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In a world of their own...Team cognition in long-term cohabitating teams

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Gabriel Plummer

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Abstract

Teams such as those that travel in outer space require team members to cohabitate for long periods of time. These teams are unique. Team members not only work together, they live together and in some ways are more like families than work groups. How does long-term cohabitation affect teamwork? These teams, while they are interdependent both functionally and in terms of their team's goals, have quite different experiences from teams working in an office. These teams do not have the chance to leave each other and are isolated from any form of external support. I studied 9, 4-person teams living in isolation in the NASA analog HERA (Human Exploration Research Analog) for either 30 or 45 days. Triangulating across multiple methodologies, I glean new insights into team cognition as it develops and affects the performance of these teams. I found that shared task and team mental model similarity tended to increase early in the mission and then stabilize whereas trends in shared vision tended to increase in later phases of the mission. Additionally, interpersonal stressors had different impacts depending on the type of team cognition: hindrance network density negatively impacting shared team mental model similarity, but positively impacting shared vision. In my fourth chapter, I found that higher team mental model similarity and shared vision were positively related to coordination task performance, but negatively related to creative task performance. These variables had opposite effects for problem solving performance with the former benefitting performance and the latter negatively impacting performance. Additionally, the relationships between these variables depended on whether average levels of team cognitive similarity were used or trends in cognitive similarity leading up to performance. Average levels were important for creative thinking tasks, but trends in cognitive similarity were more important for problem solving tasks.

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Executive Summary

Teams spending months, even years in space journeying past Earth's orbit and possibly reaching Mars in the next 15-20 years will stretch the boundaries of teamwork and expose challenges previously uninvestigated in teams literature. I investigated the phenomenon of team cognition in the context of environments where individuals cohabitated for long periods of time working on an extended performance episode. Specifically, I explored the content of team cognition, the trends in team cognition over time, as well as the consequences of team cognition in these environments focusing on the unique conditions of cohabitation and longevity. I not only examined the dynamics of a team construct under unique conditions, but also shed light on team cognition in general by broadening the investigation into the different forms of team cognition that vary along dimensions relevant to the conditions of cohabitation and longevity. I demonstrated how these constructs unfold over time, how contextual factors differentially impacted the patterns of team cognitions and investigated the consequences of different types of team cognition.

The conditions of cohabitation, and longevity are found in environments covering a range of contexts including Antarctic research stations, Arctic expeditions, submarines, space travel, and space analogues. The environment I focused my research on was the space analogue. These environments mimic the conditions of living and traveling in space for long periods of time over great distances analogous to a long mission such as a journey to Mars. In these analogues, teams of people were confined for multiple weeks in a small habitat, isolated from the outside world. These people had to interact with the same team members every day, they had minimal personal space, limited contact with friends and family, restricted communication, sleep deprivation, periods of high workload, and long periods of boredom.

In Chapter 1, I unpack how these contextual factors could impact individual and team adaptation and functioning. The main focus of the chapter was to develop a taxonomy of team cognition constructs. The taxonomy classifies team cognition along six different dimensions. The first three: 1) content of cognition (task versus team related), 2) nature of emergence (compositional versus compilational), and 3) form of cognition (structured, perceptual, or interpretive) are commonly referenced dimensions in the team cognition literature. However, the context and requirements of teamwork in teams traveling through space extend the concept of what it means to work on a team. Therefore, the next three dimensions I included: 4) work-life relevance (work relevance versus living relevance), 5) dynamism (static, gradual, volatile), and 6) consequence horizon (short-term, mid-term, or long-term) are new dimensions that I used to organize these team cognition constructs given the unique context of cohabitation and longevity that space exploration crews experience. This taxonomy served as the organizational framework for my investigation into different types of team cognition. The first chapter has an overview of team cognition research and then discusses each type of cognition, why it is important, and how it fits into the taxonomy. ***The key point of Chapter 1 is a proposition: three contextual aspects of space teams - cohabitation, dynamism, and consequence horizon - are core aspects of how members think together over time, and incorporating them into measures and studies of team cognition may improve the prediction of team performance.***

Chapter 2 explains the development and testing of a new contextualized measure of team cognition, namely the shared vision of goals and challenges a team faces on a daily basis. This was a qualitative measure that identified the content of individuals' cognitive representations of the environment on a broader, long term basis. In this chapter, I discuss the themes that emerged, and how those themes varied over time or were impacted by contextual factors as well as a look at how shared vision (similarity of team member visions) looked in teams and descriptively changed across time. What I found was that the themes that emerged fell into both work and non-work categories, and could then be further divided into various task, logistics, social, and general living sub-categories. Mission task goals were dominant throughout most of the mission, but tended to decline in prominence towards the end when crews became more focused on their well-being. While taskwork was a major motivating focus for the crew vision, the challenges anticipated by the crew were more balanced across living related and work related issues. Finally, I was able to examine the similarity in vision across crew members and identify interesting patterns such as a crew member becoming less and less in sync with the crew over time. ***The key conclusion from Chapter 2 is that team members think about how work (tasks and logistics) and non-work (social and general living) factors affect the team, and the relative salience of each set of factors changes over time as the mission unfolds.***

In Chapter 3, I look at team cognition constructs that were continuously monitored over the course of the space analogue missions. In this study, I explored how these different constructs varied in their trends over time, addressing the need to view team emergent states in extreme environments as dynamic, multifaceted constructs that evolve over time (Salas et al., 2015). The two main questions answered in this chapter were 1) what were the trends over time in these constructs? and 2) how did the patterns in these constructs respond to stressors over the course of a long mission? I found that the trends in cognitive similarity varied widely across teams. I broke these patterns down using the communication delay schedule during the mission. I found that early on in the mission, task and team mental model similarity increased leading up to the communication delay period, and then remained relatively stable for the remainder of the mission. Shared vision, on the other hand, spiked at the onset of communication delay, and the growth trend accelerated in the final phase of the mission. Finally, I found that hindrance network density was associated with less similarity on task mental models, but greater similarity on shared goals. ***The key finding from Chapter 3 is that teams increase in their team cognitive similarity early on with regards to task related issues, but the trend is less clear when considering life-related mental maps. Additionally, trends vary widely across teams, which provides new opportunities to investigate what makes teams different in their patterns for developing cognitive similarity.***

In Chapter 4, I examine the impact team cognition had on team performance and team viability throughout the mission. Over the course of a multi-week mission, team cognition was measured continuously. Therefore, the impact team cognition had on performance was conceptualized in two ways: 1) the average amount of team cognitive similarity in the period leading up to the performance and 2) the trend in cognitive similarity leading up to the performance. Additionally, performance was assessed in three different ways: 1) execute task performance or performance on a task that required coordination and activity 2) generate performance or performance on a task that required creative thinking and 3) choose task performance or performance on a problem solving task. I found that team mental model similarity and shared vision were positively related to performance on the coordination task. I also found differing results depending on if I considered the average levels of team cognitive similarity or the trend leading up to the performance. For creative tasks, average levels of team mental model similarity and shared vision were negatively related to performance. However, with the problem solving task, the trends in cognitive similarity were more important. Trends in team mental model similarity were positively related to choose task performance, but trends in shared vision were negatively related to performance. ***There are two key findings from Chapter***

4. First, team cognitive similarity has opposite effects on different dimensions of performance - similarity benefits execute performance but harms creative thinking. Second, whereas the mean team similarity predicts creative performance, the trend in similarity is more predictive than the mean for problem solving performance. This reveals that the relationship between team cognition and performance is more nuanced than previously conceptualized, and suggests future research is needed to examine team cognition as a dynamic construct.

Finally, in Chapter 5, I consider the contributions of this work to knowledge in two domains: (1) team effectiveness research in the organizational sciences, and (2) space psychology. ***In returning to the opening proposition in Chapter 1, the dissertation concludes that dynamism, is an important aspect of team cognition that has implications for the team cognition to performance relationship. Additionally work-life relevance is an important aspect of team cognition that has implications for the evolution over time.*** By expanding the context in which team cognition is studied, it is necessary to expand the dimensions upon which team cognition constructs can vary. Dynamism, work-life relevance, and consequence horizon are new dimensions for team cognition that are made relevant by the context of cohabitation and longevity. These conclusions are reached with a programmatic set of studies using mixed methods: conceptual, qualitative, and quantitative analyses, to make fundamental advances in knowledge on team cognition. First through the organization of shared knowledge constructs into a taxonomy, and then by examining the interrelatedness among these various types of team cognition. Previous research has demonstrated the impact that team cognition has on team processes and performance, but this dissertation examines team cognition as a continuously evolving construct in a new context. This dissertation gives a glimpse into how team cognition evolves over time showing that teams converge on some forms of team cognition early on in their tenure, but converge on other forms of team cognition later in their lifespan. Additionally, the dissertation shows that factors such as interpersonal stress have different impacts depending on the type of team cognition considered. Another important discovery is the distinguishing between average levels of team cognition and the trends in team cognition leading up to performance on a task. Depending on what type of task a team is performing, it may be more important to consider the average level of team cognitive similarity or it may be pertinent to consider the trend in their cognitive similarity.

This dissertation also reveals new questions especially with regard to the differences between teams. Examining patterns over time has shown that teams differ on their trajectories, and future research should consider where these differences originate - what makes some teams converge in their cognitive similarity quicker than others? This dissertation also finds team cognition has different associations with performance dimensions. Future research is needed to investigate what performance dimensions benefit from task cognitive similarity and which may be compromised by it. Finally, this dissertation suggests that patterns matter. I found different effects on performance when I used the average cognitive similarity, versus a metric reflecting the trend over time. This opens up an intriguing question for teams research more generally. Is it the quality of team process that matters, or the general fluidity of team process that best predicts performance? Knowing whether a team is on the rise or the decline may offer new insights into team performance in long-term teams.

CHAPTER 1
THEORY DEVELOPMENT

A crew is on its way back to Earth after a successful journey to Mars. The 6-member crew had just spent 13.5 years studying the surface of Mars and conducting experiments, and now are part way through their 7-month mission home. All of the life support and mission operation computer programs are carried out by a Central Autonomous Regulatory System (CARS). When issues start to pop up on the ship such as missed pressure gauge readings, or thruster failure, fingers start to get pointed in all sorts of directions. Is this human error? Is this a problem with the automatic system? Is this sabotage by one of the crew members? As accusations fly, the crew becomes more and more fractured and isolated from each other. Nobody is working together, and the fear and mistrust continue to rise. At one point, a crew member has a mental break, only further exacerbating the distrust amongst the crew. Nobody suspects the true culprit all along...aliens!

This example, as you might have guessed, is taken from a fictional story, one written by Nick Kanas (2014), an expert on the psychological and interpersonal issues that face teams in extreme environments. Many of the real issues from scientific studies conducted in extreme environments were incorporated into this story. For instance, while aliens might have been behind the malfunctions in this scientific novel, another culprit clearly to blame here is teamwork (or lack thereof). If everyone in this Mars exploration crew were working together, sharing information, and collaborating in a coordinated manner rather than pointing fingers and running off down their own paths of suspicion, then, perhaps the aliens could have been stopped before they infested the entire human species. In other words, the crew did not have a shared understanding of the situation, and nobody had an accurate understanding of what was going on until the end. The lack of similarity amongst the crew with regards to their understanding of the issue during the crisis prevented them from cooperating and, perhaps identifying the correct cause of the problem in a timely manner. This issue where the team lacks a shared understanding of events or circumstances around them is an example of unshared *team cognition,* which is an emergent state that refers to the manner in which knowledge important to team functioning is mentally organized, represented, and distributed within the team and allows team members to anticipate and execute actions (Kozlowski & Ilgen, 2006).

While Nick Kanas' fictional example provides a clear illustration of the breakdown in shared cognitive processes, there are real examples of similar team deficiencies causing serious issues in spaceflight. Disasters in space missions have been the result of a variety of errors including a lack of cognitive coordination. For example, breakdowns in team coordination, resource and information exchanges, and role conflicts (i.e., common indicators of poor team cognition) were mentioned as contributors to both the Challenger and the Columbia space shuttle accidents (Columbia Accident Investigation Board Report, 2003; Rogers Commission Report, 1986). The Challenger was a tragic event that cost the lives of 7 crew members including Sharon Christa McAuliffe, a school teacher set to be the first civilian in space. While problems with the booster joint and seal were cited as the physical cause of the disaster, the accident report also noted a number of NASA management failures that contributed to the catastrophe, including communication failures, incomplete and misleading information, and poor management judgments that all figured into the decision-making process.

> The decision to launch the Challenger was flawed. Those who made that decision were unaware of the recent history of problems concerning the O-rings and the joint and were unaware of the initial written recommendation of the contractor advising against the launch at temperatures below 53 degrees Fahrenheit and the continuing opposition of the

> engineers at Thiokol after the management reversed its position. They did not have a clear understanding of Rockwell's concern that it was not safe to launch because of ice on the pad. If the decision makers had known all of the facts, it is highly unlikely that they would have decided to launch. (p. 82)

In the case of the Columbia shuttle disaster in which a 7-person crew died upon reentry into the Earth's atmosphere, the report acknowledges, "...the management practices overseeing the Space Shuttle Program were as much a cause of the accident as the foam that struck the left wing." (p. 11). One excerpt from the Columbia Accident Investigation Report cites the barriers to communication and lack of integration across program elements:

> Cultural traits and organizational practices detrimental to safety were allowed to develop, including: ...organizational barriers that prevented effective communication of critical safety information and stifled professional differences of opinion; lack of integrated management across program elements; and the evolution of an informal chain of command and decision-making processes that operated outside the organization's rules. (p. 9)

Aspects of the Columbia disaster even changed how the design process worked to be a more integrated process,

> In the 1970s, engineers often developed particular facets of a design (structural, thermal, and so on) one after another and in relative isolation from other engineers working on different facets. Today, engineers usually work together on all aspects of a design as an integrated team. (p. 52).

NASA has specifically recognized the role that team cognitive states play in the success of missions (Landon, Vessey, & Barrett, 2016). However, not much research has been done on team cognitive states over long periods of time and none has been done in conditions of cohabitation where individuals are constantly interacting and longevity with a crew working constantly on an extended performance episode.

This chapter briefly delves into how extreme environments can cause issues for teams that have implications for the formation and maintenance of shared cognitive processes. After this review, the focus shifts to the constructs of team cognition that I studied. Team cognition has been studied in a variety of forms, and this chapter begins by defining these constructs, and then organizes the bounty of research into a taxonomy based off of three defining characteristics across the variety of team cognition constructs: 1) content (task versus team related), 2) nature of emergence (compositional versus compilational), and 3) form of cognition (structural, perceptual or interpretive). However, the context in which teams are cohabitating for long periods of time is unique from teams studied in the team cognition literature currently. Therefore, my taxonomy goes beyond the traditionally studied dimensions and constructs of team cognition. Specifically, I organized these constructs on three new dimensions relevant to the context of teams living together for long periods of time: 4) work-life relevance (work vs living), 5) dynamism (static, gradual, and volatile), and 6) consequence horizon (short-term, mid-term, or long-term) (Table 1).

Extreme Teams vs Typical Teams

While astronaut teams traveling through space or other extreme teams might seem like they are completely incomparable to typical work teams, the truth is that the core characteristics of teamwork are common across contexts whether the team is working in an office or on a space shuttle to Mars. The core defining characteristics of a team involve (a) at least two people who (b) socially interact; (c) pursue one or more common goals; (d) perform organizationally relevant tasks; (e) are interdependent with respect to workflow, goals, and outcomes; (f) have different roles and responsibilities; and (g) are embedded in an encompassing organizational system (Kozlowski & Ilgen, 2006). Just like any team working in an organization, space exploration crews have shared goals, have bounded members with specific roles and responsibilities, and are interdependent for both goal accomplishment and task work. In Marks, Mathieu, and Zaccaro (2001) taxonomy of team process, they describe the temporal rhythm of team task accomplishment in which teams often concurrently cycle through phases of transition and action team processes on various performance episodes that vary in duration, and repetition. Even though astronaut crews are pursuing a team goal that extends across an exceptionally long performance episode, they also engage in smaller performance episode cycles throughout their mission that resemble the cycles in which typical work teams engage. If an observer were to view a segment of astronaut work life, it would likely resemble the work of teams observed in ordinary organizations. It is not until the observer zooms out and sees the whole picture that the differences become clear.

There are clear and substantial differences when it comes to considering the challenges and processes teams go through in extreme environments compared to teams operating in organizations commonly studied in teams research. When teams face challenges such as deep sea exploration, Antarctic expeditions, and space travel, they are not only called upon to work on increasingly complex problems, but they must face these challenges for lengthy and sustained periods of time in conditions that are quite unlike typical workplaces. Teams in these situations are often isolated from friends and family, confined to tight living quarters with the same people, and face physically and psychologically stressful conditions. The two distinguishing environmental characteristics that separates these extreme teams from more typical work groups are 1) Cohabitation - living and working together in isolation from ordinary sources of social support, and 2) Longevity - pursuing a team goal that requires members to continue working together in an extended task episode (Landon et al., 2016).

By virtue of their task requirements and working conditions, teams working in extreme contexts face unique problems compared to those working in more typical work environments (Landon et al., 2016). For example, teams working in Antarctica have shown psychological discomfort and distress (Wood, Lugg, Hysong, & Harm, 1999), changes to social roles and structures (Johnson, Boster, & Palinkas, 2003), health issues (Sandal, Leon, & Palinkas, 2006), and myriad process breakdowns (Palinkas, Gunderson, Holland, Miller, & Johnson, 2000). As such, studying teams in extreme contexts who are cohabitating for long periods of time reveals new experiences and obstacles likely not encountered by teams typically examined in teams research such as one-off project teams, teams in the classroom, or even military teams. In astronaut teams, crews are cohabitating together throughout their entire mission, whether they are working on taskwork, or off the clock and do not get the choice to separate or leave the group if they need a break. Having constant non-work interactions essentially elevates space exploration crews from a typical work group to more of a family dynamic so there is a heavier emphasis placed on teamwork not related to any particular task.

By virtue of this long-term, cohabitating dynamic, a crucial area of investigation is the evolution of team emergent states. Team cognition is of interest here since the content is a defining characteristic, and the content of cognitive processes in the context of cohabitation and longevity is significantly broadened. For one, the longevity of the team's overarching performance episode makes the evolution of team cognition more drawn out. Research on team cognition evolving over time is often constrained to a relatively short period and a handful of measurements. In the case of a journey into deep space or an extended stay on the space station, teams are together for much longer than teams typically studied over time, and the various forms and types of team cognition evolve in different patterns.

The second defining feature of these teams - their cohabitation - makes it so that team cognition evolving over time is not confined to work related dynamics. These teams are isolated from most other forms of social support, so they rely on each other for social interaction, but are also forced to be together past when the work has ended for the day even if someone wishes to take a break. Therefore, the content, framing, and focus of team cognition moves beyond typical work dynamics seen in teams research to encompass more social issues born from cohabitation. In the next section, I discuss in depth how team cognition is studied, how the constructs under team cognition are classified, and how that classification needs to evolve for contexts of longevity and cohabitation.

Team Cognition

In the 18th century, and persisting well into the 20th century, social psychologists were very interested in the concept of the group mind (i.e. Hegel, 1807; McDougall, 1920). The group mind was a theory where experimenters analyzed groups much the same way they would individuals. Groups were believed to be sentient, and have mental processes that guided action. This theory, while similar to modern conceptions of team cognition fell out of favor for being overly simplistic, and vague as well as being associated with extreme theories such as telepathy and other supernatural concepts. The group mind theorists also did not investigate communication processes among group members, and they identified the group mind with similar mental processes of group members rather than having the group mind as a consequence or cause of group processes (Wegner, 1987).

Prior research on team cognition falls into two main categories: shared mental models (Cannon-Bowers, Salas, & Converse, 1993) and transactive memory systems (Wegner, Giuliano, & Hertel, 1985). Shared mental models emerged as a construct in 1990 by Cannon-Bowers and Salas to investigate performance differences in teams operating in complex, dynamic, and novel situations. The concept of transactive memory, as a memory system distributed across group members, was first proposed by Wegner to explain why close personal relationships often foster the development of common memory (Wegner, Giuliano, & Hertel, 1985). One of the main differences between the two constructs is that shared mental models characterize common knowledge frameworks in a group, and transactive memory systems characterize distributed knowledge frameworks (Kozlowski & Ilgen, 2006). Whereas transactive memory research has traditionally emphasized task-oriented knowledge domains, shared mental models research has explored a wider array of cognitive content, encompassing both taskwork and teamwork dimensions (Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000), in addition to exploring technology (Lim & Klein, 2006), and strategic mental models (Marks, Zaccaro, & Mathieu, 2000). Another distinction is the dependent variables associated with transactive memory systems and shared mental models. Since encoding, storage, and retrieval of information are the main focuses of transactive memory systems, recall is usually the primary dependent variable measured in empirical work on transactive memory (e.g., Mell, van Knippenberg, & van Ginkel, 2013). In contrast, the emphasis in shared mental model research is on examining the impact of knowledge convergence on team processes (e.g., communication, coordination, performance monitoring) and performance (e.g., Mathieu et al., 2000).

The focus of team cognition literature on these two constructs has, perhaps, limited the reach of the construct. Small-group research from social psychology has a long tradition of studying cognitive constructs such as group norms and role expectations that guide interpersonal interactions among members of the group. Research on small groups shifted from social psychology to organizational psychology (Levine & Moreland, 1990), but the focus of the research also shifted to address cognitive constructs that are more focused on guiding task-relevant interactions among team members rather than interpersonal interactions (Kozlowski & Ilgen, 2006). Accepting the importance of team interactions beyond taskwork without sacrificing the focus on performance that small groups research lacked is an important bridge to make in this literature, and one particularly relevant for long-term cohabiting teams. The focus for teams such as those set to journey into space is still on their performance as there is an overarching mission as well as intermediate performance episodes, but now the risks to performance have broadened to include social adaptation (Landon et al., 2016). In the following sections, I go in depth on the team cognition constructs of interest. Shared mental models and transactive memory systems are still important to the functioning of teams in these unique contexts, but other constructs that relate more to the social cohabitation dynamic such as the informal social role perceptions in the team and the team's shared vision are also included.

Team Cognition Constructs

There are many different constructs that fall under the umbrella of team cognition, and research looking at multiple constructs at once is sparse. My examination of concepts simultaneously adds to the body of literature on team cognition by being able to disentangle the effects and relationships amongst these constructs. While I am examining multiple constructs under the same conceptual umbrella, there are defining attributes of these constructs that make them unique contributions to a team's cognition. This section introduces the constructs I studied that fall under the umbrella of team cognition, and breaks the various constructs down into an organizing taxonomy. Research broadly defines cognitive team states as mental representations that serve as a basis for individuals' actions and interactions within a team (DeChurch & Mesmer-Magnus, 2010; Mohammed, Klimoski, & Rentsch, 2000). The two main streams of research that examine cognitive functioning in teams are transactive memory and shared mental models. Additionally, this section includes social role agreement and shared vision as categories of team cognition in the taxonomy. This section defines these various team cognition constructs, and the following section defines the dimensions along which the constructs vary, culminating in a final taxonomization (Table 2).

Shared mental models. Shared mental models emerged as a construct in 1990 by Cannon-Bowers and Salas to investigate performance differences in teams operating in complex, dynamic, and novel situations. The no-look pass in basketball is the perfect example of team members knowing where to be, where others on the team are, and what others on the team are going to do; all without explicitly needing to check in or shout out exact instructions. In a 520-day analogue mission where six people were living together performing tasks in a simulated Mars mission, Diego Urbina, one of the crew members, describes the experience and some of the hurdles saying "some issues included misunderstandings between crew and ground due to the lack of live communications...We had to try to read each other's mind" (Pultarova, 2012). One of the most significant challenges faced on a long-term mission, especially one where members of a team are living together, is the need to maintain shared mental models. Shared mental models are defined as the shared, organized understanding and mental representation of knowledge or beliefs relevant to key elements of the team's task environment (Klimoski & Mohammed, 1994).

Cannon-Bowers and colleagues (1993) originally proposed four shared mental model domains: an equipment model (knowledge about tools and technology), a task model (understanding of work procedures, strategies, and contingency plans), a team interaction model (awareness of member responsibilities, role interdependencies, and communication patterns), and a team model (understanding of teammates' preferences, skills, and habits). In practice, however, researchers have tended to collapse the content into two categories: 1) teamwork, which entails knowing how to interact with team members and knowing how one person's contribution fits in with other peoples' contributions and 2) taskwork, which means knowing how to complete tasks and the interrelatedness of team objectives (Cooke, Kiekel, & Helm, 2001; Mathieu et al., 2000).

