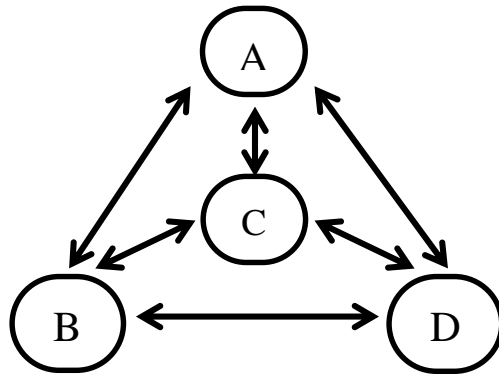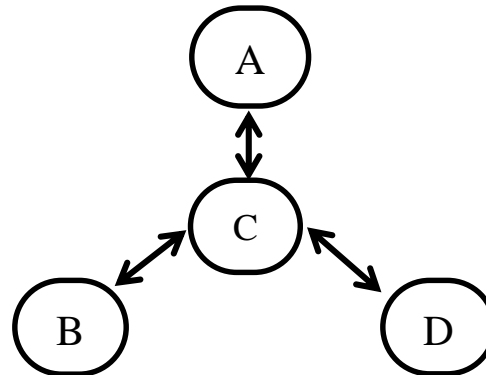
* $p < .05$, ** $p < .01$, *** $p < .001$

Figure 3

Decentralized and Centralized Communication Network
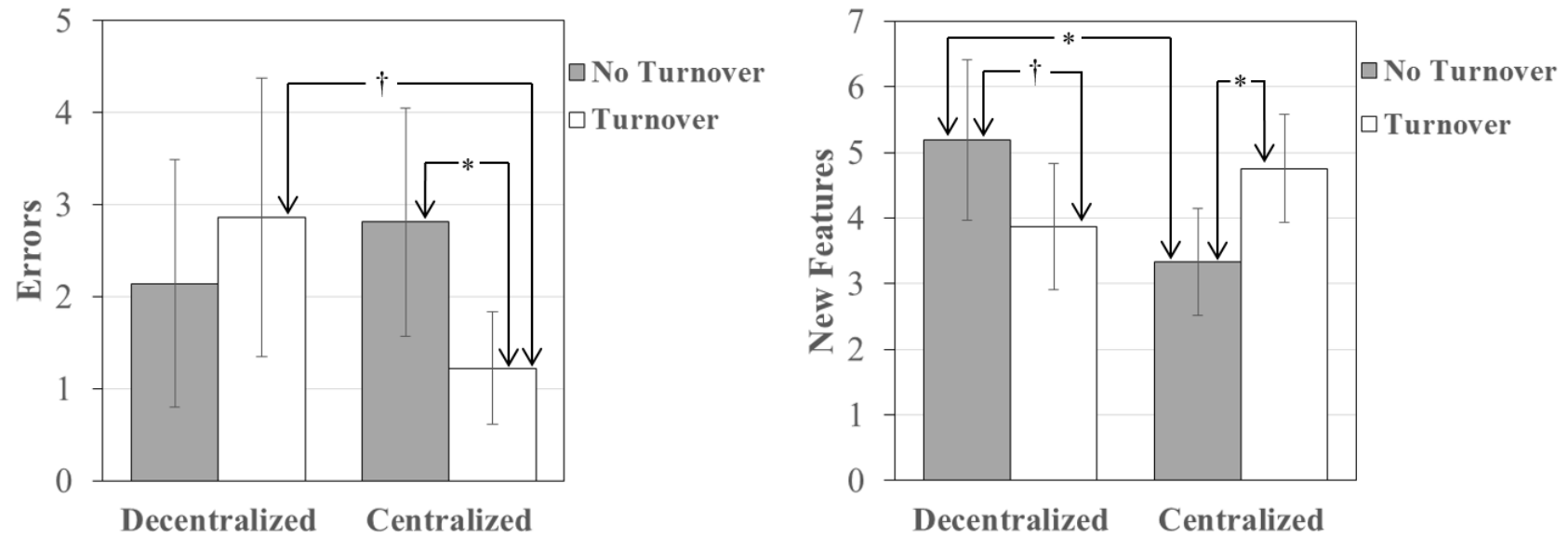
a.

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

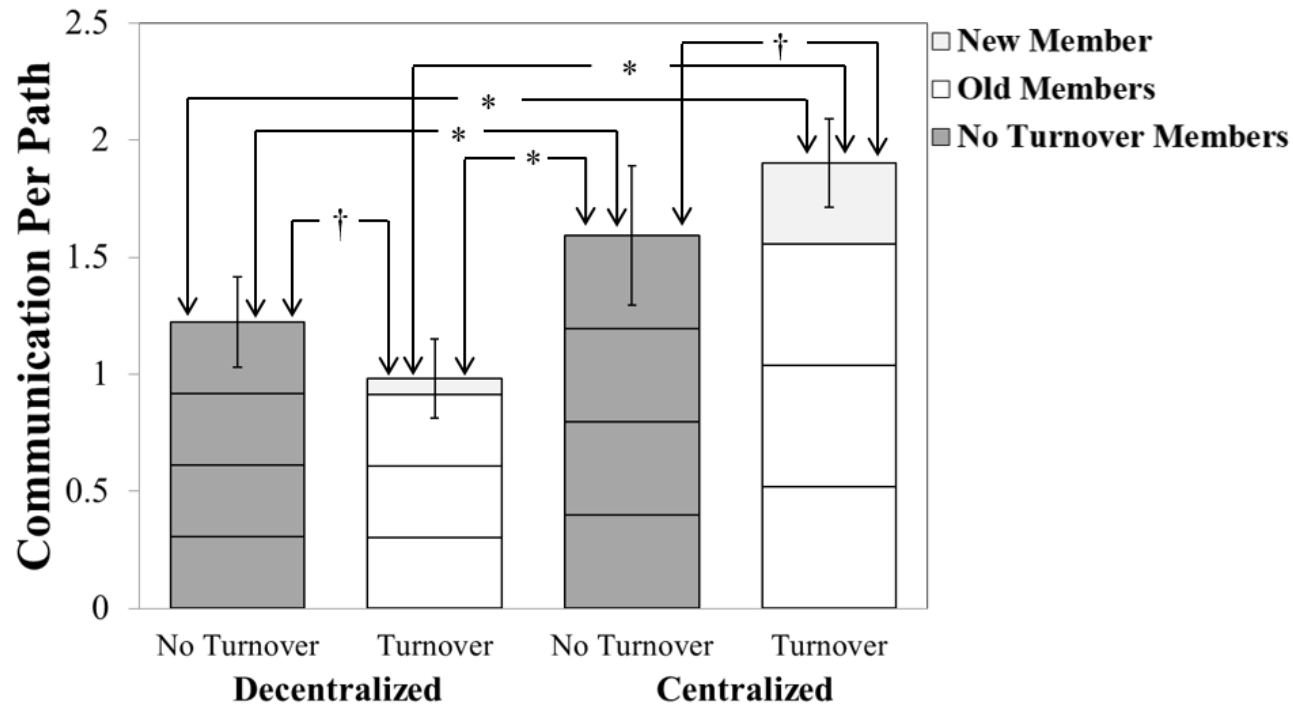*Mean Errors and New Features as a Function of Communication Network and Turnover*

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.
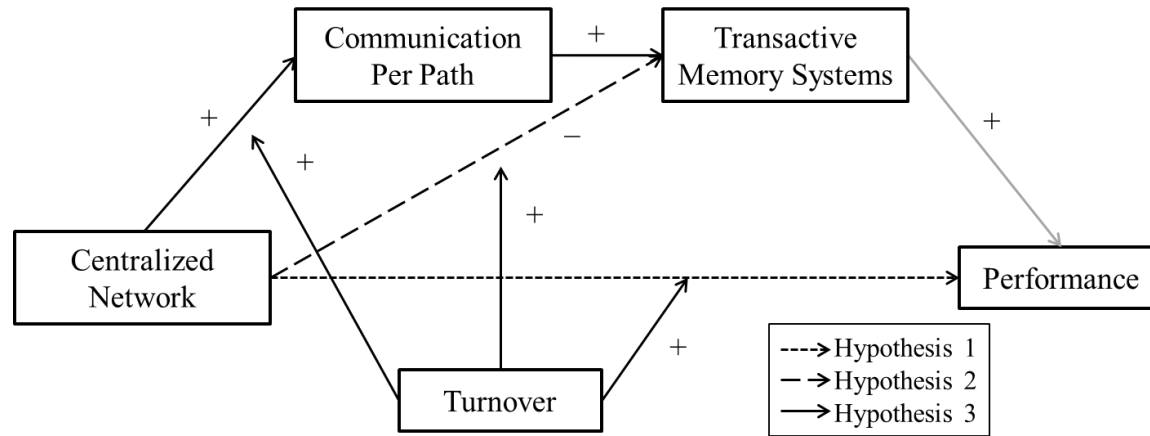*Note 4*. Planned contrasts were also performed comparing the proportion of amount of communication to the new member. Centralized had significantly more communication to their new members than decentralized groups ($p < .001$).
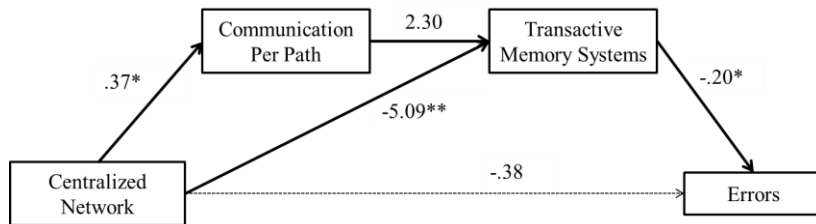† $p < .1$, * $p < .05$, ** $p < .01$, *** $p < .001$