In situations of cohabitation and longevity, these content domains cover a broader spectrum of tasks and teamwork, and the attributes of taskwork and teamwork captured in an individual's mental model need to be broad enough to encompass the full spectrum of activities in which the team engages. On board the international space station (ISS), for example, diary entries from astronauts clearly exemplify the variety of content domains people were concerned with (Stuster, 2010). While task work was a common topic of diary entries, common living patterns became salient issues as well, especially as time goes by.

> It is getting old being up here. The excitement has worn off after 2.5 months, but I still enjoy working here. It is the living up here that is old. It would be great to eat, sleep, shower, etc., at home and then go to work on the station. (p. 15)

Interpersonal issues also evolve over time in ways that would sound familiar to anyone who has lived with a roommate. The details are unique, but the grievances are similar.

> I think I do need to get out of here. Living in close quarters with people over a long period of time, definitely even things that normally wouldn't bother you much at all can bother you after a while... that can drive anybody crazy. (p.16)

> Well the day has finally arrived. I am now somewhat frustrated with my crewmates. Maybe it happens to everybody, but one of them continues not to do what they are supposed to do. Small things that wind up being big things-not vacuuming the razors when it is their time to do it, leaving stuff open on the computer, changing camera settings in the cupola. (p. 35)

An individual’s mental representation of these content domains fluctuates as time passes with constant interactions and recurring work episodes serving as triggers to update or confirm aspects of an individual’s mental model.

Shared mental models are measured on the properties of similarity and accuracy (Mohammad, Ferzandi, & Hamilton, 2010). Similarity is the degree to which meanings and understandings used to interpret internal and external events are alike among individuals. Rouse and Morris (1986) assert that when team members share knowledge, it enables them to interpret cues in a similar manner, make compatible decisions, and take the appropriate action. When a construction crew is repairing a stretch of highway, having a shared understanding of when each piece of the project is to be done, what tools are needed, and who is performing each task allows the crew to coordinate seamlessly without the need for explicit directions or extra time spent going around asking everyone what to do and what they are doing. However, when mental models overlap too much it can become a detriment to the team because it limits unique individual contribution (Cannon-Bowers et al., 1993; Levine, Resnick, & Higgins, 1993). An extreme example of this over-shared mental model phenomenon is "groupthink," which is defined as extreme concurrence-seeking that produces poor group decisions (Janis, 1982). The construction crew that is too aligned might not listen to innovative ideas or be unable to adapt when unexpected circumstances arise.

The second property, accuracy refers to the extent that shared mental models reflect the true nature of the world (Edwards, Day, Arthur, & Bell, 2006). The construction crew might all be on the same page when it comes to this highway project, but that does not mean that they are correct in their thinking. They might all have the same wrong understanding about task elements such as how long the stretch of highway they need to fix is, how long they have to complete the project, or the availability of crucial supplies. New groups typically go through a “forming” stage where team members share ideas about how they will work together, and their expectations about the tasks. Team members, usually reach at least a minimal amount of understanding about the nature of the team, its tasks, and goals, and how the team will interact together (Klimoski & Mohammad, 1994).

Transactive memory systems. Transactive memory systems (TMS) emerged as a construct in 1985 when Daniel Wegner and colleagues observed that close relationship couples usually formed a shared memory scheme. They developed a terminology explaining a shared system for encoding, storing, and retrieving information. In a study conducted by Giuliano and Wegner (1985), intimate couples who had been together for at least 3 months were asked to memorize a list of 64 items. Subjects remembered items from categories they had judged to be their own areas of expertise. Additionally, members of these couples accepted the responsibility for information even when they were not expert, but they accepted responsibility for this knowledge only when they knew their partner had no history of expertise in the area. This shows how an individual's internal memory retrieval is affected by transactive constraints - knowledge of what someone else's memory can or cannot do. Later, Wegner and colleagues (1991) compared intimate couples to stranger couples doing the same memory recall task finding that intimate couples were able to recall better than strangers when no prior assignments on who memorizes what were given. However, the opposite is true (strangers outperform intimate couples) when assignments for who memorizes what are given ahead of time. This indicates that being familiar with your partner means you already have a system in place when it comes to assigning incoming information. Relying on your own system improves encoding, but providing intimate couples with a forced system that interferes with their existing encoding system hinders their collective recall. Because couples have a system of encoding information, when a new system is forced on them, they have a harder time encoding incoming information compared to couples who had no established system in place.

Hollingshead (1998a) also compared intimate couples to stranger couples and explored the retrieval process a bit more in depth. She found that intimate couples who worked face to face performed better on a knowledge-pooling task than strangers who worked face to face and better than intimate couples who worked via a computer conferencing system. This finding replicates the idea that familiarity improves information encoding in retrieval, and also that communication and access to nonverbal and paralinguistic cues is a piece of this process. Hollingshead (1998b) also established a similar result as Wegner et al (1991) finding that intimate couples recalled better when they were not allowed to communicate during the learning process compared to stranger couples, but the results flip when pairs are allowed to communicate during the learning process. It would seem that no communication is better for intimate couples since they end up relying on their implicit system already in place, but when they are allowed to communicate, they perhaps tamper with their natural system for encoding information leading to a break from their instincts, which harms their encoding and retrieval processes.

The research on couples established the concept of a team cognition process occurring when it comes to expertise distribution and processing of information. TMS research has since been extended from intimate couples to teams and organizations. From a team perspective, transactive memory is a group-level collective system for encoding, storing, and retrieving information that is distributed across group members (Wegner, 1995; Wegner et al., 1985). In contrast to the more uniform knowledge sharing characteristic of shared mental models, transactive memory is conceptualized as a set of distributed, individual memory systems that combines the knowledge possessed by particular members with shared awareness of who knows what (Wegner, 1995). Research indicates that the benefit of a TMS is that members are able to specialize in different but compatible information domains and use each other as external cognitive aids (Kozlowski & Ilgen, 2006).

Some of the first research on TMS in teams rather than couples was conducted by Liang, Moreland, and Argote (1995) who examined the task performance of laboratory teams whose members were either trained together or alone. These teams or individuals were trained to assemble transistor radios either with their groups or separately. A week later, subjects were asked to recall the assembly procedure and actually assemble a radio either in the groups they were trained or with an assembly of individuals who were trained alone. Groups whose members were trained together recalled more about the assembly procedure and produced better-quality radios than groups whose members were trained alone. Analysis of video tapes indicated that group training improved group performance primarily by fostering the development of transactive memory systems among group members based on ratings of their specialization, task coordination, and task credibility. Additional studies have gone on and proven the impact that TMS has on performance above other possible factors such as improved communication (Moreland & Myaskovsky, 2000), and generic learning or group development (Moreland & Thompson, 2006)

Informal social role agreement. Informal social roles refer to informal functions or relationships fulfilled in a team such as task leader, story teller, or volunteer (Bales & Slater, 1955). Informal social roles contrast with formal roles in that formal roles are those prescribed by groups, organizations, or cultures and are reflected in the designation of formal positions (e.g., commander, pilot, surgeon). Additionally, there is a distinction in the literature between informal roles and latent roles. Latent roles are ones that are not regarded as formally salient and culturally prescribed for classifying people in an organization (Gouldner, 1958). Although early research recognized a link between latent and informal roles in organizations (Gouldner 1957; Becker & Geer 1960) there is a fundamental difference between the two. Whereas all latent roles are informal, not all informal roles are latent. In this sense there are informal, as well as formal social roles, that are salient and acknowledged throughout a team's existence. On the other hand, there are informal social roles that can be dormant or hidden emerging only when circumstances or conditions warrant (e.g., due to external or internal events).

The social role structure of a team can be seen as a bipartite network with the team members as one mode and the social roles as the second mode. Each individual has a dynamic conceptual map of these team member nodes and social role nodes with links between a team member and a social role signifying that the individual believes the teammate fills that particular social role. The map of informal social roles in a team is distinct from transactive memory systems because these roles go beyond specific task work to encompass broader social dynamics, which become relevant in conditions of long-term cohabitation. Assessment of these social maps can be done similarly to methods concerning mental model similarity by assessing agreement between team members' individual maps. Social role agreement is the degree to which members of the team all have the same idea of who fills what roles. Presence of agreement reflects a lack of role competition and conflict in that there is agreement on the set or sets of individuals performing such roles (Johnson, Palinkas, & Boster, 2003).

Shared vision. Similar to the other constructs of team cognition, shared vision is capturing the similarity or distribution of a mental representation within the team, but is specifically focused on the extent to which the members of the team share an understanding of the strategic vision they are aimed at achieving (Wildman et al., 2012). This mental representation is not referencing the requirements of taskwork, or the characteristics of a team, but rather is focused on knowledge or understanding of an overarching mission relevant to the team. Nanus (1992) described vision as a mental model of a future state of a process, a group, or an organization, Thoms and Greenberger (1995) described vision as a cognitive image of the future, which is the basis of group member motivation, planning and goal setting, and Kouzes and Posner (1987) defined it as an ideal and unique image of the future. Pearce and Ensley (2004) explain their view of shared vision as a team process where team members shape and create a vision of the future. These conceptualizations of shared vision entail a general purpose of a team or a single performance goal. In teams that are cohabitating for long periods of time, the long-term ultimate goal (such as returning home safely from a trip to Mars) is distal and more like a vague necessity forced upon the crew given the circumstances. However, in the time between the beginning and end of a space exploration mission, the team pursues several goals that cover a broad range of content areas that vary in their criticality. For these teams, I conceptualize vision as a cognitive representation of what the team needs to achieve, and what obstacles the team will need to overcome on a short term basis (i.e., on a given day).

As the name implies, shared vision is assessed based on how similar one person's conceptualization of the future is to that of another person. In addition to how shared the vision of a team is, another form of assessment is what is the content of the team vision. Teams in organizations often have a vision constrained to the achievement of task goals related to the success of the company or department. When a team is living together for months in a confined space, the goals of the team are bound to fluctuate between issues directly related to accomplishing tasks and issues that are more directed towards the challenges of cohabitation and well-being. Part of the challenge in capturing shared vision in these types of teams is understanding the issues that individuals focus on. The next chapter delves into the creation of a qualitative measure used to explore the motivations and challenges people in these environments face on a daily basis. The following section explains the dimensions of team cognition along which these constructs vary.

Taxonomy of Team Cognition in Cohabitating Teams

In this section, I establish a taxonomy for organizing the various team cognition constructs. DeChurch and Mesmer-Magnus (2010) offer a conceptualizing framework of team cognition that serves as the foundation for this taxonomy. Team cognition has been shown in numerous reviews to be an important underpinning of team functioning and effectiveness (e.g., Kozlowski & Bell, 2003; Mathieu et al., 2000; Mohammed et al., 2000). In their meta-analysis of the team cognition literature, DeChurch and Mesmer-Magnus categorized team cognition based on three dimensions: content of cognition, nature of emergence, and form of cognition. In addition to these three established dimensions, I expanded this taxonomy to include the dimensions of work-life relevance, dynamism, and consequence horizon, which are necessary to encompass the dynamism and variability of these constructs in teams living together for long periods of time. The full taxonomy and classification of constructs is seen in Table 2.

Content of cognition. The first dimension of team cognition is the type of content represented in the cognitive representations. Team cognition can be distinguished based on the extent to which content is related to the task or related to the team. Task-related cognition refers to team members' understanding of the nature of the task and the goals related to the task at hand. Team-related cognition refers to team members' understanding of the nature of team interaction. Task related cognition allows individuals to interpret information similarly and coordinate behavior without the need for explicit communication leading to more effective teamwork. In contrast, team related content characterizes how team members are expected to interact and when interaction is needed. Research has demonstrated that both team and task content are important aspects of team cognition as related to team performance and viability (Edwards et al., 2006; Mathieu et al., 2000; Mohammed et al., 2000).

The team cognition constructs I reviewed cover both teamwork and taskwork content areas. Shared mental models are often measured for both taskwork and teamwork. Transactive memory systems, on the other hand, refer to knowledge contained in the system about a specific task so TMSs fall under taskwork. Social role agreement and shared vision are constructs that broaden the definition of these content areas since these constructs reference cognitive domains relevant to living together and working on extended performance episodes. Social role agreement, therefore is concerned with team content in general and shared vision can reference either team or task content depending on the changing demands of the mission.

Nature of emergence. Team cognition is commonly referred to as a bottom-up emergent construct, which means that the origin of team cognition begins at a lower level (i.e., the cognition in the mind of an individual) and then there are properties that emerge at a higher level (i.e., the team). The manner in which a construct manifests at the team level from the individual level is referred to as the form of emergence. Kozlowski and Klein (2000) describe the different forms of emergence ranging from compositional emergence (in which the individual-level building blocks are similar in form and function to their manifestation at the team level) to compilational emergence (whereby the construct manifested at the team level is different in form to the individual-level counterpart). Compositional emergence occurs when the manifest team cognition construct is comprised of similar cognition within the minds of the individual team members. At the other end of the emergence continuum is compilational emergence. This form of emergence reflects a team level construct of the patterning in team- and/or task-related cognition among team members.

Shared mental models are prototypical examples of a team cognition construct that is compositional in nature. That is, each team member has a mental model and the team construct is the similarity between two individual mental models. Research on transactive memory systems, the extent to which the team develops a differentiated pattern of encoding and retrieving knowledge and information needed for the team to function and perform, is a prototypical example of a team cognition construct that is compilational in nature. Each team member has a different mental representation, and the team as a whole possesses all of the knowledge and information needed to perform its task and to function as a coherent whole. Shared vision, where everyone has an idea of the future state of the team or mission, and these visions are assessed on how shared or similar they are across the team reflects a typical compositional construct. Social role agreement also reflects a similarity between two individuals' mental representations of who fulfills specific social role functions in the team.

Form of cognition. The third dimension is the form of cognition. Research can be differentiated based on cognition as individual's perceptions or cognition as individual's structured thought patterns. Research on team cognition has focused on three different forms of cognition: (a) perceptual, (b) structured, and (c) interpretive, though most extant research fits within the first two categories (Rentsch, Small, & Hanges, 2008). Perceptual cognition examines team members' beliefs, attitudes, values, prototypes, and expectations, but "does not provide a deep understanding of causal, relational, or explanatory links" (Rentsch et al., 2008, p. 146). Structured cognition focuses on the pattern of knowledge and then models the collection of knowledge patterns across the team. Often, structured cognition is assessed with Pathfinder, multidimensional scaling, or pairwise comparisons, whereas perceptual cognition is assessed with rating scales. Interpretive cognition is not frequently studied in the literature, however, Rentsch et al. (2008) identified it as a third category of form of cognition, wherein cognitive similarity is inferred via qualitative analyses processes (e.g., sense making or using case studies, observations, interviews, or essays).

Most of the constructs I reviewed are classified under structural cognition. Team and task mental models both represent the knowledge of individuals as attribute nodes that are organized with a specific structure. Transactive memory systems, while often measured perceptually (Lewis, 2004) are more and more being viewed as networks of people and knowledge, which reflects a more structural form. Finally, Social role agreement is the network of roles and people connected to those roles so the result is a pattern of knowledge represented by the network structure. Shared vision, while not a new construct, is new to the context of cohabitation and longevity. This construct falls under interpretative cognition because it is assessed qualitatively and the similarity is based on qualitative assessments of individual visions aggregated to the team level.

The three dimensions of team cognition constructs explained above are all ones established in the literature, and their moderating effects have been investigated (DeChurch & Mesmer-Magnus, 2010; Mesmer-Magnus, Niler, Plummer, Larson, & DeChurch, 2017). The next three dimensions I discuss are important dimensions that have not been considered in the literature as they are more relevant to the unique context I studied. Living and working with the same group of people means that the knowledge representations team members share are not constrained to the work dynamic, Shared representations on how to live together in this context of cohabitation would be just has important for team success as shared knowledge on how to work together. Therefore, the fourth dimension (first new dimension) is work-life relevance. The fifth dimension is the dynamism of the constructs. Research on team cognition over time is rare, and the existing research only includes 2-3 measurements over the course of the study. Additionally, these teams have the freedom to separate and return to their own homes when they are not working together. Given the complexity of cohabitating teams such as astronaut crews and the environments they operate, team cognition should be viewed as dynamic, shifting in response to a variety of triggering events. Some of these constructs are more prone to fluctuations or vulnerable to new information while other are less movable. Finally, the sixth dimension I classified the constructs across is their consequence horizon. How these constructs change over time is an important dimension, but separate from that is how do these constructs impact the outcomes of the team across a long period of multiple performance episodes? Some of the constructs might have immediate implications for a task being performed right at that moment, while other constructs tend to have a slower, possibly more sustained release for when their impacts are felt. The following sections explain these dimensions in more detail as well as where the various team cognition constructs fall along these dimensions.

Work-life relevance. Studying team cognition in organizations often only needs to focus on cognition concerning teamwork or taskwork related to completing projects or tasks with your work team. A crew on a journey to Mars would be sharing much more of their lives with each other, and, suddenly, how people work together is not the only thing critical to mission success. In fact, when NASA considers the challenges of going to Mars, the main concerns have often not been of the mechanical or physical challenges, but rather the social ones (Lantis, 1968). Work-life relevance is a dimension of team cognition concerned with what part of the team dynamic the construct is built around. Is this construct applicable to the crew's working dynamic, or is it applicable to the crew's living dynamic? Both are critical to mission success, but they represent different types of cognitive integration. Shared mental models are perfect examples of work relevance since they represent knowledge structures about their taskwork or how to work together as a team. Transactive memory systems also fit clearly under work relevance since knowledge of team member contributions on specific tasks is relevant to work dynamics and would not spill over into living dynamics. Shared vision is a construct that exists in both domains as demands of the mission fluctuate between mission tasks or logistics and team interaction or well-being demands. Finally, social role agreement is a perfect example of life relevance as these are informal roles that people fill beyond work life, and relate heavily to how members view the team as a social unit.

Dynamism. Dynamism is the fifth dimension in the taxonomy and is highly relevant due to the extended nature of performance episodes. Dynamism refers to how stable construct remains over time. Some constructs such as personality or values are static over time even in extraordinary conditions such as isolation and confinement (Bell, Brown, Abben, & Outland, 2015) while other constructs change gradually meaning that they fluctuate, but changes are slower, and not extreme. Finally, volatile constructs are those most vulnerable to constant, and extreme fluctuations based on new information. Teams over time have been studied in the mental model literature with some support for factors such as role differentiation leading to less communication, and therefore less similar team cognition over time (Levesque, Wilson, & Wholey, 2001). Additionally, Mathieu et al., (2005) found that time alone did not result in changes to mental model similarity. These studies, while capturing some of the dynamics over time, do not look at teams who are processing constant inputs related to their team cognitive structures due to the fact that these teams do not get to go home at the end of the day. Social role structure is a great example of a construct that is static given that social role classification is not considered a day to day behavior analysis, but rather an enduring trait applied to an individual. On the other hand, shared vision would be expected to be relatively volatile as the demands of the future are fluctuating based on the activities of the day, and everyone's expectations for the future are bound to vary. Shared mental models and transactive memory systems sit in the gradual area of dynamism. Over time, there will be some elements of mental models or TMS structure that will need to shift as people engage in multiple pairings, interact with different teammates, and encounter changes in tasks and goals, but knowledge of previous tasks is applicable in the understanding of the present tasks so there is likely to be some carry-over, and stabilization.

Consequence horizon. Consequence horizon is concerned with the outputs resulting from team cognition. Literature has established the positive relationship between team cognition constructs and team process and performance (Mathieu et al., 2000). Often these relationships are contained within a single performance episode. However, consequences during a long-term space mission play out constantly, and the impact that team cognition constructs have on outputs may be immediate, or they may be witnessed further along in the lifespan of the team. I define consequence horizon as the immediacy of impact of team cognition constructs. Some constructs such as shared mental models and transactive memory systems have immediate consequence horizons in that they impact the tasks a team is working on at that moment. Shared vision, on the other hand, has delayed consequence horizon as the vision of the future plays out over the course of a whole day as expectations are either met or missed. Finally, social role agreement has an extended consequence horizon as the impact of how a team perceives the informal roles of its members unfolds gradually, and those roles get acknowledged and fulfilled more and more down the line.

In Table 2, each of the team cognition constructs are classified along all six dimensions. The cells shaded grey in the table indicate dimensions or constructs that have been established in the team cognition literature. Namely, the dimensions of content of cognition, nature of emergence, and form of cognition, and the constructs of mental models, and transactive memory systems. The remaining cells are unfilled representing the expansion of team cognition constructs and dimensions that this taxonomy adds to the team cognition literature. Seeing as these new dimensions, however, are not established in the team cognition literature, but rather deduced theoretically based on the unique context of the teams I studied, the classification of constructs along these dimensions should also be considered exploratory.

Summary and Preview

The above taxonomy sets the stage for how I conceptualized and examined team cognition in teams cohabitating and collaborating for long periods of time over the course of an extended performance episode. My studies focused on three of the team cognition variables from the review: shared mental models, social role agreement, and shared vision. While all constructs represent cognitive representations of key elements within a team's relevant environment that are shared across team members, they are distinct in that they vary in their content, their nature of emergence, form of similarity, work-life relevance, dynamism, and consequence horizon. The expectation is that, due to these differences, these constructs unfold differently over time, have different patterns, and variability. Additionally, the differences between these constructs has implications for the type of factors that influence their development as well as the consequences that follow.

In the next study, I developed the measure of shared vision employed in the context of these unique conditions. The measure was meant to capture the content and similarity of a team's expectation for the future at a level that zoomed in enough to capture variation over time, but was broad enough to include the full context of the crew's experience. Stuster (2010) examined a similar phenomenon at the individual level on board the international space station using astronaut diary entries. In Chapter 3, I examined the evolution of certain constructs over time to identify variants in patterns both within and across team cognition constructs. Chapter 4 examined the consequences of team cognition and how the relationships dynamically played out over time. Finally, in Chapter 5, I discuss the broader implications, limitations, and future directions of this research.

General Setting and Methodology

The following studies all took place in one of NASA's space analogues, called the Human Exploration Research Analogue (HERA), located at Johnson Space Center (Figure 1). HERA is a two-story, four-port habitat unit, and connects to a simulated airlock and hygiene module. The total space comprises 148.1 m^3. HERA has a surveillance video and audio system, space flight-like timeline and task book viewer to provide a space mission experience (Cromwell & Neigut, 2014). The habitat is meant to mimic the isolated and confined conditions that a crew on a long-term space mission would experience. The crews I studied spent either 30 or 45 days inside HERA.

Population

The subjects of these studies were members of nine 4-person crews (N = 36) with four of them spending 30 days and four of them spending 45 days inside the HERA. One of the crews was intended to spend 45 days in the analogue, but their mission was cut short on mission day 22 due to a hurricane in the area. Three of the crews were same-gender (two all male and one all female) and the other six crews were mixed gender. Pictures of all nine crews can be seen in Figure 2. These participants were meant to represent people who could be included on a team going to Mars. Therefore, participants had to meet certain requirements to make them comparable to astronauts. Participants had to have an advanced degree in a STEM field or military background, the ability to pass the NASA long-duration spaceflight physical, which included distance and near visual acuity (must be correctable to 20/20 in each eye), and blood pressure not to exceed 140/90. Participants ranged in age from 26-55, and were limited to a maximum height of 6'2" to account for the confined quarters of the typical space shuttle (Cromwell and Neigut, 2014).

Procedures

Prior to all missions, candidates applied to be a member of the crew. They went through testing and interviews, and final groups of four were assembled. Prior to entry into HERA, all four crew members went through training on all of the tasks they would be asked to do inside the habitat and baseline measures of individual differences were collected. Once inside the habitat, the crews' schedules were very strictly laid out where every hour of the day was scheduled for them (including down time). Their sleep schedules were set, the tasks they worked on were regimented, and surveys were scheduled throughout the mission as well. One notable difference between the 30 and 45-day missions was the sleep schedule. In the 30-day missions, the crews were allowed eight hours of sleep every day of the mission until the 24th day when they were forced to stay awake for 36 hours straight to simulate extreme sleep deprivation. In the 45-day missions, the crews were continuously sleep deprived by only being allowed five hours of sleep during the week (Monday-Friday), then being allowed eight hours of sleep on Saturday and Sunday.