Figure 6

Statistical Framework and Models Predicting Errors by Turnover Condition
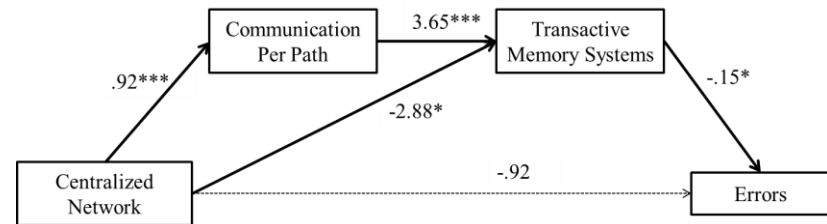
A.

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

Variable	Shared Social Identity	TMS (Lewis)	TMS (Lewis)	Production Knowledge	Innovation Knowledge	Individual-level Specialization	Group-level Specialization	Member Knowledge Accuracy
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Centralization	.15	-1.32	-.63	.78	-.55	-.04	.16	-.18
	(.16)	(1.83)	(2.03)	(1.67)	(.43)	(.08)	(.12)	(.35)
Density	.16	-.97	-1.26	-3.67*	-.77†	.17*	.40**	-1.37***
	(.16)	(1.83)	(2.07)	(1.71)	(.44)	(.08)	(.12)	(.36)
Centralization * Density	-.50*	2.83	2.94	6.11*	2.49***	-.17	-.40*	.92†
	(.23)	(2.69)	(2.91)	(2.40)	(.62)	(.11)	(.17)	(.50)
Shared Social Identity		10.16***	9.63***	7.38***	1.06**	-.19**	-.07	.52†
		(1.57)	(1.78)	(1.47)	(.38)	(.07)	(.11)	(.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 detectible differences between the two samples.
Note 2: values in parentheses are standard errors.
* $p < .05$, ** $p < .01$, *** $p < .001$

Table 8
Predicting dependent variables

	Errors	Errors	Errors	Errors	Innovative Ideas	Innovative Ideas	Innovative Ideas	Innovative Ideas	Innovative Ideas (Ranked and Rated)	Innovative Ideas (Ranked and Rated)	Innovative Ideas (Ranked and Rated)	Innovative Ideas (Ranked and Rated)
Variable	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	.61	2.70	2.61	.26	.21	.59	.63	.22	.19	1.18	1.19
	(1.88)	(1.79)	(1.78)	(1.73)	(1.12)	(1.26)	(1.33)	(1.33)	(1.35)	(1.51)	(1.37)	(1.39)
Dense network	.28	-.07	-1.64	-1.24	.37	.25	2.14	1.95	-.66	-.88	1.94	1.89
	(1.89)	(1.79)	(2.10)	(2.04)	(1.12)	(1.29)	(1.57)	(1.57)	(1.35)	(1.54)	(1.61)	(1.64)
Centralized *Dense	-.91	.11	2.24	1.57	-.39	-.22	-2.61	-2.29	-.10	.58	-3.89†	-3.81
	(2.76)	(2.65)	(3.00)	(2.92)	(1.66)	(1.83	(2.24)	(2.25)	(1.99)	(2.19)	(2.30)	(2.35)
Shared Social Identity	-8.55***	-4.89*	-4.54*	-2.97	-1.26	-1.40	-1.07	-1.79	-1.45	-1.85	-1.90	-2.08
	(1.62)	(2.08)	(1.91)	(2.02)	(1.30)	(1.45)	(1.43)	(1.56)	(1.57)	(1.73)	(1.47)	1.63)
TMS (Lewis)		-.36*		-.28†	.21*	.21*		.13	.26*	.23†		.03
		(.14)		(.15)	(.09)	(.10)		(.11)	(.10)	(.12)		(.12)
Production Knowledge			-.65***	-.58**			.06	.02			-.07	-.08
			(.18)	(.18)			(.13)	(.14)			(.14)	(.14)
Innovation Knowledge			.22	.65			.69	.49			1.79***	1.73**
			(.67)	(.69)			(.50)	(.53)			(.52)	(.55)
Group Level Specialization			-5.28†	-4.22			.08	-.41			1.70	1.57
			(2.64)	(2.61)			(1.97)	(2.01)			(2.03)	(2.10)
Member Accuracy			-1.89†	-1.47			1.06	.87			1.97**	1.92*
			(.94)	(.93)			(.70)	(.72)			(.72)	(.75)
R²	.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 2: Values in parentheses are standard errors.

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

CHAPTER 4 – FIGURES

Figure 7

Communication Networks

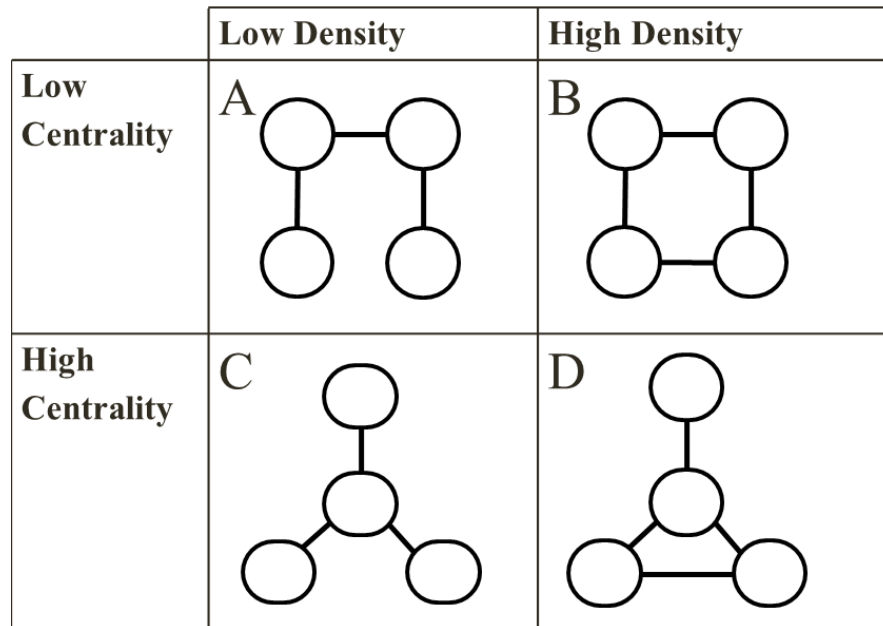|	Low Density	High Density
Low Centrality	A	B
High Centrality	C	D