Tasks

The crew had a very structured schedule during their stay in the analogue with each person's day planned down to the minute including when they could sleep and eat. There were times when the whole team would be working on the same tasks or engaging in the same activity (for instance, everyone slept at the same time), and there were other times when individuals were scheduled to be doing separate things. The main task that extended throughout the entire time in the analogue was an asteroid rendezvous and exploration task. However, intermingled with the main task were plenty of shorter tasks that were not directly related to the asteroid mission.

Overarching mission task. During the missions, the overarching goal the crew was working towards was to journey to the asteroid “Geographos” to explore, collect rock samples, and then return home. Crew members spent the beginning of the mission in the outbound phase in which they simulated the trip to the asteroid. Crew members rendezvoused with the asteroid and spent the next few days conducting operations on the asteroid. Crew members then left the asteroid and began the return phase of the mission, returning to Earth on the final day of the mission. During the journey, there was a communication delay that gradually increased from a 30 second to a 5 minute one-way delay between the crew and mission control. The time delay period in the 30-day missions began on day 13 of their mission and lasted until day 21. In the 45-day missions, the time delay spanned days 16-28 of the mission. The time increased as the crew got further from Earth on their way to the asteroid, and then decreased as they returned to Earth.

Additional tasks. Throughout their stay in isolation on this overarching journey to the asteroid, the crew was constantly completing various science tasks, as well as general maintenance, training, and emergency simulations. In addition to these tasks the crew completed several tasks implemented by researchers such as problem solving tasks, creativity tasks, ethical dilemmas, information sharing tasks, and various others along with plenty of surveys. When not working on tasks, crews were exercising, eating, spending down time socializing or generally doing whatever they wanted. There were stretches where there was plenty of scheduled down time

CHAPTER 2

SHARED VISION MEASURE DEVELOPMENT

This chapter describes the development of a measure of shared vision for a team's daily goals and challenges and investigates the content of vision responses in the first 4 crews in HERA (30-day missions). The development of this measure began by establishing the qualitative coding process that went into interpreting the content of an individual's vision. Next, once the content of the vision was established, I examined the patterns in content over time in terms of what ideas were the focus of the team's vision at different points in the team' lifespan. Finally, I explored teams' shared vision over time - conceptualized as the similarity amongst team members' individual visions.

Method

A full description of the HERA setting, participants and mission was provided in the previous chapter. This study examined four of the eight 4-person HERA crews, specifically the four 30-day mission teams (N = 16). Two of those crews were same gender (1 all male and 1 all female), and the remaining two teams were mixed gender. Pictures of these crews can be seen in the top four pictures of Figure 2.

Measures

The goal of this study was to establish a measure of shared vision, so the measure of interest was of an individual's vision for the near future (i.e., that day's events), which I then aggregated to the team level. Vision is defined as a cognitive image of the future that serves as the basis for motivation, planning, and goal setting (Thoms & Greenberg, 1995). The vision for the day's events was elicited every day excluding Sundays following the crew's daily planning meeting (26 measurements throughout the 30-day mission). Crew members responded to a survey eliciting the goals and challenges they expected to face each day, namely they responded to two questions: (1) "What are the crew's main goals for today?" And (2) "What challenges is the crew facing today?" Responses were open ended, with no minimum or maximum length restrictions. Responses ranged from single word entries to multiple sentences.

Analyses

The analyses to examine this measure took place in a series of steps meant to first examine the content of vision in context, and then to explore the structure of shared vision within teams over time. Step 1 was to systematically read through responses to the goals and challenges prompts, and create categories or themes using an inductive coding method (Lee, 1999; Patton, 2002). Once categories were discovered, two independent raters coded responses into those themes, and created a final agreed upon coding. Step 2 was to chart the general pattern of goals and challenges mentioned by the crew as a whole over the course of the mission broken down by mission phase. Finally, for step, 3 I quantitatively calculated how similar two individuals were with regards to their strategic visions at different phases of the mission. The following sections describe the coding process and examination of patterns over time in greater detail.

Coding Procedure

Qualitative coding of open-ended responses was conducted using a method commonly referred to as "inductive analysis", which has been applied in the qualitative examination of teams in the past (Carsten, Uhl-Bien, West, Patera, & McGregor, 2010). With inductive analysis, the researcher draws out major themes throughout the review of the data. Categories continue to be refined and parsed out in an effort to develop a theory that explains a certain phenomenon or experience. Since responses in this study were open ended, it was possible that a respondent had multiple goals or challenges that fell into different categories on a single day. However, once a portion of the text was assigned into a category, the same portion of text would not be counted as a different type of goal or challenge. Frequent occurrences of confusion over where a portion of text belonged led to the merging or diverging of categories into new codes.

In the first step, I reviewed the data and continually created, divided, or further refined first order categories that were emerging in the data in an effort to fully capture the breadth of responses while maintaining clear definitions between categories. The goal of this stage was to create as many categories as needed to organize responses in a coherent fashion. Once the first-order categories were finalized, another independent coder reviewed the data and assigned responses into one or more of the established categories. The second coder was given background on the questions being responded to as well as the technical background of the HERA procedures so that she understood the specific language being used that referred to specific tasks or events being done during the mission. Cohen's Kappas were calculated for each first-order category to assess agreement between the two coders. Agreement ranged from .43 - 1.0, and average interrater agreement was .81.

Once responses were coded into first-order categories, the research team met for the third phase of categorization and discussed the categories, and created second order categories that captured a broader theme among subgroups of first order categories. Finally, the second order categories were further clustered into 2 superordinate categories to reflect the most basic division of themes. All levels of themes with definitions and examples are summarized in Table 3.

Shared Vision

The next step was to examine the similarity among crewmembers for each mission and time-frame. This was accomplished by turning the two-mode, crew-by-theme profile matrices into one-mode, crew-by-crew matrices. The metric used to represent similarity among the crewmembers in these matrices is the Jaccard's similarity coefficient. Jaccard's coefficient was chosen since it treats the overlapping 1's in the dichotomized two-mode matrices as similarity but not the overlapping 0's. Only mutual inclusion results in similarity, not mutual exclusion. There were 24 crew-by-crew agreement matrices generated using the igraph package in RStudio and those were consolidated into two graphics: one containing goals and the other representing challenges. For these visualizations, red nodes reflect shared vision on Goals and the networks with blue colored nodes represent shared vision on Challenges. These final graphics represent the relative amount of agreement between the crewmembers throughout each phase of the communication delay for each of the four missions.

Results

Despite the unique prompts for generating goals and challenges, I identified similar first and second-order categories of responses for both questions, with the exception of one category (contact with people outside of NASA) that did not appear in the challenges, and one category (none/unknown) that did not appear in the goals. In total, 690 goals and 428 challenges were reported across the four crews. Below, the 15 common first order themes are described with examples for both challenges and goals.

Themes

Two superordinate categories were identified for the goals and challenges prompts: (1) life related, and (2) work related. Within the life related category, two second-order categories of responses were identified: (1) well-being, and (2) social. Within the work related category, two second-order categories of responses were identified: (1) mission tasks, and (2) mission logistics. Within each second-order category were between 3-4 first order categories that reflected the most detailed level of coding. I review each below and provide sample participant responses indicative of each category.

Well-being. Within the well-being category, I identified four topics that re-occurred across crew members and missions: (a) general living, (b) physical health, (c) mental health, and (d) sleep. On average (across the 4 crews), 17.5% of all goals and 24.7% of all challenges contained well-being themes over the course of the 30 day mission making them the second most mentioned categories for both goals and challenges (see Table 4 for a breakdown of category proportions).

General living. In the general living category, individuals mentioned issues with adapting to routines, relaxing on the weekends, familiarizing themselves with the habitat among other things. On average, general living made up 50.8% of all well-being goals and 22.3% of all well-being challenges. Below are examples of participant responses to the goals and challenges associated with the general living category:

Goals
"Orientation of the hab." Mission 1, day 1
"Get to the end" Mission 1, day 26
"Relax and recover our vigorousness." ~ Mission 2, day 21
"Finish mission strong" ~ Mission 2, day 22
"Rest and relaxation. Housekeeping, morale activities." ~ Mission 3, day 5
"Relaxation and housekeeping" ~ Mission 3, day 11
"Getting to know the spacecraft..." ~ Mission 4, day 1

Challenges
"Lack of comfortable seating" ~ Mission 1, day 11
"Finding all the equipment…" ~ Mission 4, day 1
"Routine is the biggest challenge - and staying fresh." ~ Mission 4, day 12

Physical health. The physical health category contains statements regarding an individual's comfort or well-being statements about the body. That could include illness, exercise, medical conferences between the crew member and a doctor, or general discomfort with the conditions. Physical health was not mentioned much as a challenge (1.6% of well-being challenges on average), but this category did make up 9.9% of well-being goals. The following are examples of participant responses to the goals and challenges associated with the physical health category:

Goals
"...private medical conference..." ~ Mission 3, day 14
"Routine tasks including [e]xercise" ~ Mission 4, day 19

Challenges
"Some crew members experiencing some bowel distress this morning." ~ Mission 4, day 7
"Illness and poor sleep" ~ Mission 4, day 7

Mental health. Mental health statements refer to an individual's state of mind. Stress, and moodiness are main representatives from this category. Perhaps expectedly, mental health made up a greater proportion of well-being challenges (27.5%) than well-being goals (12.3%), although both were mentioned more than physical health. Below are examples of participant responses to the goals and challenges associated with the mental health category:

Goals
"Chill. Stay sane" ~ Mission 1, day 5
"Get through the day" ~ Mission 1, day 23
"stay fresh, focused and positive." Mission 4, day 19
"Keep spirits up." ~ Mission 4 , day 26

Challenges
"Starting positive" ~ Mission 1, day 10
"Maintaining a positive attitude…" ~ Mission 3, day 11
"Keeping ourselves motivated through the last few days of the mission." ~ Mission 3, day 24
"Maintaining enough energy for it all. We all woke up a bit tired today but some morning dancing put us in a good mood!" ~ Mission 4, day 4

Sleep. The final well-being category has to do with sleep. This is not surprising in that these crewmembers, similar to astronauts on the ISS, regularly experience periods of sleep deprivation. Statements about fatigue, being sleep deprived, or general statements about the sleep schedule fit in this category. Goals and challenges referring to sleep might seem suitable for mental or physical health, but sleep emerged as such a consistent and frequent theme that it was coded as its own category. This is consistent with themes Stuster (2010) found in his analysis of astronaut diaries. Statements in this category made up 27.1% of well-being goals, and 48.7% of well-being challenges. The following are examples of participant responses to the goals and challenges associated with the sleep category:

Goals
"S*taying awake and non cranky" ~ Mission 1, day 22*
"Recovery and not sleeping through cognitive testing" ~ Mission 1, day 22
"Ge[t] through sleep deprivation" ~ Mission 2, day 19
"Not falling asleep tonight" ~ Mission 2, day 19
"...recover from the 36 hour sleep deprivation…" ~ Mission 2, day 21
"9, 10, never sleep again…" ~ Mission 3, day 21
"Perform a variety of tasks and tests after a 10-hour sleep which followed a long period of sleep deprivation." ~ Mission 3, day 23
"Get through the 36 hour shift without bloodshed." ~ Mission 4, day 22

Challenges
"Not taking naps during down time." ~ Mission 1, day 5
"Staying awake" ~ Mission 1, day 22
"Sleep deprivation day. We are 25 hours into a 39 hour shift" ~ Mission 4, day 23

Interpersonal. The interpersonal categories are the second set of life related categories, and include all forms of interaction. What began as a single interpersonal category was divided into four separate categories of interaction: (a) interpersonal relationships within crew, (b) interpersonal relationships between crew and mission control, (c) communication, and (d) contact with people outside NASA. Goals and challenges in these categories all involved interaction or feelings about other people. Statements in interpersonal categories made up 9% of all goals and 15.4% of all challenges.

Interpersonal relationships within crew. Naturally, cohabitating with the same three people for 30 days in a confined environment is going to lead to plenty of interaction. Any statements referring to other crew members, conflicts, cohesion building, or teamwork were sorted into this category. As expected, these statements made up a significant amount of the interpersonal goals and challenges (33.7% of interpersonal goals, and 53.6% of interpersonal challenges). Below are examples of participant responses to the goals and challenges indicative of interpersonal challenges within the crew:

Goals
"Get along with each other even as we face stressful situations." ~ Mission 1, day 1
"Maintain high crew morale." ~ Mission 1, day 4
"Make MS1's birthday awesome." ~ Mission 1, day 16
"Successfully complete mission objectives as a team" ~ Mission 2, day 3
"...maintaining strong crew integrity." Mission 2, day 3
"Maintain group cohesion and smooth function as a team" ~ Mission 2, day 7
"Successful day off and team bonding." ~ Mission 2, day 15
"Stay cohesive and functional through mission objectives" ~ Mission 2, day 19
"Maintain good crew relations" ~ Mission 2, day 21

Challenges
"These folks panic at the first sight of issue, quivering like cold chihuahuas." ~ Mission 1, day 8
"...maintaining crew integrity..." ~ Mission 2, day 11
"Staying awake all night without getting on each other's nerves." ~ Mission 2, day 19
"Are my crewmates really only kidding about leaving me on the asteroid?" ~ Mission 3, day 16
"Staying civil despite sleep deprivation." ~ Mission 3, day 21
"...continue to develop group strategies for the duration of our mission" ~ Mission 4, day 2
"...keeping arguments to a minimum. Let's just say the crew is ready for the weekend - it's been a long week." ~ Mission 4, day 10

Interpersonal relationships between crew and mission control. Initially, all interpersonal relationships were grouped together, but it became clear that a portion of these statements were unique in that they were not referencing other crew members, but were concerned more with dynamics with the mission control support, or component teams within their multiteam space exploration unit. While this category made up a very small percentage of the interpersonal statements (2.4% of interpersonal goals and 4.6% of interpersonal challenges), they clearly were referencing a different experience from those of interpersonal relationships within the crew. The following are examples of participant responses to the goals and challenges indicative of interpersonal challenges between the crew and mission control:

Goals
"Play nice with MCC." ~ Mission 1, day 6

Challenges
"Negative interaction from MCC" ~ Mission 3, day 23
"Frustration building. Poor instructions from MCC." ~ Mission 4, day 10
"Second shift of MCC." ~ Mission 4, day 20

Communication. At first, I considered collapsing communication into the one of the prior interpersonal relationship categories. However, communication was specifically mentioned and highlighted consistently enough to convincingly fall into its own category. In addition to typical communication concerns, the teams in HERA also had to manage a simulated communication delay between themselves and mission control that increased as they simulated their trip to the asteroid, and decreased back to zero as they simulated their return home. Given these challenges, communication-related comments made up 28.8% of all interpersonal goals and 41.7% of all interpersonal challenges. The following are examples of participant responses to the goals and challenges indicative of communication:

Goals
"Good communication with each other and MCC." ~ Mission 1, day 2
"Shifting back to live comms with MCC" ~ Mission 1, day 19
"Maintain … strong communication…" ~ Mission 2, day 7

Challenges
"Good [communication]" ~ Mission 1, day 7
"[Communication] delay." ~ Mission 1, day 15
"...vague instructions and miscommunication due to a time delay." ~ Mission 2, day 13
"Communicating with respect instead of authority." ~ Mission 4, day 12
"Communication issues and I'm right and your not right verbages." ~ Mission 4, day 19
"Communication issues on sleep deprivation and being mindful." ~ Mission 4, day 23

Contact with people outside NASA. The final interpersonal category includes instances of comments regarding contact with people outside of NASA. While the crew was largely isolated from the outside world, they did have opportunities to see friends or families in blocks of time called private family conferences (PFCs). They also were required to give presentations to classrooms or other public venues through video conferences during blocks labeled public affairs office (PAOs). This category was rare; the following is an example of a goal mentioned from this category:

Goals
"...PAO [(Public Affairs Office)] recording/blog"
"PAO event with Challenger Center Alaska"
"... two PAO videos, one for first graders and one for fifth graders"

Mission tasks. Mission tasks is the first work related set of goals and challenges. Task work is a large part of what the HERA crews do throughout their missions. As is typical for space teams, their schedules are very regimented and controlled, and there are many experiments requiring the teams to complete task work. With that said, it is no wonder that mission tasks were a significant focus of the HERA crews' goals for each day (58.1% of all goals mentioned). Mission tasks were also a significant portion of challenges (23.5% of all challenges), but in terms of rank ordering, they were less prominent compared to goals (see Table 4). Mission tasks included the following categories: (a) general task completion, (b) asteroid exploration mission, (c) campaign level tasks, and (d) researcher implemented tasks.

General task completion. Given that the HERA crews had a lot of tasks to complete each day, there may be days where no specific tasks stand out as particular goals or challenges for the crew, but they indicate that, in general, task completion is part of their vision for the day. Statements in general task completion are concerned with getting tasks done, being successful in their tasks, or just getting through the tasks without mentioning any one in particular. These statements were the second most mentioned category within mission tasks for both goals (25.8%) and challenges (26.2%). The following are examples of participant responses to the goals and challenges for general task completion:

Goals
"To complete all of our tasks in an efficient manner" ~ Mission 2, day 3
"The successful completion of all tasks [a]nd objectives" ~ Mission 2, day 7
"Successfully complete mission objectives." ~ Mission 2, day 18
"...maintaining our high performance standards despite being in the middle of the mission (far enough in that the novelty is wearing off, but far enough from the end that we do not yet have the finish line to motivate us)." ~ Mission 3, day 10

Challenges
"Task transition" ~ Mission 1, day 19
"To complete our objectives in an efficient and timely manner" ~ Mission 2, day 3
"...perform up to high standards expected." ~ Mission 2, day 20
"Balancing activities." ~ Mission 4, day 6
"Success!" ~ Mission 4, day 14

Asteroid exploration mission. Throughout the mission, the crew's overarching narrative is that they are on their way to rendezvous with an asteroid called Geographos. Once their shuttle reaches Geographos, they explore the surface and collect samples, and then they fly back. Throughout this journey, there are a number of tasks related to this narrative including extravehicular activities (EVAs) and multi-mission space exploration vehicle (MMSEV) tasks. Statements referencing this overarching narrative were the most mentioned among mission task themes for both goals (38.5%) and challenges (32.4%). Below are examples of participant responses to the goals and challenges related to the asteroid exploration mission:

Goals
"Get our rocks off (the asteroid)" ~ Mission 1, day 16
"Preparing to rendezvous with asteroid Geographos. We really want to perform well on our EVA MMSEV today." ~ Mission 2, day 11
"Successfully land on asteroid Geographos and return samples to the ship." ~ Mission 2, day 13
"...rock the MMSEV-EVA sim" ~ Mission 3, day 3
"Rendezvousing with Geographos and conducting our first "real" MMSEV/EVA." ~ Mission 3, day 14
"Last day of rendezvous! Flying a quality MMSEV/EVA mission." ~ Mission 3, day 16
"To do well on our beta test with MMSEV/EVA." ~ Mission 4, day 7
"To successfully collect samples on the asteroid during our rendezvous. We're excited!" Mission 4, day 14

Challenges
"EVA MMSEV training. To do well." Mission 1, day 4

"Well tomorrow is rendezvous so we're focused on that." Mission 2, day 10
"Increasingly challenging EVA objectives." ~ Mission 3, day 2
"Are my pockets big enough for all these asteroid rocks?" ~ Mission 3, day 16
"Recover from MMSEV mistakes from yesterday…" ~ Mission 4, day 3

Campaign level tasks. In addition to the overarching asteroid exploration mission, the crew has certain sets of tasks built into their NASA-orchestrated schedule. These tasks are independent of the asteroid mission as well as any research being implemented by outside researchers. These tasks are not tied into the overarching narrative, but rather are replications of such tasks space exploration teams undertake, and include emergency simulations, rover building, on-board training, and other various drills. This category of comments made up 19.8% of all stated mission task goals and 20.6% of all mission task challenges. Below are examples of participant responses to the goals and challenges related to the campaign:

Goals
"[T]ry not to suck at robot." ~ Mission 1, day 9
"...learning to respond to simulated medical emergencies." ~ Mission 3, day 7
"Cognition tests and wrapping up our science experiments for the mission." Mission 3, day 25

Challenges
"Getting through the rover task successfully." Mission 4, day 11
"Robot" ~ Mission 2, day 1
"My [robot] score is already great... Can I keep it up?" ~ Mission 3, day 9
"Going through an emergency sim quickly and successfully." ~ Mission 4, day 5
"Getting through the rover task successfully." ~ Mission 4, day 11

Researcher-implemented tasks. The final category of mission task goals and challenges fall under researcher-implemented tasks. There are several outside research institutions conducting research on HERA participants, and many of them implement tasks and surveys for the crew to complete. These tasks would sometimes be mentioned by name, or other times referred to in more general terms (e.g., "surveys"). Statements in this category made up 15.9% of all mission task goals and 20.9% of mission task challenges. Below are examples of participant responses to the goals and challenges related to the various science tasks HERA crew members were completing:

Goals
"...complete several PI studies that are happening today" ~ Mission 2, day 11
"...brine shrimp!" ~ Mission 4, day 5
"Cognition ii and multi team task battery." ~ Mission 4, day 12

Challenges
"Data collection issues" Mission 1, day 2
"Remembering to complete food surveys…" ~ Mission 3, day 15
"NINScan :-)" ~ Mission 3, day 20
"Making sure we don't interrupt cognition, and assorted other deconflictions" Mission 3, day 25
"New items such as microbiome testing that are not done before or trained previously." Mission 4, day 2

Mission logistics. The second work-related set of categories fall under the umbrella of mission logistics. These types of statements are not referencing tasks necessarily, but rather a lot of the conditions that the work is conducted through. Mission logistic categories include (a) schedule, (b) workload, and (c) equipment. While they were the third most mentioned types of goals on average (15.36% of all goals), they were the most frequently mentioned types of challenges (36.4%).

Schedule. As mentioned previously, the HERA crew members have a very regimented schedule that is fully controlled for the whole day including sleeping and eating. The schedule is a very prominent feature of these crew members' daily lives, and accounts for the largest proportion of mission logistics goals (69.5%) and challenges (48.6%). Statements that fall under this category include references to time or the schedule in general, often commenting on keeping up or staying ahead of the schedule. Below are examples of participant responses to goals and challenges related to scheduling:

Goals
"Get accustomed to the concept of continually monitoring our progress on the timeline." Mission 1, day 1

"Stay on timeline. Busy day…" ~ Mission 1, day 6
"Figure out how to balance a packed timeline…" ~ Mission 1, day 13
"Get back on schedule after unplanned evac." ~ Mission 2, day 10
"Staying on the timeline and doing quality work despite this being a busy day..." ~ Mission 3, day 6
"...coordinating schedule to maximize time" ~ Mission 4, day 2
"Self scheduling tasks for next few days" ~ Mission 4, day 3

Challenges
"[T]ime pressure" ~ Mission 1, day 8
"Busy timeline" ~ Mission 1, day 25
"Time crunch!" ~ Mission 2, day 10
"We have a ver[y] busy schedule, staying on task will be important." ~ Mission 2, day 23
"Staying on top of the very full timeline today, which seems designed to push us to th[e] limit!" ~ Mission 3, day 12
"Making sure we complete the tasks efficiently and on time." ~ Mission 4, day 3

Workload. Workload is a category that split off of schedule during the process of coding. There were a significant number of references to the amount of work scheduled for a given day, and these statements were distinct from references to the schedule. Workload-related statements make up 9.4% of mission logistic goals and 24.2% of mission logistic challenges. Below are examples of participant responses to the goals and challenges related to workload:

Goals
"*High workload day: stay on the timeline to try to get everything done plus additional tasks assigned from MCC." ~ Mission 1, Day 1*
"Deal with a very high workload..." ~ Mission 2, day 11
"Busy day - main goal is to get it all done" Mission 4, day 12
"A busy day with many tasks to complete." ~ Mission 4 , day 25

Challenges
"Getting back to a busy timeline after a couple quiet days." ~ Mission 1, day 18
"Staying on task for the 4.25 hour solid block of tasks" ~ Mission 1, day 19
"Very high workload." ~ Mission 2, day 11
"Staying sharp despite the relatively light workload today." ~ Mission 3, day 15
"Busy day with little down time if we fall behind or if unexpected items are dropped on us" ~ Mission 4, day 12

Equipment. The final category under mission logistics concerns issues involving equipment. The HERA crew, like any crew on a space mission, is responsible for maintaining or repairing all of their own equipment. Additionally, there are several pieces of hardware that the crew must wear during certain days as part of data collection efforts by outside institutions. Comments regarding equipment made up 21.1% of all mission logistic goals and 27.3% of all mission logistic challenges. Below are examples of participant responses to the goals and challenges related to equipment:

Goals
"...troubleshooting errant systems" ~ Mission 3, day 1
"...various system maintenance tasks…" ~ Mission 3, day 13

Challenges
"Technology crapping out on us." ~ Mission 1, day 4
"Hardware issues with astroskin" ~ Mission 2, day 22
"Technical difficulties" ~ Mission 3, day 1
"Music dropping off for PLEX, heart rate watch not recording and polar strap beginning to be too loose." ~ Mission 4, day 3

Changes in vision

In addition to the coding of emergent themes in these data, I also examined patterns of category prominence for vision of the day's goals and challenges at different times throughout the mission (see Figures 3 and 4). The missions were 30 days, and I broke each mission into three distinct time periods in an effort to capture the main phases of the crew's overarching asteroid exploration mission: (1) pre-communication delay (days 1-13; the beginning phase of the mission where the crew began their journey to the asteroid, Geographos), (2) during communication delay (days 14-23; wherein the crew first got further away from Earth and experiences increasing communication delays, when they arrived on Geographos and were operating at max communication delay, and when they began the return trip and experienced decreasing communication delays), and (3) post-communication delay (days 24-30 wherein the mission neared completion and the crew returned to Earth). Since the amount of time is not the same within each period, I plotted the data according to the percentage of total goals or challenges mentioned during each time period.