Figure 8

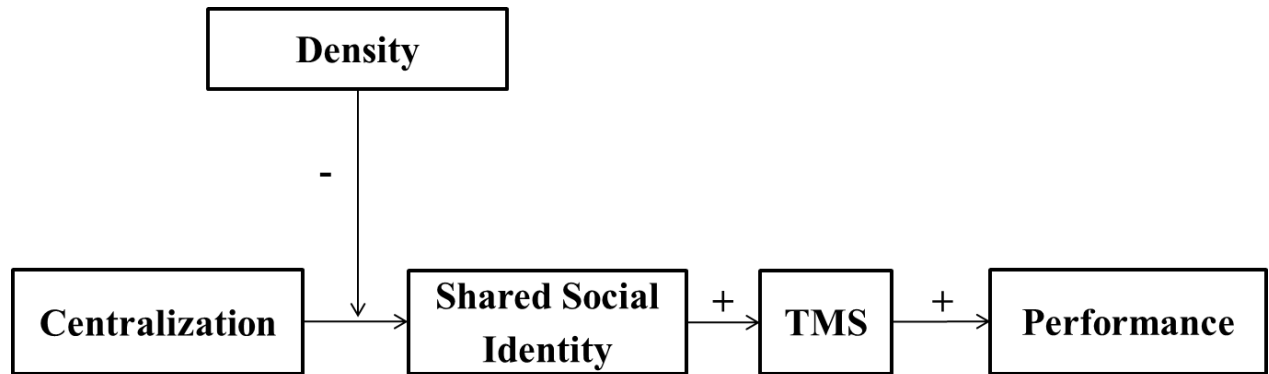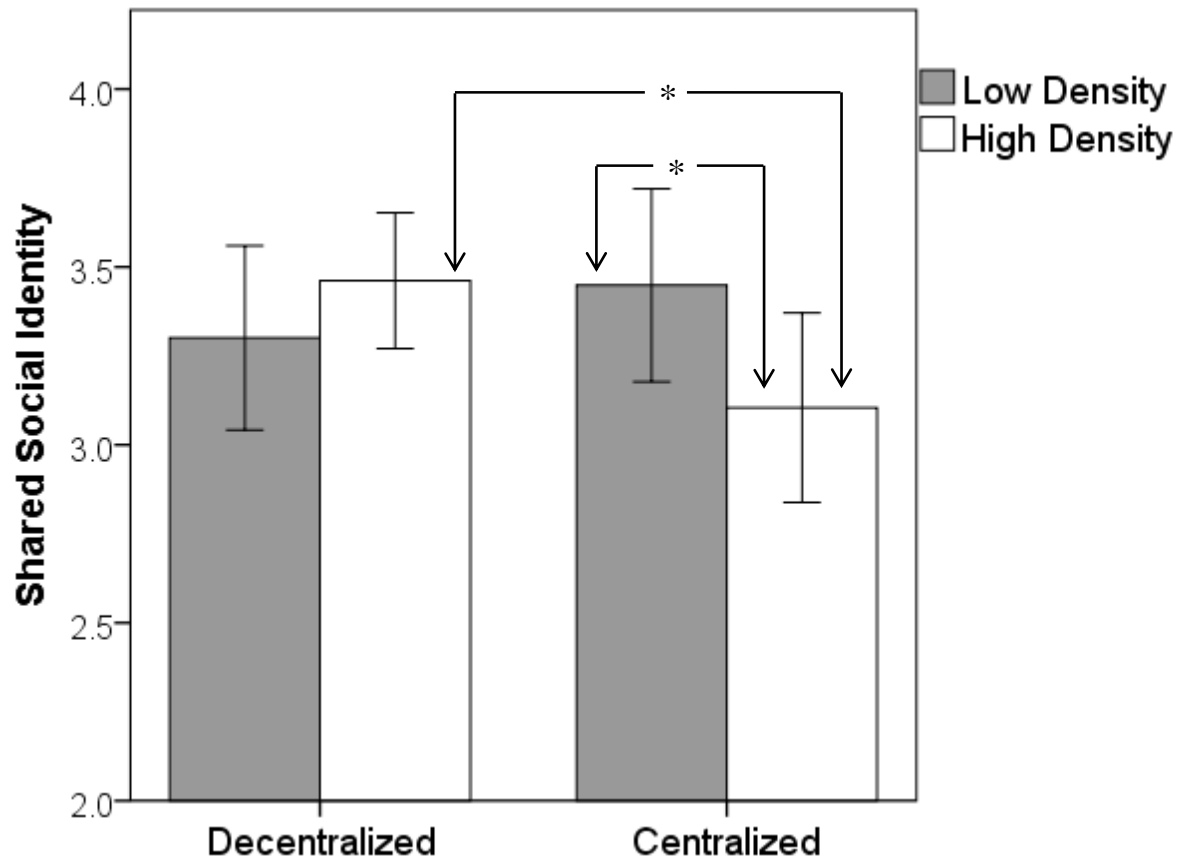*Statistical Framework for Moderated Serial Mediation*