Patterns in goals over time. Figure 3 charts the proportion of goal categories over time at the level of second order categories (well-being, interpersonal, mission tasks, and mission logistics). Across all missions, mission task-related goals were the most mentioned for most of the mission. However, for all four crews, the prevalence of mission task-related goals decreased during the final phase of the mission (post-communication delay). Conversely, well-being goals increased in prevalence during the final phase of the mission. Table 5 summarizes which goal category was most cited for each time period for each of the four crews. All four crews mentioned mission task goals most frequently during the pre-communication delay and during-communication delay phases. At the end of the mission two crews still mentioned mission task goals most frequently (despite the decrease in mention of mission task and rise of well-being), and two crews mentioned well-being goals most frequently at the end of mission.

Patterns in challenges over time. Figure 4 charts the proportion of challenge categories over time at the level of second-order categories (well-being, interpersonal, mission task, and mission logistics). Similar to goals, mission task-related challenges decreased in the final phase of the mission across all four crews. However, unlike goals, mission task challenges were not the most frequently mentioned during the beginning and middle phases of the mission. Looking at Table 6, I saw mission tasks began as the most frequently mentioned challenge in the pre-communication delay phase for only one crew, and another crew began with well-being as the most frequently mentioned challenge. The other two crews' most cited challenges during the first phase of the mission related to mission logistics. During the communication delay period, one crew that cited logistics most frequently at the beginning switched to mentioning mission task-related challenges the most. The other three crews cited mission logistics challenges the most during communication delay (with one crew mentioning logistics and interpersonal challenges equally). Finally, the last phase of the mission had a similar pattern to goals in that well-being challenges rose in the final phase, becoming the most frequently cited (or tied for most frequently cited) in three out of four crews.

These patterns hint at the general evolution of crew vision over the course of their missions. The next section looks more closely at how crew members align on a shared vision of goals and challenges they face.

Shared Vision Over Time

In addition to examining the goals and challenges members of the crew each experienced individually, I also wanted to establish the degree to which members of the crew had a shared vision in terms of their goals and challenges throughout a mission. I have examined what the experiences were, and general patterns over time as well as, more specifically, who was experiencing what throughout the mission. Finally, I answered the question of how shared two crew members' visions were, and how did people tend to converge or diverge over time.

The networks in Figures 5 and 6 show the connections between members of the crew using the Jaccard's similarity coefficient described earlier. These figures are broken down by mission phase, and separated into goals and challenges. The nodes are the members of the crew labeled the same as in the previous networks: CMD (commander), FE (flight engineer), MS1 (mission specialist 1), and MS2 (mission specialist 2). The thickness of the links between individuals is determined by the Jaccard's similarity coefficient so the thicker a line gets, the more similar those two individuals were to each other in terms of the goals or challenges they envisioned in that phase of the mission. These networks allow us to view, in general, if ties between individuals are strengthening or weakening, as well as if a particular individual is changing his or her connections to the group, or if a specific pair fluctuates throughout the mission. Specific patterns, and trends for shared vision along with other team cognition constructs in these crews is examined explicitly in the next chapter, however, here I shared descriptive trends that emerged in these data.

One story that stood out for crew 1 was the change in the flight engineer's (FE) connection to everyone else in the crew (Figure 5). While the rest of the crew remained relatively constant in terms of their similarity to each other, or at least recovered from a dip in the second phase of the mission, the flight engineer steadily became less and less similar to all of her crew mates in terms of her vision both with challenges and goals. The average Jaccard's similarity coefficient (henceforth referred to as J) between the FE and other crew members is 0.44 at the beginning of the mission, then dips to 0.26 during communication delay, and continues to decrease to 0.13 by the final phase of the mission. Reference back to Figure 5 and see that, in the beginning, everyone had a fair amount of challenges they were dealing with in phase 1. In the middle phase, I saw that while everyone else was dealing with multiple issues, many of which overlapped, the flight engineer's vision narrowed indicated by the fewer number of challenges she envisioned. Finally, in the end, the flight engineer was only connected to the rest of the crew by their shared challenge of sleep. There was a similar pattern in the goals where I saw the vision of the flight engineer narrowed along with her connections to the rest of the crew (average $J = 0.56$ pre comm delay, 0.38 during comm delay, and 0.26 post comm delay).

In crew 2, I considered the during and post communication delay phases more closely than the pre communication delay phase due to the missing data. For the challenges people faced during communication delay, MS1 was strongly connected with MS2 ($J = 0.57$), but had weaker connections with the other two crew members (J = 0.13 between MS1 and CMD and 0.22 between MS1 and FE). However, in the final phase of the mission, the connections between MS1 and CMD and FE were stronger (J = 0.38 between MS1 and CMD, and 0.56 between MS1 and FE).

In mission 3, I saw that the none or unknown stance on challenges was prominent, especially for the commander and mission specialist 2. This was the driving factor behind the crew shared vision in terms of daily challenges where I saw, specifically, that MS2 has the weakest connections amongst crew members in the first phase of the mission (average J = 0.33 compared to 0.51 for CMD, 0.54 for FE and 0.41 for MS2), then two subgroups formed with CMD and MS2 sharing the same singular vision that challenges are unknown (J = 1) and FE and MS1 linked, albeit more weakly than the other pair (J = 0.44). Finally, in the post communication delay phase, connections between the two subgroups were bridged, although MS2 and FE never reconnected in terms of shared challenges. When I examined the shared goals amongst crew members (Figure 6), I did not see the same fracturing, but I saw the strongest shared vision in the beginning phase of the mission with an average J amongst all crew members of 0.53, and shared vision between people getting smaller over time (average crew J = 0.40 during communication delay and 0.34 post communication), especially connections between the commander and the rest of the crew (Average CMD J = 0.43 pre communication delay, 0.26 during communication delay, and 0.20 post communication delay).

Mission 4 followed a slightly different pattern than the other crews. The similarity networks show that everyone had a shared vision somewhat at the beginning, and then there was a major drop off in the middle phase of the mission in terms of similarities of envisioned challenges (average crew J = 0.50 pre communication delay, and 0.19 during communication delay). The connections between the crew rebounded in the final phase, but not to the point they were at the beginning of the mission (average crew J = 0.35). For crew 4's goals, I saw that, like the challenges they faced, the crew vision was most shared in the first phase of the mission (average crew J = 0.63). They dropped off in similarity in the second phase (average crew J = 0.40), which persisted into the final phase of the mission (average crew J = 0.38).

Discussion

This chapter established a measure for eliciting the vision of individuals cohabitating for long periods of time in confinement and isolation. I elicited open-ended responses about daily experiences of the HERA crews working on 30-day missions at NASA's Johnson Space Center. The analyses also went further than previous studies in that I examined patterns at the team and individual level as well as the convergence on a shared vision amongst crew members. Through the coding process, I found that the same overall themes were reflected in both responses about the crew's goals and their responses about challenges they expected to encounter. I identified 15 first-order categories including (1) general living, (2) physical health, (3) mental health, (4) sleep, (5) interpersonal relationships within crew, (6) interpersonal relationships between crew and mission control, (7) communication, (8) contact with people outside NASA, (9) asteroid exploration mission, (10) campaign level tasks, (11) researcher implemented tasks, (12) general task completion, (13) schedule, (14) workload, and (15) equipment. These categories were summarized into four second-order categories to reflect broader themes: (1) well-being, (2) interpersonal, (3) mission tasks, and (4) mission logistics. At the broadest level of categorization, these statements fell under work or non-work related themes

This thematic coding revealed the issues that motivated and challenged teams spending extended periods of time in extreme contexts. The categories derived from these responses bear some similarities to the themes that emerged in the Stuster diary study (2016), especially the non-work related categories. In Stuster's report, outside communications, adjustment, group interaction, equipment, and sleep were all among the top mentioned categories in the ISS study; this is similar to themes that emerged from the HERA crews. One major difference between a space analogue meant to mimic conditions on a journey to Mars, and the ISS is the focus on the preponderance of task work required throughout the mission from the overarching asteroid mission, NASA implemented taskwork, and outside research institution tasks and surveys. Perhaps being placed in the context of a mission (rather than conducting research) guides the orientation of crew members to focus on task work especially when it comes to goals since mission task categories made up the top three goals and accounted for nearly 50% of all goals mentioned. The communication delay schedule might have also played a role in the diminished prominence of interaction outside the crew. Outside communication played a major role on the ISS, but both contact with people outside of NASA and interpersonal relationships between the crew and mission control were the least frequently mentioned goals and challenges (contact with people outside of NASA did not even show up in challenges).

Another important conclusion drawn from these data was the patterns that appeared to evolve over time. The results made it clear that mission task goals were the most prominent for the first two phases of the mission, though decreased in prevalence toward the end of the mission, where goals about well-being took the forefront. This pattern was similar across all four crews. I found a similar pattern with challenges, though the relative proportions were different. Prevalence of mission task-related challenges decreased toward the end of mission, when well-being challenges took greater prevalence. Unlike goals, however, mission task challenges were not so clearly dominant in the beginning two phases of the mission. Only one crew mentioned mission tasks the most in the first phase, and only one crew (a different one) mentioned mission challenges the most in the middle phase with no crews citing mission tasks most often in the final phase. Well-being was the most mentioned type of challenge for one crew in the beginning, and all four crews increased the amount of well-being challenges in the final phase with well-being becoming the most frequently (or tied for most frequently) mentioned category for three out of four crews.

The patterns in goals and challenges over time revealed that the content of the crew's vision evolved over the course of the mission. Towards the end of a mission, crews started thinking less about the tasks they needed to complete each day and became more concerned about their own well-being. This could be a sign that sleep deprivation and/or the mental and physical fatigue of a long mission in stressful conditions was taking a toll. This pattern may also suggest that as crew members became accustomed to the tasks they had been doing all mission, these tasks became less of a challenge to the team and were therefore less of a focus. For example, one participant made an insightful observation regarding his/her main task goal during the middle of their mission: "[a key goal is] *maintaining our high performance standards despite being in the middle of the mission…* [we are] *far enough in that the novelty is wearing off, but far enough from the end that we do not yet have the finish line to motivate us".* This was a perfect example of how focus on task motivation changed over the course of a mission.

Another interesting conclusion that may be drawn from these responses relates to the recurring incidence of concerns about certain goals/challenges that, while they did not rise to the level of "prominent" nevertheless continued to surface throughout the mission. For example, while interpersonal issues were never the most mentioned goal or challenge for crews, they continued to surface over time, and such challenges, when they do surface, have the potential to become seriously disruptive and threatening to the crew's functioning and viability over time. The analysis also reveals that certain factors did not offer much in the way of motivating potential for the crew, but did seem to constitute significant challenges when poorly managed. For example, concerns about 'logistics' were far more frequently mentioned as a challenge compared to a goal, suggesting that crews were not as motivated by (or did not know how to) address logistics issues such as scheduling, workload variations, and equipment issues, but they did seem to provide significant challenges to the crews.

Once I saw what issues individuals experience throughout the mission, I wanted to examine how similar individuals' visions were to each other. I saw stories like when the FE in crew 1 grew more and more dissimilar from her crew mates over the course of the mission. Additional surveys from this mission indicated that this person was becoming an outcast of the crew in other ways so this divergence of experience could be a catalyst or result of other forms of withdrawal from the crew. These similarity networks also were a way to examine sub grouping or fracturing in the crew such as in crew 3 when the CMD and MS2 became a sub unit and FE and MS1 became another sub unit in the middle phase of the mission. The divide was bridged by the end, but MS2 remained disconnected from FE. This was also a crew whose members frequently withheld judgement about the crew's challenges for the day, often declaring that the challenges were unknown, or there were no challenges expected. Therefore, the fracturing may not have been so much divergence of experience, but a difference in mindset between those who were expecting more issues to pop up, and those who were unwilling to speculate about what issues would arise.

Understanding the experiences of cohabitating teams like those working in HERA offers a valuable window into what makes these teams different from versus comparable to 'typical' teams. Understanding these similarities and differences can help scientists better design specific interventions to improve team process and outcomes in such extreme tasks. For instance, understanding when interpersonal challenges become most prominent in the timeline of a long mission can guide researchers and NASA personnel to know when to ‘tune in’ to crew challenges and implement interventions at critical points during the mission.

It’s also enlightening to compare the crew vision with what those outside the crew (e.g., mission control) may think is important. For example, should mission control prioritize a certain mission task as ‘priority one’ for that day’s schedule when the crew prioritizes ascertaining critical equipment functionality, deterioration in shared cognition and multiteam coordination and effectiveness is likely to occur. Understanding how crew vision changes over the course of a mission is one step in avoiding dangerous miscommunications and miscoordinations at crucial points during a mission.

Finally, this study provides insights into how best to structure a schedule for teams in these circumstances. Knowing when sleep challenges are at a peak will help mission control know those are probably not the times to impose a lot of complex tasks, or at the very least, know when they might have to be available to provide more support than is typical. If task work goals tend to decline at the end of missions, then maybe that is not the time to implement unfamiliar tasks that require the crew to be fully committed to their taskwork.

CHAPTER 3

TEAM COGNITION AS A DYNAMIC CONSTRUCT

Theory and Hypotheses

In this study, I examined three of the constructs of team cognition outlined in Chapter 1: shared task mental model similarity, shared team mental model similarity, and shared vision. Shared task mental model similarity is the degree to which team members have a shared understanding of task requirements, the work procedures, strategies, and contingency plans. Shared team mental model similarity is the extent to which team members share an understanding on team member responsibilities, role interdependencies, and communication patterns (Mohammed et al., 2010). The third construct, shared vision is specifically focused on the extent to which the members of the team share an understanding of the future state, or process of the team (Pearce & Ensley, 2004). This mental representation is not referencing the requirements of any specific task, the characteristics of the team, or the team interaction processes but rather is focused on knowledge or understanding of an overarching, but shifting goal or mission relevant to the team.

Specifically, in this study, I examined the dynamism in these constructs over time. In my taxonomy, dynamism refers to how stable does a construct remain over time, and I classified the team cognition constructs as static over time, gradual meaning that they fluctuate, but changes are slower and milder, and volatile, which are constructs that are most vulnerable to constant, and extreme fluctuations based on new information. Research on team cognition over time is sparse, and team constructs over time in teams cohabitating for long periods of time is even more rare. In general, longitudinal studies on team cognition have produced inconsistent results, with most, though indicating either no growth or even some decline in similarity over time (Mathieu et al., 2005).

There has been some theory regarding other emergent team phenomenon over time that may lend insight into team cognition evolution. For instance, Hackman (1992) suggests that increased cohesiveness that develops over time may lead to groupthink and other negative outcomes associated with the rejection of dissenting opinions. The longer a team spends together also tends to increase team member familiarity, which would especially be the case with cohabitating teams. It has been argued that familiarity may be beneficial early in a team's existence, by fostering rapid coordination and integration of team members' efforts (Cannon-Bowers et al, 1995). However, familiarity may eventually become a liability as the lack of membership change contributes to growing ineffectiveness and entropy (Guzzo & Dickson, 1996). Similarly, Katz (1982) has suggested that communication within teams declines as teams age. Katz and Allen (1988), who examined 50 R&D teams, provided support, showing that declines in communication were associated with effectiveness declines over time. Importantly, they also reported that the greatest communication decay was in those areas most central to team activities.

Taken together, these findings suggest that familiarity benefits team cognition, and so I expected that initially, as cohabiting teams lived together and began to align their thinking about the task and each other, that cognition would become more similar. However, based on the work showing that teams together for a long time communicate less with each other, I expected that team cognitive similarity would decline with increasing time together. There is some evidence in long term missions that teams reach a point somewhere in the third quarter of a mission when interpersonal and affective issues reach their peaks (Bechtel & Berning, 1991). Bechtel and

Berning document this effect initially in teams spending the Winter in Antarctica, but find additional support for this third quarter effect in research done on submarine missions, during other Antarctica Winter stays, and on the International Space Station (Stuster, 2010). At some point after the midpoint of the mission, regardless of length, teams tend to experience lows in mood and morale, and peaks in aggression, irritability, sleep issues, and anxiety. Therefore, while time together initially may aid the convergence of cognition at the team level, evidence of extended time together leading to declines in team functioning combined with the research documenting the pattern of individual and interpersonal dynamics over the course of a long mission led me to propose:

H1: There is an inverted U trajectory of team cognition over time, a) shared task mental model similarity, b) shared team mental model similarity, and c) shared vision initially increase in the beginning of the mission, but decrease as the mission passes the midpoint into the third quarter of the mission.

Another stream of research to focus on to shed light on team cognitive phenomenon over time is individual cognition and information processing. Some evidence from Antarctic research suggests that clinical cognitive changes may occur in individuals who are exposed to isolated, and confined environments for long periods of time. In one study of 109 days, chronic stress resulting from multiple sources, including limited sleep, intense physical activity, and low calorie diet, was associated with impaired cognitive function and mood. Recovery was rather quick with cognitive functioning improving within about 3 days once stressors were removed (Lieberman, Castellani, & Young, 2009). Stress has been found to affect cognitive processes such as attention, memory, problem-solving, judgment, and decision-making (Staal, 2004), which are critical components of individual performance. For example, individuals narrow their attention, rely more heavily on heuristics and biases, decrease vigilance, demonstrate performance rigidity, and reduced problem-solving ability (Salas, Driskell, & Hughes, 1996).

These processes subsequently influence individual level task and social behaviors. At the team level, the individual effects of stress combine to impact team processes such as communication, coordination, and cooperation (Burke, Priest, Salas, Sims, & Mayer, 2008). For instance, teams experiencing stress see drop offs in situational awareness and adopt a more individualistic perspective (Driskell, Salas, & Johnston, 1999). Stress can also impact team affective states such as cohesion, psychological safety, and collective efficacy (Griffith & Vaitkus, 1999; Jex & Thomas, 2003), which also contribute to drop-offs in communication and other core team processes such as back-up behaviors, team monitoring, and other prosocial helping behaviors (Burke et al., 2008).

The formation of team level cognitive understanding hinges on the sharing and interpreting of information coming from the environment and teammates (Burke, Stagl, Salas, Pierce, & Kendall, 2006). Individuals need to be able to identify and recognize relevant cues in the environment that trigger the need to adapt, and subsequently communicate these cues to the team trigger emergence of team cognition. Researchers have also agreed that acute stress negatively affects information-processing capabilities by narrowing an individual’s breadth of attention. As a result, individuals tend to focus attention on sources of information that are considered a priority and tend to ignore secondary or peripheral tasks (e.g., Gladstein & Reilly, 1985; Staw, Sandelands, & Dutton, 1981).

The emergence of shared understanding at the team level is driven in large part by the processes of learning and sharing (Grand et al., 2016). Team cognition convergence could break down from stress through the hindrance of both these processes at multiple stages. In the process of learning new information, individuals on a team may not all notice the change in their environment. Their attention is narrowed and not all information that previously was being noted (absent stress) is making it past the narrower filter. Even if individuals attend to the new information, they still have to encode, and interpret the information and then integrate it with their current knowledge. Limitations on information processing capabilities brought on by stress would likely hinder the ability to encode new information. In the case of sharing, those who do take notice may not be amenable to sharing their new information with the team given the stressful circumstances. Finally, even if new information is shared, other team members need to acknowledge the new information, decode and then incorporate the information into their current knowledge.

Based on the finding that environmental stressors lead to declines in cognitive functioning and mood, I expected team cognition to become less similar when people were exposed to stressors because individuals under stress would be less likely to take notice, and/or less able to incorporate the new knowledge updating their individual cognition. Examples of stressors cohabitating teams on a long mission experience are communication difficulties, sleep deprivation, high workload, interpersonal friction, and generally high coordination and cooperation, demands (Kanas, 1998; Palinkas, 2001; Slack et al., 2016). When the needs of the tasks or processes of a team shift, the cognitive and affective effects of multiple stressors could lead to several possible breakdowns in the chain of team cognition convergence. Therefore, I proposed:

H2: Teams experiencing stressors experience declines in a) shared team mental model similarity, b) shared task mental model similarity, and c) shared vision.

Method

These hypotheses were tested using crews spending time in NASA’s Human Exploration Research Analogue (HERA) located at Johnson space center. A full description of the habitat and scenario can be found at the end of Chapter 1.

Sample

The participants studied included nine 4-person crews (*N* = 32) with four of them spending 30 days and four of them spending 45 days inside the Human Exploration Research Analogue (HERA) located at Johnson Space Center. One of the crews was intended to spend 45 days in the analogue, but their mission was cut short on mission day 22 due to a hurricane in the area. Three of the crews were same-gender (two all male and one all female) and the other six crews were mixed gender. Participants had to meet certain requirements to make them comparable to astronauts that would go on a mission to Mars. Participants had to have an advanced degree in a STEM field, the ability to pass the NASA long-duration spaceflight physical, which includes distance and near visual acuity (must be correctable to 20/20 in each eye), and blood pressure not to exceed 140/90. Participants range in age from 26-55, and are limited to a maximum height of 6’2” to account for the confined quarters of the typical space shuttle (Cromwell and Neigut, 2014).

Measures

Three types of cognition were measured that map onto constructs listed in the taxonomy presented in Chapter 1 (Table 2): task mental models, team mental models, and shared vision. Shared vision was broken down into shared vision of goals and shared vision of challenges These constructs were measured using a variety of surveys at different time schedules.

Mental models. Individuals completed task and team mental models by rating the perceived relationships between various attributes. Each measure listed its respective attributes and corresponding definitions along the top and side of a grid. Respondents rated each attribute of the mental model in relation to all other attributes for that model using a 7-point scale ranging from ‘1’ (very strongly unrelated) to ‘7’ (very strongly related). Participants completed this measure daily (excluding Sundays) for a total of 26 measurements in 30-day missions and 38 measurements in 45-day missions.

Since the mental models were based on the general task of succeeding in their HERA mission, the task attributes were based off of the general types of tasks the crew completes: (1) *completing individual work tasks*, (2) *completing crew responsibilities*, (3) *communicating with mission control*, (4) *completing extravehicular activities (EVAs)*, (5) *ensuring crew health and safety*, (6) *performing maintenance activities*, (7) *participating in scientific studies*, and (8) *managing our time and staying on schedule.* The items for the team mental model attributes were derived from Marks, Mathieu, and Zaccaro's (2001) taxonomy of team process: (1) *building cohesion within the crew,* (2) *managing conflict within the crew,* (3) *setting goals for ourselves,* (4) *motivating one another,* (5) *backing up crew members as needed*, (6) *Coordinating our work*, (7) *monitoring our progress*, and (8) *planning our activities.*

Mental model similarity. Mental model similarity was calculated using an inverted Euclidean distance formula. When two individuals complete the pairwise comparison measure, they have a vector of relatedness values. In order to compare how far apart 2 individual's vectors are to each other, I subtract the corresponding relatedness ratings from each other, square that difference, sum up all the squared differences, and take the square root of that sum of squares. That number is the distance between the two vectors. The next step is I divide that distance by the maximum possible difference (i.e. if one person entered all '1s' and the other person entered all '7s'). This gives a number between 0 and 1 for a proportion of possible difference between two people. Finally, I invert the number by subtracting it from 1 in order to get a proportion of possible similarity as opposed to distance. Using this formula, I get 6 similarity calculations between the 4 crew members (6 possible pairs of teammates). I then average these 6 similarity ratings to get an average team similarity for both task mental models and team mental models.

Vision. Vision is defined as a cognitive image of the future that serves as the basis for motivation, planning, and goal setting (Thoms & Greenberg, 1995). In order to elicit an individual's vision, every day excluding Sundays over the course of the 30-day and 45-day missions, crew members have a daily planning meeting, and following that meeting, crew members respond to a survey eliciting the goals and challenges they expect to face each day. Participants responded to two questions: (1) "What are the crew's main goals for today?" And (2) "What challenges is the crew facing today?" Responses were open ended, with no minimum or maximum length restrictions. Responses ranged from single word entries to multiple sentences.

Shared Vision. In my previous study, I explored the measurement and nature of shared vision in great detail. Shared vision is the aggregation of individual level vision to a team construct, and I used a similarity metric. First, I coded the open-ended responses into first order, and second order categories using an inductive coding method (in depth description of these categories in Chapter 2). There ended up being 15 categories for responses about daily goals and 15 categories for responses about daily challenges (categories were the same in both except each had one unique category): (1) *general living,* (2) *mental health,* (3) *physical health,* (4) *sleep,* (5) *asteroid mission,* (6) *campaign level tasks,* (7) *PI implemented tasks,* (8) *general task completion,* (9) *schedule,* (10) *workload,* (11) *equipment,* (12) *communication*, (13) *interpersonal within crew,* (14) *Interpersonal between crew and mission control,* (15 goals) *contact with people outside NASA,* (15 challenges) *none/unknown.* Once responses were coded, on a given day, an individual response was characterized by a series of 0s and 1s, with 1 indicating that the individual mentioned that theme that day, and I can compare two individual's responses by seeing how their 1s and 0s line up. The metric I used to represent similarity among the crewmembers is the Jaccard's similarity coefficient. Jaccard's coefficient was chosen since it treats the overlapping 1's in the dichotomized two-mode matrices as similarity but not the overlapping 0's. Only mutual inclusion results in similarity, not mutual exclusion. This calculation allowed me to assess the relative amount of agreement between the crewmembers throughout over the course of the entire mission.

Stress. Stress is commonly defined as a relationship between an individual and his or her environment that is seen as taxing or exceeding their resources and endangering their well-being (Lazarus & Folkman, 1984). Russian cosmonaut, Valery Ryumin once said, "All the conditions necessary for murder are met if you shut two men in a cabin and leave them together for two months" (Mundell, 1993). While the team members spending 30 or 45 days inside HERA have never murdered each other, they are placed under a variety of stressors. An individual's perceptions of environmental demands, their personal capacity to meet these demands, and motivation are central to the stress experience. The main environmental stressors experienced at various points in HERA missions for all crews was imposed communication delays between the crew and mission control. In addition to imposed environmental stressors, two other stressors assessed were: interpersonal stress, and daily obstacles.

Communication delay. Communication delay conditions have been shown to be significantly associated with increased individual stress/frustration (Kintz, Chou, Vessey, Leveton, & Palinkas, 2016). In their study of teams on the International Space Station, crew well-being and communication quality were also significantly reduced in communication delay tasks compared to control. Qualitative data suggest communication delays impacted operational outcomes (i.e. task efficiency), teamwork processes (i.e. team/task coordination) and mood (i.e. stress/ frustration). In HERA missions, communication delays occur in both 30 and 45-day missions during which the teams are on a simulated mission to an asteroid. The communication delay gradually increases as the team gets further from Earth (on the mission to an asteroid) and then it gradual decreases back to zero as the team returns to Earth. For 30-day missions, the delay begins on mission day 13, and continues until mission day 21. During that time the progression of delay times is (in minutes): 0.5, 1, 3, 5, 5, 5, 3, 1, 0.5. On the 45-day missions, the teams are on the same simulated mission, but it is drawn out longer. The delay begins on mission day 16 and extends until mission day 28 with the progression being (in minutes): 0.5, 1, 2, 3, 5, 5, 5, 5, 5, 3, 2, 1, 0.5. Therefore, communication delay can both be measured as a dichotomous presence or absence variable, or as a continuous variable increasing and then decreasing during the specific phase of the mission.

Interpersonal stress. Interpersonal stress pops up in many different forms during a long mission when a team is living together. I measure interpersonal stress through two measures 1) the social relationships between crew members using sociometric questions and 2) self-reported status conflict within the crew. Roughly every four days throughout the missions (7 measurements in 30-day missions and 11 measurements in 45-day missions) team members reported on specific social relationships between themselves and other crew members. During the 30-day missions, team relationships were elicited on days 1, 5, 10, 15, 21, 25, and 28. On the 45-day missions, team relationships were captured on days 1, 6, 11, 15, 21, 26, 29, 34, 29, 43, and 45. One question was “who makes tasks difficult to complete?” In order to compute a metric of interpersonal stress for the crew at each time period, I computed the network density of hindrance relations. In the case of difficult working relationships, higher density indicates more interpersonal stress. Additionally, in this same survey, I measured self-reported status conflict (Bendersky & Hays, 2012). This is a four-item measure that assessed the degree of conflict surrounding individual contributions and influence. The items were responded to using a 7-point Likert scale (ranging from 1 = strongly disagree to 7 = strongly agree). Example items included: "*My team members experienced conflicts due to members trying to assert their dominance"* and *"My team members disagreed about the relative value of members' contributions".* Responses were averaged to get a team status conflict score.

Breadth of daily obstacles. During a long mission, teams experience alternating periods of extreme monotony and activity; a cycle that repeats itself throughout the entire mission and that often takes place rapidly. These conditions can create both physical and cognitive work overload, associated feelings of anxiety, and behavioral decrements (Dietz et al., 2010). Sikora, Beaty, and Forward (2004) illustrate the importance of considering both the co-existence of multiple stressors when examining their effects by modeling the cumulative effects of asynchronous, multiple, and overlapping stressors on individuals. I conceptualize the degree of co-existing stressors using the challenges portion of the daily shared vision survey. Participants are asked daily (excluding Sundays) what challenges are the crew facing today? These open-ended responses are coded into categories and breadth of daily obstacles is operationalized as the number of different challenge categories mentioned by the team as a whole.

Analyses

In these data, there are nine teams who provided multiple measurements over the course of their mission. This nesting structure to data means the assumption of independence assumed in OLS regression models was violated because multiple data points came from a single team. Therefore, there was variance in both the intercept and slopes that was attributable to team membership. I used multilevel models, which take this nesting of data into account. These multilevel models allow the intercept of a model to vary across teams (random intercept models). These models can additionally allow slopes to vary across teams (random slopes models) so that the effect of one variable on another can be different for each team. My data had two levels with level 1 being time and level 2 being the team since there are multiple time periods nested in teams. A level 1 variable is one that is measured multiple times for each team, and therefore has within team and between team variation (e.g. team cognition measurements) whereas a level 2 variable would be one that was measured once for each team, therefore having between team variation, but no within team variation (e.g. team gender proportion). All of my analyses investigated how level 1 predictors impacted level 1 outcomes meaning a predictor measured multiple times predicting an outcome also measured multiple times. This means that the type of variation I predicted was within team variation.

In all analyses, the protocol I used was a step by step model building and model comparison approach. Some hypotheses required growth models, others discontinuous growth models, and others more ordinary hierarchical linear models, but all analyses progressed using a similar step by step approach. Model comparisons allowed me to test the log-likelihood ratio of two competing models as long as they differed only in the random terms of the model. As long as the same predictors were included in both models, I was able to tell if, for instance a random slopes model fit the data better than a random intercepts model. All following analyses took the general approach in which I began with a null or empty model, added predictor variables, and then examined variance in slopes of those predictor variables.

Hypothesis 1 posited that three types of team cognition similarity: shared task mental model, shared team mental model, and shared vision would have an inverted U trajectory over the course of the mission. This hypothesis, therefore, was assessed using quadratic growth models (Bliese & Ployhart, 2002). Bliese and Ployhart outline the steps required for building growth models through a model comparison approach. Models were tested and compared using the multilevel package in R (Bliese, 2016).

Step 1 began with estimating the ICC1s of the outcome variables (in this case, the three team cognition variables) using a null or empty model with just a random intercept. In step 2, I estimated the fixed effects of the time parameters first adding a linear term and then adding a quadratic term while including a random intercept. In this step, comparing log-likelihood ratios of models with just linear versus models with linear and quadratic terms was not possible since the models had different predictors. However, a quadratic model was deemed a better fit than a linear model when the quadratic term was significant. In step 3, I determined the variance in time parameters by first including a random effect for the linear term, and then random effects for both linear and quadratic terms, and comparing those random slopes models to their respective fixed slope model counterparts. For step 3 in the model building process, I used log-likelihood model comparisons to determine if the current model fit the data better than the previous model. This is done using the anova function in the multilevel package, which compares the log-likelihoods of the two competing models.

Hypothesis 2 posited that stressors would lead to a decrease in the three team cognition similarity variables (shared task mental models, shared team mental models, and shared vision). The stressors I examined included communication delay, hindrance network density, status conflict, and breadth of daily challenges. In order to test Hypothesis 2, I used two different methods depending on the stressor. In the case of communication delay, I used a discontinuous growth model (Bliese & Lang, 2016), because there are repeated measures from numerous time periods punctuated by one or more discontinuities (i.e. the beginning and end of the communication delay period). For the other stressors that were assessed multiple times throughout the mission, I built hierarchical linear models using the stressor variable as a level 1 predictor.

The basic discontinuous growth model is an extension of the linear growth model where time is re-coded to account for the influence of a change event. Instead of one term looking at the linear or quadratic pattern of team cognition over time, there was an initial “time” parameter that was essentially the trend of the variable leading up to the stress event (the beginning of communication delay). Then there was a “trans” parameter that could either indicate the absolute change in the variable at the moment of transition or a relative change given the previous trajectory from the “time” parameter. Finally, there is a “recovery” parameter that reflected either the change in slope following the transition event (beginning of communication delay) or the absolute value of the post-transition slope. Both relative change and absolute change provided useful, but different information about the patterns in team cognition that factored into addressing Hypothesis 2. In my models, I included two transition and two post terms to model the transition into communication delay and the difference in slope during the communication delay period, as well as the transition out of communication delay and the difference in post communication delay slope. Figure 7 is an example with the model terms diagrammed for task mental model similarity for the first mission.

In the cases of breadth of challenges, hindrance network density, and status conflict, there were no single events on which to base a discontinuous growth model. Therefore, I used hierarchical linear models with the time periods nested in teams to examine the effect of these stressors (level 1 predictors) on team cognitive similarity (level 1 outcomes). The first step in these models, just like in the growth models was to estimate the ICC1s of team cognition variables, however, that step was already completed in step 1 of the first hypothesis. Step 2, similar again to the growth models, was to estimate the fixed effects of the stress variables on the outcome team cognition variables in a random intercepts model. Finally, step 3 was to compare models with random intercepts to models with random slopes using the models comparison method. Parameters were interpreted based on the most simplistic model that best fit the data. Therefore, if a more complex model (i.e. one that had mode random effects) was not a significantly better fit than a more simplistic model based off the log-likelihood ratio, then I interpreted the parameters from the more parsimonious model.

Results

Means, standard deviations, and intercorrelations for the team cognition variables can be seen in Table 7. In that table, I broke shared vision into three variables: combined shared vision, shared goals, and shared challenges - essentially separating out based on the two prompts described in Chapter 2. The correlation between shared goals and shared challenges was low ($r = 0.02$) suggesting that they were distinct variables. Therefore, all analyses were conducted using both versions of the variable – combined and separated out. Scatterplots plotting team cognition over the course of each mission can be seen in Figures 8-12.

One important step to investigate prior to moving forward with hypothesis testing was to investigate the nesting structure of the data. Similarity begins by being averaged to the individual level (average the similarities between an individual and his or her teammates), and it can be averaged to the team level, which is an average of all 6 dyads in the team. Additionally, these similarity scores are assessed multiple times throughout a mission. Therefore, the levels to these data are: time (level 1), individual (level 2), and team (level 3). My initial investigation into the data structure began with a simplified 2-level model of time (level 1) nested in team (level 2). ICC1s and ICC2s for the team cognition variables in this structure are in Table 8. ICC1 is a measurement of the proportion of variance attributable to group differences (Bliese, 2000). For instance, the ICC1 of task mental model similarity is 0.79, which indicates that 79% of the variance in task mental model similarity is due to differences between the groups (in this case differences between the nine teams). Indeed, all of the ICC1s for team cognition variables show that at least 10% of the variance was attributable to team membership, and all but one ICC1 was above the median from James (1982) survey of articles reporting ICC1s. This is the main reason for using a multilevel framework, because an OLS regression model ignores that variance, or otherwise treats it all as within team or residual variance, which leads to mis-estimations of standard errors for coefficients. ICC2 is an estimate of the reliability of group (team) means with high numbers indicating that the means for each group are relatively stable over time.

I further investigate the evolving structure of the data in Table 9, which shows the ICC1s or variance attributable to the team in a 3-level structure of time (level 1) nested in individuals (level 2) nested in teams (level 3). Additionally, these calculations were made for each week of the mission to investigate if the between team differences became more accentuated as time went on. ICC1s in Table 9 show that the variance attributable to between team differences was lowest in the first week of the mission suggesting, perhaps expectedly, that team cognition becomes more of a team level construct as members spend more time together. Finally, Table 10 presents an alternative structuring to the data in which I investigate time as the grouping factor. In this case, I am investigating the variance attributable to mission week in a 2-level structure of team (level 1) nested in time (level 2). The low ICC1s and ICC2s in Table 10 indicate that team as the grouping variable is the better fitting structure to the data - that there are more differences attributable to team membership than there are differences attributable to the week of the mission the measurement was taken. The following analyses proceed with the 2-level structure of time (level 1) nested in teams (level 2).

Hypothesis 1

Hypothesis 1 stated that There would be an inverted U trajectory of a) shared task mental model similarity, b) shared team mental model similarity, and c) shared vision over time. This hypothesis was tested using growth models (Bliese & Ployhart, 2002). In Bliese and Ployart's approach, they start with the simple regression model and progressively add complexity in terms of random effects. At each step, they compare log-likelihood ratios (deviances) between models to aid decisions about including specific terms. The aim is to develop the most parsimonious model, so they test whether adding more complexity to the model improves model fit above and beyond the existing terms in the model. I began my models with a random intercept model, bypassing the basic regression model. Bliese and Ployhart admit that it is very unlikely that longitudinal data would be independent. In practice, they prescribe beginning with a random intercept model. In the random intercept model, it is often valuable to estimate the intraclass correlation coefficient (ICC1) to determine the strength of the nonindependence (Bryk & Raudenbush, 1992), which are present in Table 8. The ICC1s for the team cognition variables all indicated significant between group variability indicating it was reasonable to begin with a random intercept model rather than a simple regression model.

The next step after estimating the ICC1s from the null random intercept models was to add fixed time parameters beginning with linear terms, and then progressing to quadratic terms and so on until additional parameters were no longer significant. In these models, the trajectory of the specific team cognition variable was still held constant across the nine missions, but the intercept or starting point was allowed to vary across missions. I present the models in sequence (null model, linear model, quadratic model, and random slopes model) for each team cognition variable in Tables 11-13. For task mental model similarity (Table 11), there was a significant positive linear trend ($\beta = .02$, $p<.05$). These variables have been transformed into z scores, so this result indicates that for every increase in time, task mental model similarity increased by .02 standard deviations. In the quadratic model for task mental model similarity, the quadratic term was negative, but not significant ($\beta = -.0003$, $p>.1$). This result indicates that a linear model was a better fit for the data than a quadratic model. Another way to estimate the impact of adding terms to the model, especially when it is not possible to conduct log-likelihood comparisons, is to examine the change in residual variance, which gives what I referred to in the tables as a pseudo R_2. In the null model, the residual variance was 0.26, and adding the linear parameter to the model reduced the residual variance to 0.23 meaning that the linear trend explained 13% of the within mission variance in task mental model similarity. Adding the quadratic term further reduced the residual variance by a near zero amount (0.0007) thus only explaining an additional 0.3% of the residual variance. For team mental model similarity (Table 12), the results were similar. The linear effect was positive and significant ($\beta = .01$, $p<.05$) with a pseudo $R_2 = 0.04$. The quadratic term was negative, but not significant ($\beta = -.0003$, $p>.1$) with a pseudo $R_2 =.003$. For combined shared vision (Table 13), the linear trend was not significant ($\beta = -.005$, $p>.1$) with a pseudo $R_2 \sim 0$ (there's actually a minor increase due to reducing the degrees of freedom by 1) thus, there was no need to progress to a quadratic model. In terms of trends over time, separating out shared vision into shared goals and shared challenges did not make a difference so only the combined shared vision results are displayed. At this point in the analysis, I concluded that Hypothesis 1 was not supported given the non-significance of the quadratic terms.

Even though the quadratic models were not significant, I continued with the last step of the growth model building process, which would be considered exploratory analyses since the hypothesis was not supported in the previous step. The next step of the growth model building process was to add random slopes in for the linear terms and compare the random slopes models to the random intercept models using log-likelihood comparisons. The random slopes models kept the random intercepts and added a random slope for the linear parameter meaning the linear trend over time for team cognition was allowed to vary across teams. The random slopes models added two new terms into the random portion of the model. The first was the random variance of the slope meaning the variance in linear slopes across teams. The second term was the covariance of the random slope with the random intercept, which is not strictly interpretable, but gives a general idea of the relationship between the intercept and the slope. Model comparison was used since the random intercept and random slope models have the same predictors; however, the second model allowed slopes to randomly vary among teams whereas the first model does not. The ANOVA function in the multilevel package (Bliese, 2016) is a generic function used to contrast alternative models and can be used to compare –2 log likelihood values (i.e., deviances) between model 1 and model 2 . The significance of the –2 log likelihood difference is based upon a chi-squared distribution using the df associated with the number of model differences between the contrasted models (for these comparisons there was 1 df based off the fixed versus free slope).

For task mental model similarity, the random slope model was a superior fit compared to the random intercept model with a log-likelihood ratio of 82.1 (p<.05). This result indicates that there was significant variation in linear slopes for task mental model similarity between teams. In this model, the fixed linear effect (which was the average linear effect now controlling for random variation in slopes across teams) was still positive, but no longer significant (β = .1, *p*>.1). For team mental model similarity, the random slope model was a superior fit compared to the random intercept model with a log-likelihood ratio of 120.2 (*p*<.05). In this model, the fixed linear effect was still positive, but no longer significant (β = .01, *p*>.1). For combined shared vision, the random slope model did not fit the data better than the random intercept model with a log-likelihood ratio of .92 (*p*>.1). Therefore, the parameters and interpretation from the random intercept model remained the best fit. Similar results showed for shared goals (L.ratio = .005, *p*>.1) as well as shared challenges (L.ratio = .31, *p*>.1). In conclusion for these growth models, there were significant positive linear trends for task and team mental model similarity when the slopes were fixed, but when allowing the slopes to vary, which was a better fit for the data, the linear trends were no longer significant. The superior fit of the random slopes models was perhaps expected given the high ICC1s of the team cognition variables in Table 8, which indicated that a large proportion of the variance in the team cognition variables was attributable to between team differences compared to within team.

Hypothesis 2.1

Hypothesis 2 stated that Teams experiencing stressors would experience declines in a) shared team mental model similarity, b) shared task mental model similarity, and c) shared vision. For the purposes of organizing the analyses, I broke this hypothesis into two parts because the nature of the “stressors” required two different analysis approaches. For the first stressor, communication delay, I used a discontinuous growth model, and for the other three stressors (hindrance network density, status conflict, and breadth of daily challenges), I used hierarchical linear modeling. The former I have labeled Hypothesis 2.1, and the latter I labeled Hypothesis 2.2. For Hypothesis 2.1, I used Bliese and Lang’s (2016) prescribed procedure for building and interpreting discontinuous growth models, results of which I detail in the following sections.

Hypothesis 2.1 posited that there would be a decrease in team cognition following the beginning of the communication delay period. Discontinuous growth models address this hypothesis in multiple ways. Through a re-coding of the time variable, I broke the data down into the three sections (pre-communication delay, during communication delay, and post-communication delay), which yielded five parameters in the subsequent models, and I will use the terms here that appear in the tables. The first parameter was "Time", which was the linear trend in team cognition during the pre-communication delay period only. The second parameter was "Trans1", which was the relative change in the team cognition variable on the first day of communication delay compared to where it would be expected to have been given the linear trend pre-communication delay. "Recovery1" was the third parameter and referred to the relative change in slope of team cognition during communication delay compared to the pre-communication delay slope. "Trans2" was the transition out of communication delay so this parameter indicated the relative difference in team cognition on the first day of post-communication delay compared to where it would be expected to have been given the pre-communication delay slope. Finally, "Recovery2" was the relative difference in slope post-communication delay compared to the pre-communication delay slope.

Notice, these were all relative change models comparing transitions and recovery values to the pre-communication delay parameter. I built another set of absolute change models that examine the absolute change in team cognition and absolute values of recovery slopes. The terms are the same, but the values and interpretations were different in that "Trans1" and "Trans2" were the absolute difference in team cognition on the first days of during communication delay and post-communication delay respectively. Additionally, “Recovery1” and “Recovery2” were the absolute slope values of team cognition during and post communication delay respectively. Other than the recoding of the time variable, the model building steps for the discontinuous growth models are the same as those for the basic growth models from Hypothesis 1. The ICC1s for the team cognition variables were already calculated and are seen in Table 8. Additionally, the null models are the same so those are not repeated in the tables.

The next step was to add in the fixed time parameters (Time, Trans1, Recovery1, Trans2, Recovery2). The results for task mental model similarity are presented in Table 14. The Time parameter was positive and significant ($\beta = .06$, $p<.05$) indicating that the linear trend in task mental model similarity pre-communication delay was positive. The Trans1 parameter was negative, but not significant ($\beta = -.17$, $p>.1$), which means that team mental model similarity was not significantly different on the first day of communication delay compared to where it would be expected to have been given the trajectory pre-communication delay. Recovery1 was negative and marginally significant ($\beta = -.04$, $p<.1$), which suggests that the slope of task mental model similarity was relatively lower during communication delay compared to the pre-communication delay slope. Trans2 was also significantly negative ($\beta = -.62$, $p<.05$), which means task mental model similarity was lower on the first day of post-communication delay compared to where it would be expected to have been given the pre-communication delay trajectory. Finally, Recovery2 was negative and significant ($\beta = -.05$, $p<.05$) meaning the post-communication delay slope of team task mental model similarity was significantly lower than the pre-communication delay slope. Those were the results for the relative change model. The absolute change model is also presented in Table 14. These results showed that there were no absolute drop-offs or increases in task mental model similarity at either of the two transition points, and the slopes during and post communication delay were not significantly different from zero.