Figure 9

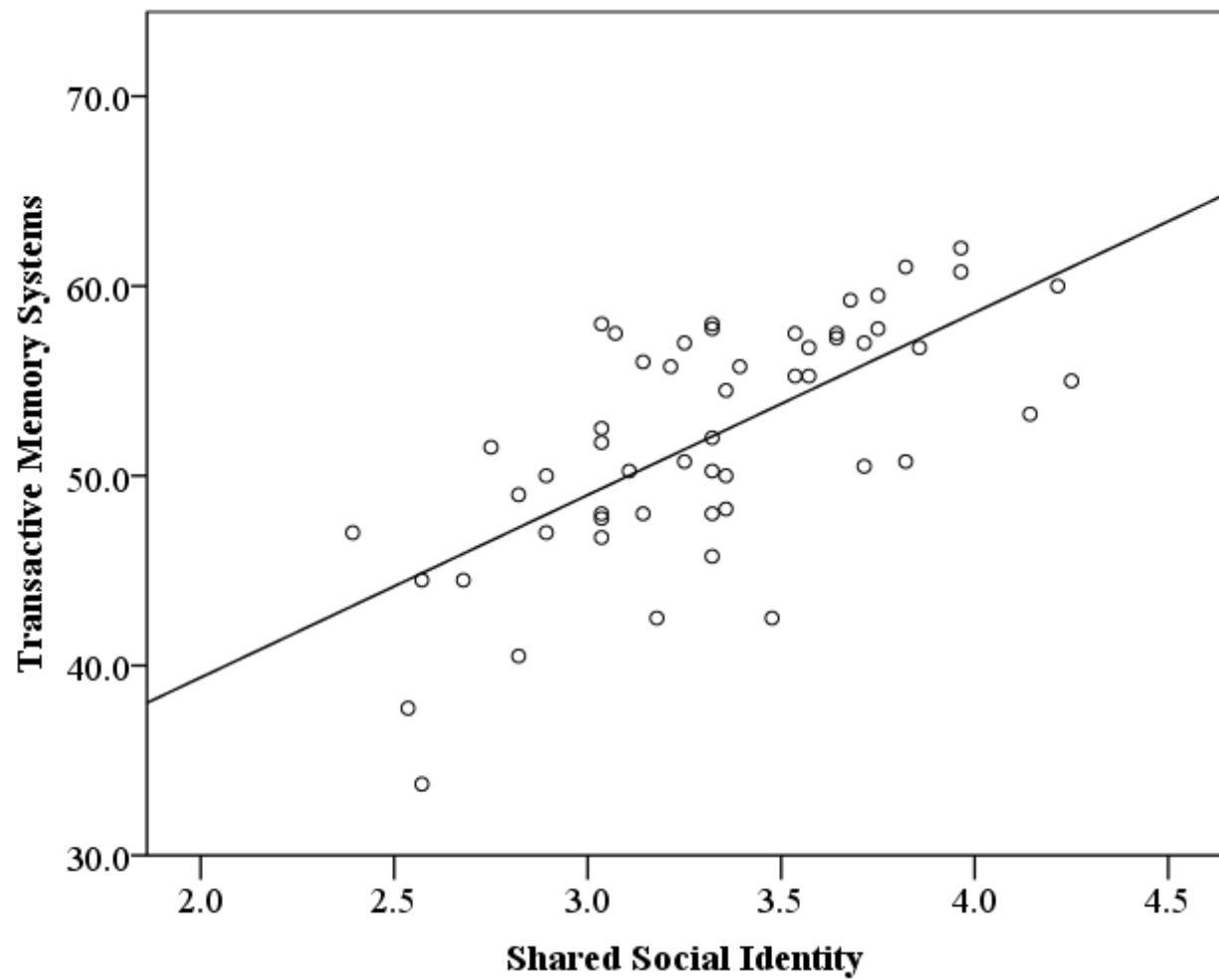*Interaction of Centralization and Density on Shared Social Identity*