Figures 13-15 plot the parameters from the relative change discontinuous growth models for task mental model similarity, team mental model similarity, and shared goals respectively.. These figures represent simulated data using the parameters from the best fitting relative change models in Tables 14, 15, and 17. Figure 13 represents the parameters from the task mental model discontinuous growth model so the initial pre-communication delay slope based on the Time parameter from the model is .04. The Trans1 term of -.06 is seen by the minor dip on the first day of communication delay (the point is .06 lower than where it would be if the pre-communication delay slope continued throughout). The during communication delay slope or Recovery1 is 0 because the Recovery1 parameter is -.04 meaning during communication delay slope is .04 lower than the pre-communication delay slope (.04 - .04 = 0). The Trans2 parameter is seen as a small spike on the first day post-communication delay. The Trans2 term in the model is -.39 meaning the level of similarity is .39 lower than where it would be if the pre-communication delay slope continued throughout. Even though the term is negative, there is a spike because even the relatively lower point is higher than if the flat trajectory during communication delay continued. Finally, there is a slight negative slope post-communication delay (-.01 to be exact) because the Recovery2 parameter is -.05 lower than the pre-communication delay slope of .04. The next step with these models, much like the basic growth models was to, one by one, add in random effects for each of the time parameters, beginning with Time, then adding Trans1, Recovery1, Trans2, Recovery2 in order, and compare models until adding random effects no longer resulted in a significantly better fit for the data based on the log-likelihood comparisons. In order to save time and space, I only describe the best fitting random slopes model for both relative change and absolute change models. For task mental model similarity, in both relative change and absolute change models, including random slopes for the Time and Trans1 terms made significant improvements upon model fit, meaning there were significant differences between groups with regards to their pre-communication delay slopes and transitions from pre-delay to during communication delay. Adding random effects beyond those were not significant improvements. Significance of terms was not affected in the absolute change model. In the relative change model, adding random slopes from Time and Trans1 reduced the standard error of the Recovery1 parameter thus increasing its significance ($\beta = -.04$, $p<.05$).

For team mental model similarity and the shared vision variables, I interpret only the best fitting random slopes model in order to report the most relevant information, skipping the random intercepts since those were not ever the best fitting. All results, including the random intercepts models for team mental model similarity are presented in Table 15 for reference. In the relative change model, including random slopes for the Time term made significant improvements upon model fit, and adding random effects beyond that were not significant improvements. In the absolute change model, including random slopes for the Time and Trans1 terms made significant improvements upon model fit, and adding random effects beyond those were not significant improvements. In the relative change model, there was a marginally significant positive linear slope pre-communication delay ($\beta = .03$, $p<.1$). The during communication delay slope of team mental model similarity was relatively lower than the pre-communication delay slope ($\beta = -.05$, $p<.05$). There was also relatively lower team mental model similarity on the first day of post-communication delay relative to where it would be expected to have been given the pre-communication delay trajectory ($\beta = -.31$, $p<.05$). Finally, the post-communication delay slope of team mental model similarity was relatively lower compared to the pre-communication delay slope ($\beta = -.02$, $p<.1$). Figure 14 illustrates these results graphed over time. In the absolute change random slopes model, there were no significant transitions or slopes except the slope during communication delay, which was negative and marginally different from zero ($\beta = -.02$, $p<.1$).

For combined shared vision, shared goals, and shared challenges the results of the random intercept models are seen in Tables 16-18. In the case of these three models, adding random slopes did not significantly improve model fit. For combined shared vision (Table 16), there were no significant relative or absolute changes at the transition points, nor were there significant absolute or relative changes to the slopes of shared vision during or post communication delay. However, there was a significant positive increase in shared goals (Table 17) at the beginning of communication delay both relative to where shared goals would be expected to have been given the pre-communication delay trajectory ($\beta = .58$, $p<.05$), as well as an absolute increase ($\beta = .54$, $p<.05$). Additionally, there was a relatively higher slope in shared goals post-communication delay compared to pre-communication delay ($\beta = .09$, $p<.05$), and the absolute change model showed that that slope was significantly different from zero ($\beta = .06$, $p<.05$). The parameters for the shared goals model are graphed out in Figure 15. For shared challenges (Table 18), on the other hand, there were no significant relative or absolute changes at the transition points, nor were there significant absolute or relative changes to the slopes of shared challenges during or post communication delay.

Taken together, these results show partial support for Hypothesis 2.1. For task and team mental model similarity there were significantly lower slopes during communication delay compared to pre-communication delay. The slope of mental model similarity post-communication delay was relatively lower than pre-communication delay as well. However, for shared goals the finding was quite the opposite in that there was an increase in shared goals at the beginning of communication delay, and the post-communication delay slope was significantly positive and relatively higher than the pre-communication delay slope.

Hypothesis 2.2

Moving on to, Hypothesis 2.2 is the subset of Hypothesis 2 (teams experiencing stressors would experience declines in a) shared team mental model similarity, b) shared task mental model similarity, and c) shared vision.) concerned with hindrance network density, status conflict and breadth of daily challenges. Similar to growth modeling, the first step (already completed) was to estimate the ICC1s for the team cognition variables. The second step was to add in fixed effects for the stressor of interest in a random intercept model. Finally, the last step was to build a random slope model allowing the effect of the stressor to vary across teams and compare model fit of the random intercept and random slope model.

Beginning with breadth of daily challenges, fixed slopes models were best fitting for all of the team cognition variables (model results in Table 19). As can be seen from the table, there were no significant effects of breadth of daily challenges on task mental model similarity, team mental model similarity, nor shared goals. The analysis was not conducted on combined shared vision or shared challenges since the predictor variable was derived from the same data as the outcome, so the variables were too correlated. Predictably, if there were a lot of challenges mentioned on a given day (high challenge breadth), then it is less likely everyone is agreeing on those challenges (low shared challenges). The next stressor I examined was status conflict, and, again, the random intercept models were the best fits for the data for all team cognition variables. The model results are in Table 20, and as can be seen from the tables, there were no significant effects of status conflict on task mental model similarity, team mental model similarity, nor shared vision.

The final stressor I examined was the density of the hindrance network. For all team cognition variables, the random intercepts models (seen in Table 21) were the best fitting models. Results showed that task mental model similarity was negatively impacted by hindrance network density ($\beta = -1.18$, $p<.05$). Team cognition was transformed into z scores, so this result means for every 1 unit increase in hindrance network density, there is a 1.18 standard deviation decrease in task mental model similarity. For team mental model similarity, hindrance network density's effect was negative, but not significant ($\beta = -.08$, $p>.1$). Results for shared vision are broken out into goals and challenges. Results showed hindrance network density had a positive effect on shared goals that was marginally significant ($\beta = 1.16$, $p<.1$), and a positive relationship with shared challenges that was not significant ($\beta = .18$, $p>.1$). Taken together, these results mostly do not support Hypothesis 2.2, although hindrance network density as a type of interpersonal stress did negatively impact task mental model similarity.

Discussion

The study in this chapter investigated the dynamics of team cognition over time. I hypothesized first that team cognition in general would follow an inverted U trajectory, increasing in the beginning of the mission and then declining in the latter half due to fall offs in communication and interaction. This hypothesis was not supported by the data. There was significant variation in linear trends across missions, so when the linear term was allowed to vary, there were no linear patterns, and no quadratic trends either. The differences in team cognition patterns across missions makes it difficult to detect an average effect so the next step in future work would be to investigate reasons for these trend differences

An examination of the discontinuous growth models, which broke the data down into pre, during, and post communication delay showed positive linear trends for task and team mental model similarity in the pre-communication delay phase, but no time trends early on for shared vision. There was then a leveling off of team cognition through the communication delay and post communication delay periods. The relative models indicate that, compared to the pre communication delay trends, there were lower values of team cognition and lower trajectories at the transition and recovery phases. However, the absolute models reveal that these relative differences were not declines, but rather a flattening of the trajectory. In other words, teams converge early in a mission on team and task mental model similarity, but growth slows at the onset of communication delay and further growth does not get stimulated at any other point in the mission. For shared goals, however, there is little growth in the beginning and middle phases of the mission, although there was a spike at the onset of communication delay. Convergence on shared goals significantly accelerated post-communication delay, which ultimately reflects the opposite trend of team and task mental model similarity.

A possible interpretation of the result concerning team and task mental model similarity could be that, rather than individuals falling out of synch due to lack of communication, individuals were coordinately simplifying their mental maps and visions of the future. It is also possible that repeated measurement led to individuals remembering and repeating their same answers. These individuals were surveyed constantly for multiple weeks so survey fatigue was also possibly a factor that led to individuals answering less carefully (repeating the same answer each day), which would lead to relatively constant levels of similarity amongst the team members. For shared goals, the late-mission convergence could be the result of a narrowing of options as the mission ends, there are fewer goals to achieve or think about as everyone could begin focusing on the conclusion of the mission. Additionally, a spike at the onset of communication delay may have a similar cause in that the crew converges on shared goals when there is a salient event occurring such as the end of the mission or, in this case, the beginning of a new logistical requirement.

In addition to examining general trends over time, I investigated how the pattern of team cognition responded to various environmental, or interpersonal stressors throughout the course of the mission. My expectation was that stress would lead to declines in team cognition due to the narrowing of focus and inability to attend to details that would allow for synchronized updating of cognitive structures. This hypothesis was partially supported and also revealed interesting differences between team cognition constructs. The discontinuous growth models addressed the impact of the environmental factor, communication delays built into the mission. These results showed that slopes during and post communication delay were significantly lower than the pre-communication delay slopes for both task and team mental model similarity. However, for shared goals, there was a sharp increase in goal alignment at the beginning of communication delay, and the post-communication delay slope for goal alignment was positive and higher than the pre-communication delay slope. This demonstrates that the dynamics of team cognition depends on which type of team cognition is being considered. Team and task mental model similarity are variables more focused on taskwork relevant issues while shared goals is a variable more generally focused on work and life issues. One interpretation of these results could be that work related team cognitive similarity has a quicker and more direct ascent early mission while life related team cognitive similarity is more volatile early on and teams reach agreement later in the mission. With regards to the sudden increase in shared goals at the advent of communication delay, this could have been the result of a salient event (the presence of a new feature to the mission) leading everyone to focus on the same goal(s). This possibility is supported by the fact that the second transition point coming out of communication delay was not different from where it would have been if the initial pre-communication delay slope had continued.

When I examined the other stressors, neither breadth of daily challenges nor status conflict predicted any change in team cognitive similarity. However, hindrance network density revealed another interesting distinction between types of team cognitive similarity. Hindrance network density was negatively related to task mental model similarity, but positively related to shared goals. Therefore, the more individuals on a team saw each other as hindrances to task completion, the less in sync they were with regards to their task mental models, but the more in sync they were with regards to their envisioned goals. This is another possible distinction between work relevant team cognition and life relevant team cognition. Interpersonal stress led to the breakdown in work related mental model similarity, which might be expected because hindrance network density could be indicative that people were not seeing eye to eye when it came to task completion. On the other hand, interpersonal conflict was a unifying factor when it came to goal sharing, and this could be because interpersonal stress is a salient feature when living and working with the same people for several weeks, so goals may have centered around that feature, much in the same way that the salient event of communication delay beginning led to a sharp uptick in shared goals.

This chapter contributes to the literature on team cognition by studying development and evolution of team cognition constructs over time in teams using frequent measurements collected on teams from the time of their inception to the dissolution. Previous research on team cognition over time would either be for shorter periods of time (e.g., a few hours) and/or include only a few measurements. In both cases, it is hard to understand the full picture of what is happening especially if there are not clear linear trends. In teams cohabitating for long periods of time, looking at a few different time points does not really capture how a team changes on a day to day or week to week basis. This chapter demonstrates the value of looking at team emergent states with frequent measurements in order to capture the fluctuations and plateaus occurring during a long mission.

One example of how individual and team functioning, and well-being unfolds over the course of a long mission is the documentation in a variety of contexts of the third quarter phenomenon (Betchel & Berning, 1991). Their research has found that there is a point past the middle of the mission (around the three quarters mark), regardless of length, when there are greater issues with team and individual affective states. Declines in group mood, team morale, individual affect, peaks in aggression, and increases in sleep issues are some of the various issues that have been examined. Knowing when teams are most at risk for experiencing these issues has important implications for interventions and monitoring performance, and the same can be said of team cognitive states, which have demonstrated implications for team process and effectiveness (Kozlowski & Ilgen, 2006).

CHAPTER 4

CONSEQUENCES OF TEAM COGNITION

Team cognition is now identified as "one of the more developed collective cognition literature streams" (Mathieu, Maynard, Rapp, & Gilson, 2008: 429) and "arguably the best developed in terms of conceptualization, measurement, and demonstrated effects". Kraiger & Wenzel (1997) suggested that influence factors occur across four different levels: environment, organization, team, and individuals. In a controlled environment such as a space analogue, environmental factors would include mission requirements or limitations such as communication delay, and sleep deprivation. Organizational factors include the compensation system, education, and training. Team-level factors relate to the characteristics of tasks and processes. Individual factors include personality and motivations. This chapter focuses on individual and team levels since environmental factors were covered in Chapter 3, and HERA was isolated from organizational influence. This chapter expands the literature by combining team cognition constructs (shared mental models, transactive memory systems, shared vision, and social role agreement) and attempting to tease apart effects of each one.

Hypotheses

These hypotheses focus on the connection between team cognition and multiple dimensions of team performance. A team performing over the course of a long mission engages in tasks with a range of characteristics that demand different sets of skills and behaviors. I investigated how team cognition was both beneficial and also a detriment to different dimensions of performance.

Team performance: Team performance is an objective or subjective judgment of how well a team meets valued objectives (Salas, Rosen, Burke, & Goodwin, 2009). Team performance has long been the poster child for outcomes in the teams research literature (Kozlowski & Bell, 2013). One cannot fully understand team performance, however, without considering the nature of the tasks being performed (e.g., Gladstein, 1984; Goodman, 1986; Hackman & Morris, 1975). McGrath (1984) proposed that most group tasks can be classified into categories that reflect the following four basic processes: “choose,” “negotiate,” “generate,” and “execute.” Intellective choosing tasks or problem-solving tasks require choosing correct answers for a complex problem. Negotiate tasks require resolving conflicting viewpoints on an issue that does not clearly have a correct answer requires. Creativity tasks, such as brainstorming, require idea generation, and execute tasks are those requiring physical movement, coordination, or dexterity, such as psychomotor tasks and athletic contests.

The types of tasks most often studied in the team cognition literature fall into the execute category, especially in the literature of shared mental models (Mohammed et al., 2010). Team performance has most often been operationalized as scores obtained from computer simulations (e.g., number of targets shot down, mission completion rate). A significant amount of studies conducted in diverse settings using different shared mental model measures has firmly established a positive relationship between shared mental model similarity and team performance (e.g., Cooke et al., 2001; Cooke et al., 2003; Edwards et al., 2006; Ellis, 2006; Lim & Klein, 2006; Marks, Sabella, Burke, & Zaccaro, 2002; Marks et al., 2000; Mathieu et al., 2005; Mathieu et al., 2000; Rentsch & Klimoski, 2001; Smith-Jentsch, Mathieu, & Kraiger, 2005). Meta-analytic results have strongly supported the shared mental model similarity-performance link across a variety of team types and measurement type (DeChurch & Mesmer-Magnus, 2010a; DeChurch & Mesmer-Magnus, 2010b).

The agreement on roles among teammates has been shown to have an impact on team effectiveness. Hall (1955) recognized the importance of members' agreement on social roles for producing coherent groups. In the absence of role consensus, there is what is called ''role collision,'' described by Hare (1976) as a ''type of conflict which may occur if two different individuals in a group perform roles which overlap in some respects.'' Heterogeneity can produce effective groups by simply reducing the potential for role collision. Freeman et al. (1979) show a relationship between group effectiveness and variation in centrality. Groups with large variation in members' centrality were more effective than groups with little or no variation in member centrality with the expectation that variation in role characteristics corresponds to variation in centrality. Similarly, MacKenzie (1976) demonstrated the relationships among group hierarchy, task processes, and group efficiency in that more hierarchical groups processed tasks more effectively and were more efficient.

H1: Team cognition, a) task mental model similarity, b) team mental model similarity, c) social role agreement, and d) shared vision, is positively related to execute task performance.

Other types of team performance are not as fully investigated in the team cognition literature. However, there is some research on team innovation or creativity that falls under generate performance from McGrath's (1984) taxonomy. For instance, it is argued that when shared mental models overlap too much it can become a detriment to the team because it limits unique individual contribution (Cannon-Bowers et al., 1993; Levine et al., 1993). Overly similar mental models may stifle creativity because having too much overlap in their understanding about task and team aspects of work may reduce their ability to innovate and be creative (Skilton & Dooley, 2010). On the other hand, previous studies suggest a positive effect of SMM on adaptation, which is closely related to creativity and innovation because teams need to solve problems and create new products in order to be able to adapt (Burke et al., 2006; Resick et al., 2010; Uitdewilligen, Waller & Pitariu, 2013). Later empirical evidence has shown a positive link between mental model similarity and self reported creativity (Santos, Uitdewilligen, & Passos, 2015). However, the ability to generate new ideas after spending weeks living in close proximity with teammates isolated from external sources of information likely makes the relationship between team cognition agreement and creativity closer to Skilton and Dooley's (2010) point of view that when team members work together on creative projects, they internalize and synchronize their understanding of the task and team requirements, which become less likely to change the more internalized they get. In subsequent tasks, team members may avoid discussing novel ideas and diverging points of view in order to avoid conflict and not to disrupt the status quo.

H2: Team cognition, task mental model similarity, b) team mental model similarity, and c) shared vision, are negatively related to generate task performance.

Team viability. Team viability is the desire or willingness to remain with your team (Hackman, 1987). Most research on team cognition focuses on team performance as the outcome of interest (Mohammed, Ferzandi, & Hamilton, 2010). Especially important for teams spending long periods of time living together is the possibility that a team can "burn itself up" through unresolved conflict or divisive interaction, leaving members unwilling to continue working together (Hackman, 1987, p. 323). In general, being on the same page with regards to task and teamwork makes coordination of activities easier, more seamless, which makes the experience of working together more rewarding. For example, Schneider and Bowen (1985) showed that a shared, collective vision in which service was the salient strategic imperative predicted customers' satisfaction with their bank branch. Additionally, teamwork schema agreement was positively associated with both team viability and member growth (Rentsch & Klimoski, 2001).

Research on teams spending the Winter at the Amundsen-Scott South Pole Station found that globally coherent networks in winter-over groups were associated with group consensus on the presence of critically important informal social roles (e.g., expressive leadership) where global coherence is the extent to which a network forms a single group composed of a unitary core and periphery as opposed to being factionalized into two or more subgroups. Conversely, the evolution of multiple subgroups was associated with the absence of consensus on critical informal social roles. The Amundsen example also illustrates the importance of role heterogeneity; varying the role characteristics of group members allows them to fit in and function well with each other. By screening the role characteristics of possible expedition members, Amundsen minimized the potential for conflict due to role collision.

H3: Team cognition, a) task mental model similarity, b) team mental model similarity, c) shared vision, and d) social role agreement are positively related to team viability.

Method

Sample

The participants studied included nine 4-person crews (N = 32) with four of them spending 30 days and four of them spending 45 days inside the Human Exploration Research Analogue (HERA) located at Johnson Space Center. One of the crews was intended to spend 45 days in the analogue, but their mission was cut short on mission day 22 due to a hurricane in the area. Three of the crews were same-gender (two all male and one all female) and the other six crews were mixed gender. Participants had to meet certain requirements to make them comparable to astronauts that would go on a mission to Mars. Participants had to have an advanced degree in a STEM field, the ability to pass the NASA long-duration spaceflight physical, which includes distance and near visual acuity (must be correctable to 20/20 in each eye), and blood pressure not to exceed 140/90. Participants range in age from 26-55, and are limited to a maximum height of 6’2” to account for the confined quarters of the typical space shuttle (Cromwell and Neigut, 2014).

Measures

Three of the team cognition constructs: team and task mental models, and shared vision are measured the same way outlined in Chapter 3. In this section I will define the measurement of the remaining team cognition construct: social role agreement as well as the outcome variables.

Social roles. Social roles were measured roughly every four days over the course of the mission (7 measurements in 30-day missions and 11 measurements in 45-day missions). During the 30-day missions, the social roles perceptions were elicited on days 1, 5, 10, 15, 21, 25, and 28. On the 45-day missions, the social roles were captured on days 1, 6, 11, 15, 21, 26, 29, 34, 29, 43, and 45. There were 12 possible roles each crew member can be assigned to. A participant can choose to elect multiple people for the same role or nobody for a given role. They participants also have the freedom to elect the same person for all roles as well as elect a person for none of the roles. The 12 roles were emerged through interviews with individuals spending a year or Winter isolated in Antarctica (Johnson & Weller, 2002): (1) *social director,* (2) *leader,* (3) *everybody’s buddy,* (4) *peacemaker,* (5) *jokes with,* (6) *comedian/clown,* (7) *storyteller,* (8) *counselor,* (9) *someone to count on,* (10) *committed to work,* (11) *volunteer,* and (12) *follower.* Participants were also allowed to fill in ‘other’ roles for each person. The four crew members in a mission filled in these role questionnaires for each other member of the crew as well as for themselves.

Social role structure and similarity. Individual perceptions of social roles are aggregated to the team level in a few different ways. Similarity is the degree to which one person's view of the social roles of the team matches with another person's views. This calculation is achieved using Jaccard's index. One person's social role perceptions was represented as a series of 1s and 0s with the 12 social roles repeating four times (one set of roles per crew member). A 1 indicates that the individual believes a specific crew member about fulfills the specific social role. The Jaccard coefficient measures similarity between finite sample sets, and is defined as the size of the intersection divided by the size of the union of the sample sets.

Viability. Viability was assessed using an 8-item self report survey roughly every four days throughout the mission (7 measurements in 30-day missions and 11 measurements in 45-day missions). During the 30-day missions, viability perceptions were elicited on days 1, 5, 10, 15, 21, 25, and 28. On the 45-day missions, viability was captured on days 1, 6, 11, 15, 21, 26, 29, 34, 29, 43, and 45. The survey was adapted from Resick et al. (2010) and Bell and Marentette's recommendations (2011). Example items include *"I really enjoy being a part of this HERA crew"* and *"If I could leave this team and work with another HERA crew, I would".* Responses are collected on a 7-point likert scale (strongly agree - strongly disagree).

Team performance. Throughout the HERA crew's tenure, they engage in a variety of tasks and surveys that yield performance along different dimensions. Throughout the HERA missions, The crews perform tasks belonging to one of four categories proposed by McGrath (1984): "choose," "negotiate," "generate," and "execute.". Three of these tasks (choose, negotiate, and generate) are completed as part of a 3-task battery completed three (30-day) or four (45-day) times spaced throughout the mission. The execute task is performed 18 (30-day) or 23 (45-day) times throughout the mission.

Choose. Choose task performance was assessed using a problem solving task. Problem solving (PS) in this approach is defined as a team's ability to select a demonstrably correct answer (McGrath, 1984; Straus, 1999). PS was assessed using tasks that present participants with survival scenarios such as the classic NASA moon survival task (Hall & Watson, 1970). Each participant is provided with an explanation of the situation and a list of 15 available items, which they must rank in order of their importance 1 (most important) to 15 (least important) to crew survival. Crews completed the tasks using instructions presented in Qualtrics. The instructions were to spend 10 minutes independently reviewing the scenario and rank the items. Next, the crew members were instructed to spend 15 minutes discussing their rankings and arrive at a final crew ranking that represents their best assessment of the importance of the items. We utilized parallel versions of the task by varying the survival scenario and the objects ranked by the crew.

Problem solving was scored by calculating the difference between the crew ranking of the item and the correct ranking, based on subject matter expert rankings for each scenario. I computed the absolute value of the deviation of each item's crew assigned rank from the expert ranking, and then summed the deviations. Since greater deviation reflects lower performance, I reverse scored this measure by converting them to negative numbers, making zero the best possible score and -112 the worst possible score. For example, if a magnetic compass and flashlight were ranked 5 and 13 by the crew and 13 and 5 by a subject matter expert respectively, the two items would both be scored as 8 for the crew, giving the crew a total score for those two items of -16. These scores were then standardized across crews and time points.

Generate. Generate task performance was assessed using a creative thinking task (CT), which is typically defined as the production of ideas that are both novel and useful (Amabile, 1983). CT was assessed using an Alternative Uses Task (AUT, Guilford, 1967) approach. The instructions were to generate as many uses for a specified object. I administered five parallel versions of the task by varying the object the crew used to brainstorm. Crews completed the tasks using instructions presented in Qualtrics. The instructions included timing guidelines. Crew members were instructed to spend five minutes individually generating uses, and then came together as a crew to discuss items.

Creative thinking was scored using three dimensions: fluency, flexibility, and novelty. Fluency was calculated by summing the total number of non-repeating uses generated by the crew. Flexibility was the number of types of ideas generated for each crew. For example, a car stop and a door wedge count as separate items in terms of fluency but only represent one type of idea (wedge). The number of categories for each item was determined by three raters categorizing all the items generated by the crews. If two of the three raters agreed on the category, the item was classified as that category (Tadmor, Galinsky, & Maddux, 2012). If two raters did not agree, the item was discussed to reach a consensus. Finally, each crew was evaluated using an objective novelty measure (Kaufman & Sternberg, 2010; Lu, Akinola, & Mason, 2017). This was determined by calculating an output dominance score - how often an item was listed relative to all items generated by all crews. Each item received a score and each crew's items were averaged to represent their novelty score. The fluency, flexibility, and novelty scores were then standardized using the distribution of all crews each assessed at three or four times (depending on the mission). The standardized scores on fluency, flexibility, and novelty were averaged to compose a team creativity score.

Execute. To assess team performance on an "Execute" task, I analyzed data from the MMSEV/EVA, a virtual reality space simulation. The crew members overarching mission during the 30 or 45 days was to journey to the asteroid "Geographos" and collect rock samples before returning home. In order to reach the surface of the asteroid to collect rock samples, crew members participate in an extra-vehicular activity (EVA) in which members take a multi-mission space exploration vehicle (MMSEV) to the surface of the asteroid. During this task, the four-person crew works together to complete psychomotor objectives at specific locations on an asteroid. The pilot and co-pilot remain on the MMSEV for the duration of this task. They pilot the MMSEV between the ship and the asteroid, as well as direct the other two crew to each objective by using a painting-laser. The other two crew members depart the MMSEV upon arrival at the asteroid. They proceed to the coordinates of each assigned objective to collect various types of rock samples. Data showing how the team attempted to complete these objectives were hand recorded by NASA operations personnel during this task.

A team of three undergraduate volunteers were trained to interpret and code the performance data for both campaigns. The task was scored in such a way as to make the performance coding generalizable across the 30 and 45 day missions. Each coder compared the data to the teams' assigned objectives for a given mission day, and coded each objective as "complete," "partial completion," or "no evidence for completion." The tasks were divided between the three coders so as to have each task coded twice. The coders agreed on the majority of data for each campaign. In campaign three, of 1098 total codings, coders agreed on 902. Joint probability of agreement for campaign three was calculated at 82.15%. In campaign four, of 6307 codings, coders agreed on 6010. Joint probability of agreement for campaign four was 95.29%. All discrepancies between codings were resolved using consensus between the three undergraduates and a graduate student task expert. Performance scores are made into *z*-scores, and are centered on the average performance across both campaigns.

Analyses

I analyzed these data using hierarchical linear models. These measures were captured at multiple time points throughout the mission, so the data were nested (time points nested in teams). Most of the constructs are compositionally emergent at the team level meaning that the team construct (e.g. team viability) was conceptualized as an aggregate of individual perceptions; in this case, an average of individual responses (Kozlowski & Klein, 2000). Some of the constructs such as the team performance metrics did not have an isomorphic individual level of the data, so those data were nested time periods in teams without an individual level. In the case of the compositional constructs, ICC1s were used to justify aggregation of the construct to the team level since these were conceptualized as team constructs.

The hypotheses linked team cognition to team performance, and were tested using the hierarchical linear model building steps prescribed by Bliese (2002). Just like the analyses for in Chapter 3, the first step in these models was to estimate the ICC1s for the outcome variables (team performance and team viability). Step two was to investigate the fixed effects of the team cognition variables in random intercepts models. Each team cognition variable was put into a separate model in order to complete step 3, which was to compare random intercepts models to random slopes models for each specific variable. This was done to investigate if the effect of the specified team cognition variable on team performance varied significantly across teams. Finally, step 4 was to build a combined model with all of the team cognition variables as predictors with the random slopes specified for the variables where the random slopes model fit better than the random intercepts model in step 3.

Hypothesis 1 stated that team cognition similarity would positively impact execute team performance. The execute task was a level 1 outcome variable measured either 18 or 23 times (depending on length of mission) throughout the missions. Team cognition variables were measured on two different time scales, both of which were different than the execute task time scale. Shared team and task mental models along with shared vision were assessed daily excluding Sundays resulting in 26 or 38 measurements. In order to investigate the impact of these variables on execute task performance, I used the team cognition similarity measurement from the day the team performed each execute task episode. Social role agreement, on the other hand, was measured less frequently than the execute task was performed (7 or 11 times throughout the mission). Therefore, for models including social role agreement, I aggregated the execute task performance, taking the mean score across the days in between social role agreement measurements. For the combined models that used social role agreement, I also aggregated the other three team cognition variables averaging them across the days between social role agreement measurements.

Hypothesis 2 posited that team cognition would have a negative impact on generate task performance. The generate task was part of a three task battery administered either three or five times throughout the mission (level 1 outcome variable). The impact of team cognition on generate task performance was tested in two ways. The first was similar to Hypothesis 1 in that I averaged the team cognition variables across the days in between the generate task episodes to assess the impact of average team cognition similarity on generate task performance. The second method I used was to calculate the slope of the daily team cognition variables (team and task mental model similarity and shared vision) in between each performance episode and use that as the predictor of generate performance. Method one looked at how the absolute mean value of team cognitive similarity impacted performance, while method two looked at how the trend of team cognitive similarity leading up to the performance episode impacted performance.

Finally, Hypothesis 3 posited that team cognition similarity would positively impact team viability. This analysis was carried out the same way as Hypothesis 1 with team viability measured 7 or 11 times (level 1 outcome variable), and team cognition being averaged when necessary between measurement instances. It was not possible to use the slopes method for this hypothesis for the same reason it was not possible for the first hypothesis – because there were not always enough days in between outcome measurements to calculate a reliable slope.

Results

Hypothesis 1

Hypothesis 1 stated that Team cognition, a) task mental model similarity, b) team mental model similarity, c) social role agreement, and d) shared vision, would be positively related to execute task performance. I built separate models for each team cognition variable as well as a combined model at the end. Step 1 in building these models was to estimate the ICC1 for the outcome variable (execute task performance) located in Table 8. With an ICC1 of .58, I was confident that there was significant intercept variation between teams, so I proceeded with step 2, building the random intercept models.

All of these models included time as a control variable to account for the fact that, naturally, over time, teams would likely improve on the execute task. The final model for task mental model similarity along with the other models is presented in Table 22. In the random intercept model, task mental model similarity had a marginally significant positive impact on execute task performance ($\beta = .16$, $p<.1$). In the random slopes model, when the effect of task mental model similarity was allowed to vary across teams, the impact of task mental model similarity was positive, but no longer significant ($\beta = .07$, $p>.1$). Additionally, a comparison between the two models resulted in a log-likelihood ratio of 5.05, which was marginally significant (p<.1) indicating that the random slopes model was the better fit for the data. The pseudo R_2 indicated that the final model explained 45.6% of the residual variance in execute task performance, although the majority of this variance explained was tied to teams' improvement on the task over time.

The final model for team mental model similarity is presented in Table 22. In the random intercept model, team mental model similarity had a significant positive impact on execute task performance ($\beta = .22$, p<.05). In the random slopes model, when the effect of team mental model similarity was allowed to vary across teams, the impact of team mental model similarity was positive, but no longer significant ($\beta = .21$, p>.1). Additionally, a comparison between the two models resulted in a log-likelihood ratio of 12.02, which was significant (p<.05) indicating that the random slopes model was the better fit for the data. The pseudo R_2 indicated that the final model explained 45.1% of the residual variance in execute task performance, although the majority of this variance explained was tied to teams' improvement on the task over time.

The final models for shared goals and challenges are presented in Table 22. Shared goals had a positive, but not significant impact ($\beta = .06$, p>.1), and shared challenges had a marginally significant positive impact on execute task performance ($\beta = .09$, p<.1). In all cases, the random intercepts models were the best fit for the data. The pseudo R_2 for the shared goals model explained 41.7% of the residual variance, and shared challenges model explained 42.3% of the residual variance. Again, the majority of this variance explained was tied to teams' improvement on the task over time.

The final model for social role agreement is presented in Table 22. In the random intercept model, social role agreement did not have a significant impact on execute task performance ($\beta = .1$, p>.1). The effect was also not significant in the random slopes model (β =

.1, *p*>.1), and the comparison between the two models resulted in a log-likelihood ratio of .003, which was not significant indicating that the random intercepts model is the better fit for the data. The pseudo R_2 indicated that the final model explained 15.9% of the residual variance in execute task performance, although the majority of this variance explained was tied to teams' improvement on the task over time.

In the full model presented in Table 22, I left social role agreement out because it was not at all related to execute task performance. Additionally, including social role agreement would have required aggregating the other variables over time periods between social role agreement measurements, decreasing the number of observations. Therefore, the full model had fixed effects for task and team mental model similarity, shared goals, and shared challenges predicting execute task performance. There were also random effects for task and team mental model similarity based on the random slopes models fitting better than the random intercepts models for those two variables when they were entered one at a time. Team mental model similarity was positively related to execute task performance and marginally significant ($\beta = .28$, $p<.1$). Additionally, shared challenges was positively and significantly related to execute task performance as well ($\beta = .1$, $p<.05$). The pseudo R_2 indicated that the full model explained 48.8% of the residual variance. In total, Hypothesis 1 was partially supported with two team cognition variables positively related to execute task performance, and three variables not significantly related.

Hypothesis 2

Hypothesis 2 stated that Team cognition, task mental model similarity, b) team mental model similarity, and c) shared vision would be negatively related to generate task performance. Models with mental model similarity or shared vision as predictors used two approaches: the first was to use the slopes of the variables leading up to the performance episode since there were at least four days between generate task performance episodes. The second approach was to average team cognition across the days leading up to the performance episode. The ICC1 for generate task performance (Table 8) was .59, which indicated there was ample between team variance to proceed with random intercepts models. In the subsequent models, I used time as a control variable, but this time I used time as a categorical variable since there were three or four performance episodes depending on the campaign, and, unlike the execute task, the content of these tasks changed each time so there was less reason to expect a linear improvement over time.

In the first set of models, using the slopes of team cognition leading up to generate task performance, I initially entered each variable individually, and then built a full model. The results of the best fitting models are presented in Table 23 along with the full model. In the individual variable models, no team cognition variables were significantly related to generate task performance. The same is true when variables were combined in the full model. The pseudo R_2 was .74, but the majority of that variance explained must have been attributed to the time factor. The second set of models presented in Table 24 used mean team cognition as predictors instead of slopes. Again, the random intercepts models were the best fits for the data so those are the models interpreted and presented in the table. When variables were entered individually, team mental model similarity ($\beta = -.36$, $p<.05$) and shared challenges ($\beta = -.49$, $p<.05$) were both negatively significantly related to generate task performance. In the full model, the relationships between generate task performance, team mental model similarity ($\beta = -.45$, $p<.05$), and shared challenges ($\beta = -.52$, $p<.05$) were also negative and significant. Therefore, Hypothesis 2 was partially supported when considering average level team cognition.

Hypothesis 3

Hypothesis 3 stated that Team cognition, a) task mental model similarity, b) team mental model similarity, c) shared vision, and d) social role agreement would be positively related to team viability. The ICC1 for team viability seen in Table 8 was .82, which meant that the vast majority of explainable variance was between teams with only 18% of the total variance as within team variance. Within team variance is the source that I explained in all my models since I had level 1 predictors. With such relatively low amount of within team variance to explain, I was not likely going to be able to detect significant effects at level 1. I present the best fitting model results for each team cognition variable individually as well as the full model in Table 25. Results showed that team mental model similarity had a negative and marginally significant relationship with team viability (β = -.2, p<.1) when entered individually. In the full model, however that relationship was no longer significant (β = -.19, p>.1). The pseudo R_2 for the final model was .43. Taken together, the results indicated that Hypothesis 3 was not supported.

Additional analysis

I conducted additional analysis to explore the relationship between team cognition and the choose facet of team performance using both the slopes leading up to the performance as well as the average team cognition approach. An ICC1 of .05 (Table 8) indicates that there is not much variance attributable to team membership. However, these analyses, like all preceding ones examined level 1 relationships so the variance I was attempting to detect was within team meaning the target I was trying to hit was the much larger portion of the variance pie. I still proceeded with the 2-level model accounting for the between team variance even though standard errors were not likely to be affected if I used a general linear model. The best fitting models using slopes of team cognition are presented in Table 26. Results showed that the slope of team mental model similarity was positively related to choose task performance (β = 4.13,

$p<.05$). However, the slope of combined shared vision had a marginally significant negative relationship to performance ($\beta = -.86$, $p<.1$). Separating out shared vision into goals and challenges showed that shared challenges were negatively related to choose task performance ($\beta = -.92$, $p<.05$). However, in the full model with team and task mental model similarity, shared goals, and shared challenges, there were no longer any significant relationships. The models using average team cognition to predict performance are in Table 27. The results showed that mean levels of team cognition were not significantly related to choose task performance.

Discussion

This chapter examined the impact that various team cognition constructs had on different facets of team performance and team viability. Additionally, this chapter investigated the difference in impact between trajectories of team cognitive similarity and average levels on team outcomes. I hypothesized that team cognitive similarity would be positively related to execute task performance since the task required coordinated action, a process that team cognitive similarity has been shown to improve in past studies (Mohammed et al., 2010). I also hypothesized that higher team cognitive similarity would lead to worse performance on the generate task, because a task that involves divergent thinking would suffer if members of the team were overly in sync. Finally, I hypothesized that team cognitive similarity would be positively related to team viability, because sharing an understanding of both living and working requirements makes coordination of activities more seamless, which makes the experience of working together more rewarding.

Hypothesis 1 was partially supported with team mental model similarity, and shared vision all positively predicting performance on the execute task performance. Task mental model similarity was positively related to the team's performance, but only when the effect was fixed for all teams. The full models showed that shared vision when it comes to the challenges of the day is the better predictor of execute task performance compared to shared goals. While the demonstration of team cognitive similarity improving performance on a coordination task is not groundbreaking, what makes these findings more impactful is that the team cognition content is not directly tied to what is being done in the execute task. Typically, team cognition literature demonstrates that cognitive similarity on task and teamwork aspects of the task being performed leads to better performance. These findings say that agreement on task and teamwork aspects of the mission in general and having a shared vision on the challenges over the entire day have an impact on one of the many tasks the team performs.

Hypothesis 2 was also partially supported with team mental model similarity and shared challenges being negatively related to performance on the generate task, which was a creative thinking task with no correct answers. For this task, average levels of team cognitive similarity were tied to performance, and the trajectory was not related. Again, the content of cognition for these constructs was not explicitly related to the task they performed, but rather the mission in general. What these results say is that the more the team agrees on mission teamwork aspects and daily challenges, on average, during the days leading up to this generate task, the worse they perform. The difference between average levels and trajectories of team cognitive similarity makes sense because team cognitive similarity is bad for creative thinking due to its detriment to divergent thought. In order for a team to be too in sync, they need high overall levels of team cognitive similarity as opposed to an increasing slope that, overall, is still low.

The additional analysis I performed was for performance on the choose task, which was a problem solving task with a documented correct answer. For this task, average levels of team cognitive similarity were not related to performance, but the trajectory of team mental model similarity was positively related to performance, and the trajectory of shared challenges was negatively related. Whereas performance on the creative thinking task was related to average levels of team cognitive similarity, it was the trend in these constructs that impacted performance on the problem solving task. The fact that shared challenges has the opposite effect as team mental model similarity could mean that increasing agreement on challenges is indicative of more salient or obstinate challenges, which are stressful, and would be bad for figuring out a task that requires cognitive focus. Overall, these results demonstrate two things: one is that what positively impacts one type of performance does not necessarily have the same relationship with other types of performance. The second is that sometimes, what is important is the average level of a construct over time, and sometimes the trajectory of the construct is more important.

Finally, Hypothesis 3 examining the relationship between team cognitive similarity and team viability was not supported. Team mental model similarity was somewhat negatively related to team viability (opposite than the hypothesized direction), and nothing else was related. The driving factor behind the lack of findings is likely due to the fact that most of the variance in team viability was between teams, and I was predicting within team variance in my models. A future question to ask would be, what factors for a team make them, on average, more viable than others?

This chapter contributes to the team cognition literature in four ways. First by examining multiple forms of team cognition at once, examining the interplay between constructs as well as teasing out the unique effects on consequences for each team cognition construct. Second, these constructs were examined over a long period of time in the context of an extended performance episode. Other research has looked at team cognition over time, and sometimes, even over longer periods of time. However, the performance episode(s) upon which team cognition in those scenarios was based make up a small portion of the individuals' focus in their lives. In other words, the ability to go home, separate from each other, and forget about their task makes those teams quite different in some ways from teams in this study that were forced to live together and constantly engaged in the extended performance episode of completing their mission. The third contribution is to identify aspects of team cognition that differentially predict performance dimensions. Given that previous studies show teams in isolation improve and decline on various aspects of performance (Larson et al., 2018), identifying team cognitive factors that may give rise to each would be useful for designing support measures for teams. Finally, the fourth contribution is to examine the impacts of team cognition trajectory compared with average levels of team cognition on team performance. A team's trend, whether it be increasing or decreasing in team cognitive similarity, says something different about what the team is going through than their average level of team cognitive similarity over the same time period. Past team cognition studies have used a limited number of measurements (usually one or two), so they were unable to use a trend over time as a predictor.

CHAPTER 5

CONCLUSION

In total, the aim of this dissertation was to make contributions to the team cognition literature through two paths. First, I organized the breadth of team cognition constructs under a unifying taxonomy that includes both established dimensions as well as new dimensions that highlight the unique circumstances of cohabitation and longevity. The setting for this research was unique compared to the office, lab, or other field teams currently examined in team cognition literature, and this dissertation supplies a roadmap for how team cognition constructs are differentiated given these unique circumstances. Second, I advanced understanding of the dynamic nature of team cognition as an emergent state using mixed methods. A purely quantitative approach would not have allowed for the breadth of team cognition that I ultimately captured in the shared vision construct. The quantitative approach used in Chapters 3 and 4 were revealing in the differentiation between types of team cognition and their patterns over time as well as their varying impacts on different types of team performance. Examining how these constructs unfold over time gives tremendous insight into the process of emergence and relationships between team cognition and team performance.

In Chapter 1 I established a framework classifying team cognition constructs.
I began with the dimensions of team cognition laid out by DeChurch and Mesmer-Magnus (2010) in their meta-analysis - content of cognition, nature of emergence, and form of cognition. However, there are other dimensions to the construct that apply more narrowly to the context of cohabitation and longevity. The dimensions I further classified team cognition on were: work-life relevance, dynamism, and consequence horizon. Previous research on team cognition has focused heavily on task related knowledge patterns that ultimately are specific to a single task. In

a context such as HERA, and space teams in general, it was critical to include a broader range of cognitive content because the team was continuously engaged in a variety of tasks and lived together for a long period of time. These dimensions, while not always relevant for short-term teams, or teams working together in a separate workplace, would be distinguishing characteristics of a construct in the case of long-term cohabitation. When a team of people cannot go home from their workplace, and are each others' only forms of social support, there is a broader range of what is important, when something is important, and how it changes over time. The importance of this chapter is to provide a roadmap for understanding team cognition, and perhaps, other team constructs in the context of cohabitation and longevity.

Chapter 2 was a study to develop a measure of shared vision in context using the first four HERA missions. It was important to develop this measure in order to gain a broader picture of the cognitive maps teams develop in these contexts. Furthermore, this approach allowed me to identify meaningful aspects of team cognition, like cohabitation, that are not captured in existing measures. Indeed, the "well-being" coding category is rich with examples of how the team is striving for and away from issues of fitness, mental health, loneliness, to name a few, that are not reflected in previous measures. The measure is an open-ended look at what members of the team see as their goals and challenges for a given day. This measure of shared vision was important to not only capture the specifics of the context, but also to capture the fluctuations in vision over time. This chapter, therefore, was able to establish a contextualized measure of how in sync were team members with regards to their vision for the future, as well as examine what was that vision. The content of what teams saw as their goals or challenges varied across work and life relevance, and shifted over the course of the mission.

Once a measure of shared vision in context was established, Chapter 3 examined the trends in shared vision as well as shared mental model similarity over time. In Chapter 3, I examined both general patterns on a grand scale across the mission, the fluctuations in that pattern in response to changes in the mission, and the impact that other stressors had on the level of cognitive similarity in the team. There were some interesting trends over time, although the patterns differ depending on the type of team cognition. In the case of mental model similarity (task and team), there was a positive linear trend in the fixed slopes models, but there was a lot of variability in the trends between missions. For shared vision, there was not much variability in trends between missions, but the fixed linear trend was still flat, and had more fluctuation on a day to day basis.

Examining the more detailed patterns in response to mission events (i.e., communication delay) also revealed differences across constructs. Returning to the taxonomy presented in Chapter 1, the differences between constructs demonstrated the role that work-life relevance plays in the evolution patterns of team cognitive similarity constructs. I found that work-related team cognitive similarity or team and task mental model similarity tended to converge early on in the mission followed by a flattening out, but life-related team cognitive similarity, on the other hand, or shared goals, followed a different pattern. Convergence was somewhat stable through most of the mission but increased at the onset of communication delay, and convergence accelerated following communication delay.

One of the contributions for this dissertation is to distinguish between different dimensions of team cognitive similarity. From previous research, we know that mental model similarity forms early on from getting to know one another and becoming familiar with the task or work being done. The different pattern followed by shared goals highlights the distinctiveness between these constructs in that shared goals is more reactive to the context or events occurring during the mission. Additionally, when examining interpersonal stressors throughout the mission, there was another divisive finding between the constructs. The density of the hindrance network (the degree to which team members thought each other made tasks difficult to complete) led to drop-offs in task mental model similarity, but led to increases in shared goals. While all of these constructs are measures of cognitive similarity amongst the team, the patterns over time, and fluctuations with response to stressors vary across constructs in line with the division between work-related and life-related team cognition.

When teams first get together, especially for an important mission, the initial convergence in terms of team cognition is more likely to be on work-related issues as those are probably more salient and, at least on the surface, more critical to mission success. Teams likely are more passive in their convergence on life-related team cognition in the beginning phases of a mission because there is not anything salient to draw the team's combined attention compared to the work that is required preparing or setting out on a mission. However, as the mission progresses, work-related cognitive maps require less maintenance as a team falls into a routine. Additionally, the longer a mission progresses, the more the cohabitation factors into the team dynamic. It could be argued that crews in the beginning of space missions might be somewhat similar to teams in an office or other typical work teams, but as the mission continues, the cohabitation begins to have more of an impact. This could be why life-related team cognitive similarity increases its trajectory later in the mission, because teams are more cognizant of the living dynamic later in a mission compared to when they are just starting out. A similar logic could be applied to the difference in response to interpersonal stress. As interpersonal stress increases, naturally that would harm the work dynamic because it would it is hard to be on the same page with someone who you think is making tasks difficult to complete. If two people were very much in sync, then there probably would not be the same interpersonal tension. With life-related team cognitive similarity, interpersonal stress could have a unifying effect because of the salience of interpersonal issues. When there is conflict in the team, it is hard not to notice it, especially in a cohabitation situation so therefore, interpersonal stress serves as a beacon of sorts for the team to converge on in terms of life-related cognitive similarity.

This chapter's contribution is in demonstrating patterns and fluctuations in team cognition over a long mission as well as illustrating that constructs of team cognition vary in these patterns. In order to get a full picture of a team's cognitive similarity over time, multiple angles must be considered. A mission to Mars or further out into space is certain to incur communication delays between the crew and mission control. This study implies that there is a critical period early in the mission for the crew to converge on their work-related mental maps. Regardless of the absolute level of team cognitive similarity, there was little development past the first third of the mission. There was also a period in the final portion of the mission during which crews tended to converge on life-related cognitive similarity. This chapter, therefore also demonstrates the importance of distinguishing between work-related and life-related team cognitive similarity. Not only do the patterns over time differ for work vs life-related constructs, but how they respond to stressors is also different with life-related constructs being much more reactive than work-related constructs to salient events such as the onset of communication delay. Life-related similarity also tended to increase with interpersonal stress whereas work-related cognitive similarity tended to decrease with such stress.

Finally, in Chapter 4, I examined the consequences of team cognition at multiple time points. Chapter 3 established some of the differences between constructs in their patterns over time, and this chapter looked to investigate how did different constructs of team cognition similarly or differentially impact different facets of performance. When it came to execute task performance - a task requiring coordinated action and communication, fixed effects for team and task mental model similarity, and shared vision showed positive relationships with performance. However, these effects had a lot of variation depending on the mission. In the best fitting models, team mental model similarity and shared challenges were the best predictors for performance on the execute task. However, when looking at a task that required creative thinking, team mental model similarity and shared challenges were negatively related to performance. Finally, when looking at team performance on a problem-solving task, team mental model similarity had a positive relationship with performance, but shared challenges had a negative relationship with performance. These three findings demonstrate two points - 1) not all types of performance are the same, and 2) that team cognition constructs can vary in their relation to team outcomes even if they influence team outcomes similarly at other times.