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.
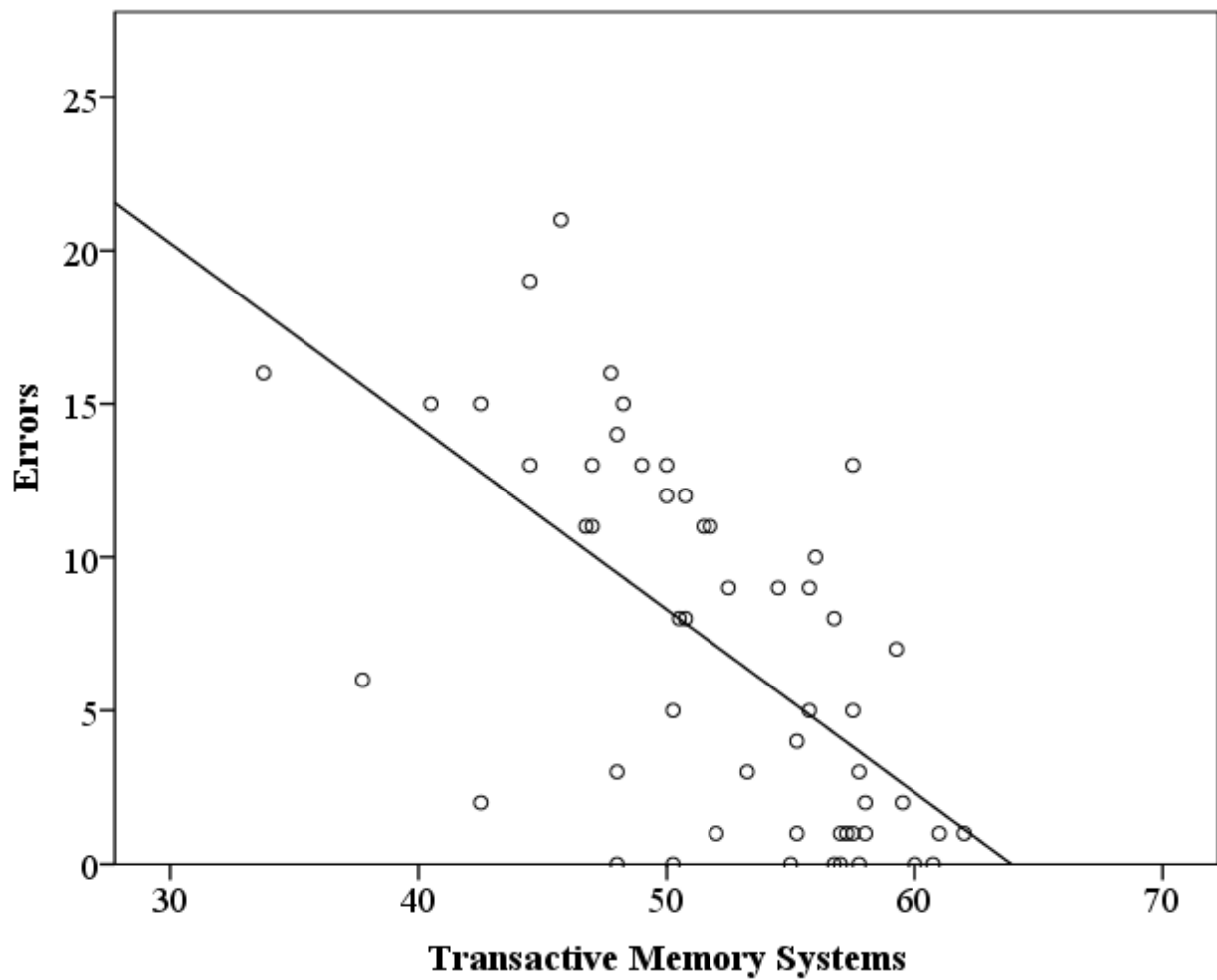
Figure 10

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.

Appendix for Chapter 4

Within each scale, the order of all items was randomized.

Transactive Memory System Scale Items (Lewis, 2003)

Specialization

1. Each team member has specialized knowledge of some aspect of our project.

2. I have knowledge about an aspect of the project that no other team member has.

3. Different team members are responsible for expertise in different areas.

4. The specialized knowledge of several different team members was needed to complete the

project deliverables.

5. I know which team members have expertise in specific areas.

Credibility

1. I was comfortable accepting procedural suggestions from other team members.

2. I trusted that other members' knowledge about the project was credible.

3. I was confident relying on the information that other team members brought to the discussion.

4. When other members gave information, I wanted to double-check it for myself. (reversed)

5. I did not have much faith in other members' "expertise." (reversed)

Coordination

1. Our team worked together in a well-coordinated fashion.

2. Our team had very few misunderstandings about what to do.

3. Our team needed to backtrack and start over a lot. (reversed)

4. We accomplished the task smoothly and efficiently.

5. There was much confusion about how we would accomplish the task. (reversed)

Note. All items use a 5-point scale where 1 = strongly disagree, 3 = neutral, 5 = strongly agree

Transactive Memory Systems (Austin, 2003)

As described in the text.

Meta Knowledge Centrality (Adapted from Borgatti and Cross (2003) as used in Mell, van Knippenberg, van Ginkel, & Heugens (2014))

For the questions below mark the extent to which you agree or disagree with the following statement.

I understand this person's knowledge and skills. This does not necessarily mean that I have these skills or am knowledgeable in these domains, but that I understand what skills this person has and in which domains they are knowledgeable.

Shown a list of all other members and responded on a 5-point scale where 1 = strongly disagree, 3 = neutral, 5 = strongly agree**.**

Shared Social Identity

The three scales below were used to assess the extent to which group members had different aspects of a shared social identity. The original names for the scales are included for clarity but all were intended to measure the extent to which group members felt that they and their teammates formed a positive or effective group.

Collective Self Esteem: adapted from Luhtanen & Crocker (1992)

This scale is intended to capture the extent to which group members felt that positively about their work group.

1. I often regretted being part of this group

2. Being a part of this group has little to do with how I feel about myself.

3. In general, I am glad I was part of this group.

4. Overall, I feel that my group was not worthwhile.

5. I feel good about the group I belonged to.

Note 1. All items use a 7-point scale where 1 = strongly disagree, 4 = neutral, 7 = strongly agree

Note 2. These items were chosen from the larger scale as these items were most relevant to work groups.

Group Identification (Doosje, Ellemers, & Spears, 1995)

These items are intended to capture the extent to which an individual thought of their group membership as important to themselves.

1. I identify with the other members of this group.

2. I see myself as a member of this group.

3. I am glad I am a member of this group.

4. I feel strong ties with the other members of this group.

Note. All items use a 5-point scale where 1 = strongly disagree, 3 = neutral, 5 = strongly agree

Perceptions of Shared Identity (adapted from Hinds and Mortensen, 2005)
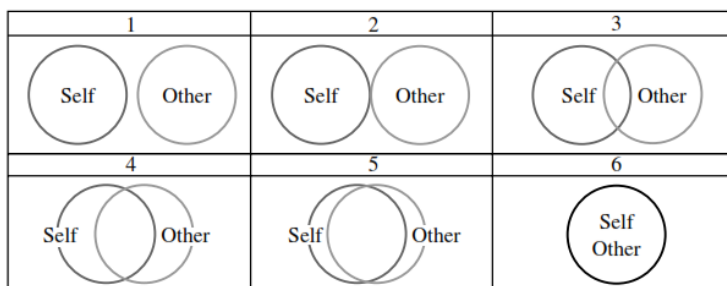
Participants were asked: "Choose the number that corresponds to the picture above that most closely matches how you feel about your relationship with your team."

Value of team and teammates

1. How much do you like the other members in your group?

2. How much do you value the other members in your group?

3. How much do you feel connected to other members in your group?

Note. All items use a 5-point scale where 1 = Not at all, 3 = Neutral, 5 = Extremely like

Task Conflict (Jehn (1994/1995) as used by Hinds and Mortensen, 2005)

1. How frequently were there conflicts about ideas in the team?

2. How much conflict about the work you do was there in the team?

3. How often did people in the team disagree about opinions regarding the work being done?

4. To what extent were there differences of opinion in the team?

Note. All items use a 5-point scale where 1 = Not at all, 3 = Occasionally, 5 = Very much

Interpersonal Conflict (Jehn (1994/1995) as used by Hinds and Mortensen, 2005)

1. How much friction is there among members in the team?

2. How much are personality conflicts evident in the team?

3. How much tension is there among members in the team?

4. How much emotional conflict is there among members in the team?

5. To what extent do people take the arguments in the team personally?

6. How much jealousy or rivalry is there among the members in the team?

Note. All items use a 5-point scale where 1 = Not at all, 3 = Occasionally, 5 = Very much

Manipulation Check questions

Direct Network Measure

1. Can Member A talk to Member B?

2. Can Member A talk to Member C?

3. Can Member A talk to Member D?

4. Can Member B talk to Member C?

5. Can Member B talk to Member D?

6. Can Member C talk to Member D?

Asked to respond Yes, No, or I don't know

Network manipulation checks

1. I felt like the communication structure we had isolated some teammates.

2. I felt like the communication structure we had made one member more vital for our

    effective coordination.

3. In our communication structure, one member could communicate with everyone.

4. I had access to enough connections to coordinate with my team.

5. I felt close to my teammates.

6. In our communication structure, we were connected to only the members on one or both

    sides of us forming a chain.

7. In our communication structure, we were connected to only the members on either side of

    us forming a circle.

8. In our communication structure, one member was isolated, only connected to one

    member, while the other members could all communicate among themselves.

9. I felt like the communication structure we had hurt our ability to get to know one another.

10. I felt like the communication structure we had hurt our ability to effectively perform.

11. I felt like there was a distinct leader in our group.

Note. All items use a 5-point scale where 1 = strongly disagree, 3 = neutral, 5 = strongly agree

These items were designed such that if the manipulation was effective:

- Centralized groups would score high on 1-3

- Dense groups would score high on 4-5

- Decentralized, sparse groups would score high on 6

- Decentralized, dense groups would score high on 7

- Centralized, dense groups would score high on 8

- Items 9 through 11 were more general