A second conclusion drawn from this chapter is the difference in the relationship between team cognitive similarity and performance depending on if I used average team cognitive similarity or trend in cognitive similarity leading up to the performance. When it came to creative thinking performance, the linear trend in cognitive similarity amongst the team leading up to the performance episode was not an impactful factor, but average levels of team cognitive similarity were impactful. Meanwhile, with the problem-solving task, it was the trends in team cognitive similarity that were impactful rather than average levels. This distinction is indicative of the complex relationships that can be uncovered by examining team cognition over time. This conclusion reveals implications for the dynamism of team cognitive similarity constructs. Previous research on team cognition takes into consideration the content and similarity of team cognition, but this dissertation highlights a need to also consider the growth trajectory as an additional dimension. Content and similarity tell what is being shared and how shared it is, but the current findings reveal the similarity trend - is it increasing or decreasing - more fully predicts performance.

While this chapter did not study the dynamism of team cognitive similarity constructs, the conclusions drawn from these results imply that dynamism of team cognitive similarity would impact the team cognition to team performance relationship. When mean levels of team cognitive similarity are important for performance such as the case for creative thinking tasks, a more stable construct would likely be more strongly related than volatile constructs because the mean is not an accurate representation of a construct that is fluctuating to extremes. However, for performance that is more related to the trajectory of team cognitive similarity, gradually changing constructs are likely better suited for prediction that constructs that do not fluctuate at all or constructs that fluctuate too much. Dynamism is really a larger phenomenon of human relationships reflecting the stability or volatility of interactions. The results from this chapter demonstrate its importance for team cognitive similarity variables by showing that patterns matter in the team cognition to performance relationship so understanding how much a construct fluctuates over time would give crucial insight into how it could relate to performance and how to intervene as well.

Implications

These studies, while conducted in a unique setting, have major implications for the broader field of teams science. With regards to research, these studies have made significant strides in the conceptualization of team cognition as a dynamic evolving construct. In Chapter 1, I framed team cognition as a multifaceted construct, and subsequent results demonstrated the need to differentiate based on the characteristics of the cognitive construct being considered. In terms of advancing teams science, the studies in this dissertation answer the questions: 1) How do distinguishing features of team cognitive similarity constructs relate to their evolution over time? and 2) How do distinguishing features of team cognitive similarity constructs relate to their impact on performance?

In Chapter 3, I show that one distinguishing feature of team cognition that is relevant to the evolution over time is the work-life relevance of the construct. work-related team cognition variables showed convergence early on in the mission compared to life-related team cognition, which showed convergence later in the mission. What this implies is that the trajectory over time for the evolution of team cognition has something to do with what aspect of the team dynamic the team cognition is tapping into. For constructs that are more concerned with the task work of a team, there is an early period of convergence followed by a somewhat static trajectory. For constructs that are more related to how a team lives with each other or functions outside of a task context, then there is more fluctuation early on with convergence accelerating later in a team’s lifespan. For the second question, I look more to the dynamism of different team cognition constructs. Chapter 4 indicates there are different relationships between team cognition and performance depending on if the average levels are measured versus the trajectory leading up to the task. Therefore, the dynamism of a construct or tendency to fluctuate over time has implications for how to manipulate team cognition to best serve the task being performed. For tasks that are impacted by average levels of team cognitive similarity, stable constructs are easiest to maintain at a high level once developed, but more volatile constructs are harder to predict. For tasks that are impacted by the trends in cognitive similarity, it is likely harder to make shifts in highly stable constructs once established, but more gradually changing constructs would be easier to influence in the right direction.

The unique context, and depth of these studies in this dissertation have implications for space psychology as well as teams science in general. For space psychology and space agencies in particular, this dissertation answers four questions: 1) How does communication delay impact crew cognition? 2) How does crew cognition impact performance? 3) What should be measured on a space mission? And 4) When should we measure it? In answer to the first question, my studies have shown that task and team mental model similarity increase leading up to the communication delay period, but then the growth slows and the trajectory flattens during and after communication delay. For shared goals, however, similarity spikes at the onset of communication delay, but the trajectory remains mostly flat leading up to and during communication delay with growth in shared goals accelerating after the communication delay period. These results imply that there is a critical period in the early part of the mission for converging on task and team mental models, but that convergence on shared goals is more dependent on the events occurring and growth accelerates later in the mission.

The second question of how does crew cognition impact performance is answered in Chapter 4. The simple answer is it depends on what type of task the crew is performing. Day-of measurements for team mental model similarity and shared challenges positively impact execute task performance. However, for creative thinking tasks, average levels of team mental model similarity and shared challenges in the period leading up to the task negatively impact performance. Finally, for problem-solving tasks, trends in team mental model similarity and shared challenges impact performance with team mental model similarity positively impacting and shared challenges negatively impacting performance. These results imply that there can be different impacts of team cognition on performance depending on the type of team cognition, the type of task being performed, and the measurement paradigm (day-of, averages, or trends). These results also give an answer to the third question of what should space agencies measure. In terms of predicting performance, which is the main goal for a space mission, space agencies would want to focus on team mental model similarity and shared challenges as those were the most impactful factors for performance. As for when they should be measured (fourth question), the results from Chapter 3 show that convergence on mental model similarity occurs early on in the mission so that would be a critical period to monitor that development. However, the results in Chapter 4 indicate that day-of, average levels, and trends in these variables are all important so knowing how they develop early, while important, is still not going to be enough for predicting how a crew will perform. To maintain an accurate picture of a crew's cognition as relevant for the crew's performance, team mental models and shared challenges would need to be monitored in regular intervals at least three or four times leading up to a major performance episode in order to have a reliable estimate of the mean and trend.

Space travel is just one among many possible contexts in which teams are spending considerable amounts of time living and working together. These results could also be applied to theatre troupes or orchestras who spend weeks sometimes in extremely intense rehearsal schedules forced to continuously interact with the same people day after day in a stressful environment. In a theatre troupe or movie crew, for instance, there are often times when multidisciplinary teams are assembled to give input on particular problems, and there are also times when there are specific issues that require a team of specialists from the same discipline. In these cases, team cognition and the relationships with different types of task performance is extremely relevant since if a team of specialists with the same background are trying to come up with a creative solution, there might be too much synchronization to allow for an appropriate level of divergent thinking. On the other hand, a multidisciplinary team assembled to tackle a problem or execute a complicated shot would probably benefit from taking a moment for everybody to get on the same page and understand how each person sees the challenges of the task and is approaching the team interaction.

The office team or classroom team is a common object of study for team cognition research, and this dissertation also has implications for managing these teams as well with the main questions for managers being: 1) How should managers intervene on team cognition? and 2) When is it important to intervene? Managers should be aware of the type of task their team is performing, and keep in mind that, while the team might be on the same page, continuously fostering or developing team cognition is still beneficial. Teams in an office often have to perform different types of tasks all in the same week or even the same day. Therefore, managers might not intervene or try to change the level of team cognition since the impacts of that intervention might have negative effects if the team performs. Instead, their intervention would be around mitigating the performance risks given the state of team cognition at the time. If a team has been working together for years and doing the same sort of work, but now needs to do something more creative, rather than try to decrease the level of cognitive similarity in the team, a manager's intervention should be aimed at mitigating the possibly excessive level of convergent thought by introducing some sort of reflexivity or deliberately divergent thinking role in the team. If a team is somewhat new working together and they have to perform a highly coordinated task, then an intervention would most likely be aimed at structuring and forcing increased team process such as communication protocols or structured check-ins to mitigate the lack of implicit coordination.

Limitations

In drawing conclusions from this particular study, certain limitations should be kept in mind. First, the teams studied under conditions of cohabitation and longevity were all stationed in the same analogue. This might call into question the generalizability of the results found in the present effort. The perspectives gleaned from these conditions were meant to be representative of environmental characteristics that a crew going to Mars would face. There are several other contexts in which teams must live together for long periods of time that vary in certain key features such as team size, degree of isolation and confinement, and the presence or absence of other extreme conditions. The differences between these contexts could mean the trends and relationships between variables play out differently. However, the context I studied was ideal for its controlled conditions that allowed me to isolate measurements and implement set performance episodes.

In a similar vein, the limited sample size might also cause concern in terms of generalizability. While the depth of the data is a major proponent of the studies, collecting month or more long missions worth of data in a unique setting such as this space analogue poses time restrictions. Indeed, many of the effects found had significant variation across teams meaning that the average effect or intercept is less informative than understanding what makes teams different. A larger sample size would be helpful in determining what caused both mean differences across teams as well as cross-level moderating factors that influenced level one relationships. As it happens, the number of teams I studied was not large enough to examine between team differences.

Finally, a methodological challenge for a longitudinal study meant to continuously monitor team states is the repeated use of the same survey over and over again. The participants not only took my survey just about every day, but they were also constantly taking surveys for several other principal investigators. Such a strenuous barrage of surveys combined with the confined and isolated conditions is bound to lead to survey fatigue. Indeed, some of the crew members' frustrations and fatigue with surveys and tasks came through in their open ended responses to the goals and challenges for the day.

A related limitation to these studies is the use of surveys in general, especially given the long-term context where the crew saw the same surveys every day. There is the possibility that participants gradually remember more and more the answers they put the previous day, and revert to those values rather than evaluating their current position for that day. For mental model measurements that were meant to capture a general cognitive map of tasks and teamwork in HERA (rather than connect to a specific task), memory for past answers, and careless answering could certainly play a role. Connections between concepts may not appear to change all that much from day to day, leading participants to decline in the level of nuance or thought they give the survey over time, becoming more likely to simply put what they recall inputting the previous day.

Future steps

The biggest remaining question born from these studies that future research ought to examine is the differences between teams. When teams are spending long periods of time spending all of the time with each other both working and living, the characteristics unique to that team are bound to build and strengthen over time. The results of these studies have shown that there are differences that exist between teams both in their mean levels of team cognition and team outcomes, the patterns in team cognition over time, and the relationships between team cognition and team outcomes. Future research ought to take these differences into consideration when designing studies in that they should include predictors at multiple levels of analysis and be sure to collect a sample that is large enough to detect higher level differences.

Future research should also consider different contextual features by comparing different analogues or combine research from multiple sites that differ in the types of extreme circumstances teams face. In HERA, teams face extreme confinement and isolation in that they are stuck together for a month or more in a small space with very limited contact with people outside themselves and mission control. However, HERA is an extremely controlled experimental tool, so features such as extreme weather conditions or random malfunctions, or anything else that would raise the stakes are absent from this testbed. Antarctic research stations, the international space station, and other expeditions have the potential to reveal how different environmental factors influence the patterns and influence of team states over time differently than this highly controlled setting.

This dissertation, while extensive in its examination of team cognition, hopefully serves as a jumping off point for future studies of team cognitive and other emergent states. For teams that are spending long periods of time living and working together, there is still so much left to understand with regards to the evolving nature of team states and processes. However, even with regard to team cognition, there are still constructs to unpack and examine such as transactive memory systems.

A trip to Mars for humans is imminent, and research such as this dissertation sheds light on the team challenges a crew may face. While the possibility of transporting alien life to end the human species as Nick Kanas writes in his novel is likely science fiction, there are plenty of real issues that a team journeying to Mars must tackle. Being in sync with each other as well as fostering continuous development of cognitive similarity will be crucial for success on such a mission.

Table 1

Taxonomy characteristics and dimensions

Characteristics	Definition	Dimensions
	Characteristics currently covered in the literature	
Content	The type of knowledge represented.	Taskwork & Teamwork
Nature of emergence	The pattern that cognition at the individual level manifests at the team level.	Compositional & Compositional
Form of cognition	The way cognition is elicited and represented.	Perceptual, Structured, & Interpretive
	Characteristics specific to cohabitation and longevity	
Work-life relevance	Cognition about the demands of cohabitation that are most relevant to team members.	Work relevant & Living relevant
Dynamism	The extent and frequency with which team cognition fluctuates.	Stable, Gradual, Volatile
Consequence horizon	The lag between observation of team cognition and its impact on team outcomes.	Immediate, Delayed, & Extended,

Table 2

Taxonomy of team cognition constructs in cohabitating teams

Dimension	Shared Mental Models	Transactive Memory System	Informal Social Role Structure	Shared Vision
Content of cognition	Task & Team	Task	Team	Task & Team
Nature of emergence	Compositional	Compilational	Compilational	Compositional
Form of cognition	Structured	Structured	Structured	Interpretive
Work-life relevance	Work	Work	Life	Work & Life
Dynamism	Gradual	Gradual	Static	Volatile
Consequence horizon	Immediate	Immediate	Extended	Delayed

Note. Shaded cells indicate that dimensions and constructs established in the team cognition literature. The white cells signify expansion of team cognition constructs and dimensions into the context of cohabitation and longevity.

Table 3

Category Labels and Definitions of Goals and Challenge Responses

Superordinate Category	Second Order Category	First-Order Category	Definition
Non-Work	Well-being	General living	Adapting to the environment, weekend activities, relaxation, and other statements about non-task, non-scheduled activities
		Physical health	Physical comfort, exercising, and PMCs (private medical conferences)
		Mental health	Attitude, morale, mood and PPCs (private psychological conferences)
		Sleep	Sleep behaviors or schedules including sleep deprivation, taking naps, wanting to sleep, fatigue, etc.
	Social	Interpersonal relationships within crew	Relationship dynamics with other crew members such as cohesion, team morale, or team building activities
		Interpersonal relationships between crew and mission control	Crew to mission control relationship dynamics
		Communication	Communication with each other or with MCC. This includes general statements about communication patterns or processes, or communication delays
		Contact with people outside NASA	Any sort of communication not involving mission control or each other. These goals usually involve PAOs (public affairs operations) or PFCs (Private family conferences)
Work	Mission Tasks	General task completion	General comments about getting things done, but without mentioning any tasks in particular
		Asteroid exploration mission	The overarching asteroid exploration mission the HERA crew is tasked with involving travel to the asteroid, exploration and collection of samples, and the return trip
		Campaign level tasks	NASA scheduled (or unscheduled) tasks that are not part of the asteroid exploration mission, but are not connected to any outside research institution
		Researcher-implemented task	Specific tasks or surveys implemented in the HERA schedule by a team affiliated with an outside research institution such as a university
	Mission Logistics	Schedule	Awareness of the schedule or staying on time or completing tasks on time/efficiently.
		Workload	Focus is on the amount of work (high or low) in the schedule, but not necessarily any time component mentioned
		Equipment	Maintenance and checking of all systems and equipment

Table 4

Average Goal and Challenge Category Rankings Across Missions

Rank	Goal Category	% of Total Goals (cumulative) *N* = 690	Challenge Category	% of Total Challenges (cumulative) *N* = 490
1	Asteroid exploration task	22.31 (22.31)	Schedule	16.87 (16.87)
2	General task completion	14.73 (37.04)	Sleep	11.38 (28.25)
3	Campaign level tasks	11.62 (48.66)	Equipment	10.41 (38.66)
4	Schedule	11.44 (60.10)	Workload	9.08 (47.74)
5	Researcher implemented tasks	9.47 (69.57)	Interpersonal relationships within crew	8.44 (56.17)
6	General living	8.78 (78.35)	Asteroid exploration mission	7.69 (63.86)
7	Sleep	4.50 (82.86)	Mental health	6.64 (70.50)
8	Interpersonal relationships within crew	3.37 (86.23)	General task completion	6.54 (77.05)
9	Contact with people outside of NASA	2.93 (89.16)	General living	6.11 (83.16)
10	Equipment	2.49 (91.65)	Communication	6.06 (89.22)
11	Communication	2.42 (94.07)	Researcher implemented tasks	4.95 (94.17)
12	Mental health	2.41 (96.48)	Campaign level tasks	4.35 (98.52)
13	Physical health	1.84 (98.31)	Interpersonal relationships between crew and mission control	0.92 (99.44)
14	Workload	1.43 (99.75)	Physical health	0.56 (100)
15	Interpersonal relationships between crew and mission control	0.25 (100)	Contact with people outside NASA	0

Table 5

Most Frequently Cited Goal Response Category

Crew	**Pre Delay**	**Comm Delay**	**Post Delay**
1	Task	Task	Well-Being
2	Task	Task	Task
3	Task	Task	Task
4	Task	Task	Well-Being

Table 6

Most Frequently Cited Challenge Response

Crew	**Pre Delay**	**Comm Delay**	**Post Delay**
1	Logistics	Task	Logistics
2	Task	Logistics	Logistics/ Well-Being
3	Logistics	Logistics	Well-Being
4	Well-Being	Logistics/ Interpers.	Well-Being

Table 7

Means, standard deviations, and intercorrelations among all study variables

Variable	*M*	*SD*	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1. Task MM similarity	.60	.09	(0.99)									
2. Team MM similarity	.63	.10	0.21	(0.99)								
3. Shared vision	.24	.14	-0.06	0.09	(0.88)							
4. Shared goals	.31	.20	-0.11	0.22	0.71	(0.80)						
5.Shared challenges	.24	.24	0.10	-0.15	0.65	0.02	(0.84)					
6. Social role agreement	.67	.09	-0.17	-0.09	-0.02	0.15	-0.14	(0.87)				
7. Team viability	6.02	.87	-0.14	-0.33	-0.06	-0.06	0.02	-0.24	(0.88)			
8. Execute performance	.61	.32	0.14	0.31	0.10	0.16	0.07	-0.15	0.45	(0.96)		
9. Generate performance	24.74	7.39	-0.40	-0.61	-0.31	-0.30	-0.01	0.38	0.06	-0.56	(0.82)	
10. Choose performance	-44.13	11.77	0.01	0.12	-0.15	-0.11	-0.17	-0.09	-0.31	-0.52	0.15	(0.04)

Note. ICC2s are along the diagonal as reliability estimates for the group means over time. Team viability was the only variable calculated using a multi-item psychometric scale, so the reliability estimate used for team viability is the Cronbach's alpha across each time period the variable was measured. MM refers to mental model.

Table 8

Variance attributable to team (ICC1) in a 2-level structure (time nested in team)

Variable	**ICC1**	**ICC2**
Task MM similarity (k = 30.55)	0.79	0.99
Team MM similarity (k = 30.55)	0.82	0.99
Shared vision (k = 29.22)	0.17	0.88
Shared goals (k = 29.22)	0.11	0.80
Shared challenges (k = 29.22)	0.13	0.84
Social role agreement (k = 8.44)	0.45	0.87
Performance Constructs		
Viability (k = 8.44)	0.82	0.98
Execute (k = 3.33)	0.58	0.96
Generate (k = 3.33)	0.59	0.82
Choose (k = 3.33)	0.05	0.04

Note. Team cognitive similarity was assessed at the dyad level then averaged to the team level. Similarity was measured multiple times each mission (26 times for C3 and 38 times for C4). K is the average group size (average number of measurements across teams), which differs depending on the variable. The higher the ICC1, the greater the proportion of variance attributable to team membership compared to variance attributable to time.

Table 9

Variance attributable to team (ICC1) in a 3-level structure (time nested in individual nested in team)

	Week 1 (9 crews)	Week 2 (9 crews)	Week 3 (9 crews)	Week 4 (8 crews)	Week 5 (4 crews)	Week 6 (4 crews)
Task MM similarity	0.41	0.40	0.46	0.47	0.45	0.47
Team MM similarity	0.39	0.43	0.43	0.47	0.48	0.48
Shared goals	0	0.07	0.05	0.03	0.19	0.17
Shared challenges	0	0.10	0.11	0	0.10	0.12
Social role agreement	0.08	0.47	0.27	0.39	0.43	0.37

Note. Team cognitive similarity was assessed at the dyad level then averaged to the individual level and the team level. Similarity was assessed multiple times per mission and separated out by week. The higher the ICC1, the greater the proportion variance attributable to team membership compared to variance attributable to the individual or time for the given week. k ranges from 21-32 for daily measures and k ranges from 8-12 for social role agreement.

Table 10

Variance attributable to mission week (ICC1) in a 2-level structure (team nested in time)

Variable (k = 7.17)	ICC1	ICC2
Task MM similarity	0	0
Team MM similarity	0	0
Shared vision	0	0
Shared goals	0.12	0.48
Shared challenges	0	0
Social role agreement	0.06	0.29

Note. Team cognitive similarity was assessed at the dyad level then averaged to the team level. Similarity was measured multiple times each mission (26 times for C3 and 38 times for C4). Data was then averaged for each week of the mission. K = 7.17, which is the average group size (average number of measurements across teams). The higher the ICC1, the greater the proportion of variance attributable to the week of the mission compared to team membership.

Table 11

Growth models for task mental model similarity, df = 265

Level and Variable	Null	Random Intercept Fixed Linear Slope	Random Intercept Fixed Linear and Quadratic Slope	Random Intercept and Random Linear Slope
Level 1				
Intercept	-0.04 (0.33)	-0.33 (0.33)	-0.40	-0.25
Linear		0.02* (0.003)	0.03* (0.01)	0.01 (0.01)
Quadratic			0 (0.00)	
Variance components				
Within-team (L1) variance	0.26	0.23	0.23	0.16
Intercept (L2) variance	0.96	0.95	0.94	0.86
Slope (L2) variance				0.001
Intercept-slope (L2) covariance				-0.10
Additional information				
ICC1	0.79			
-2 log-likelihood	455.55	427.03	439.65	344.93*
Number of estimated parameters	3	4	5	6
Pseudo R_2	0	0.13	0.13	0.41

*Note. Numbers for fixed parameters are beta coefficients based on standardized z scores with standard errors in parentheses, * = p < .05. A * following the -2 log-likelihood indicates that the random slopes model is a better fit than the random intercepts model with the same fixed parameters. Pseudo R_2 is the proportion of within team (L1) variance explained by the model.*

Table 12

Growth models for team mental model similarity, df = 265

Level and Variable	Null	Random Intercept Fixed Linear Slope	Random Intercept Fixed Linear and Quadratic Slope	Random Intercept and Random Linear Slope
Level 1				
Intercept	0.06 (0.31)	-0.07 (0.32)	-0.14	-0.06
Linear		0.01* (0.003)	0.02* (0.01)	0.01 (0.01)
Quadratic			0 (0.00)	
Variance components				
Within-team (L1) variance	0.19	0.18	0.18	0.11
Intercept (L2) variance	0.85	0.87	0.87	0.84
Slope (L2) variance				0.001
Intercept-slope (L2) covariance				-0.28
Additional information				
ICC1	0.82			
-2 log-likelihood	372.31	370.76	383.66	250.52*
Number of estimated parameters	3	4	5	6
Pseudo R^2	0	0.04	0.04	0.44

*Note. Numbers for fixed parameters are beta coefficients based on standardized z scores with standard errors in parentheses, * = p < .05. A * following the -2 log-likelihood indicates that the random slopes model is a better fit than the random intercepts model with the same fixed parameters. Pseudo* R^2 *is the proportion of within team (L1) variance explained by the model.*

Table 13

Growth models for shared vision (combined goals and challenges), df = 254

Level and Variable	Null	Random Intercept Fixed Linear Slope
Level 1		
Intercept	0.02 (0.15)	0.09 (0.17)
Linear		-0.004 (0.006)
Variance components		
Within-team (L1) variance	0.82	0.82
Intercept (L2) variance	0.17	0.17
Additional information		
ICC1	0.17	
-2 log-likelihood	715.57	723.33
Number of estimated parameters	3	4
Pseudo R_2	0	0

*Note. Only the random intercept fixed linear slope is displayed due to the lack of significance for the linear term. Numbers for fixed parameters are beta coefficients based on standardized z scores with standard errors in parentheses, * = p < .05. Pseudo R_2 is the proportion of within team (L1) variance explained by the model.*

Table 14

Discontinuous growth models for task mental model similarity, df = 261

	Relative Change		Absolute Change	
Level and Variable	Random Intercept	Random Slopes (Time and Trans1)	Random Intercept	Random Slopes (Time and Trans1)
Level 1				
Intercept	-0.54 (0.34)	-0.45 (0.33)	-0.49 (0.34)	-0.43 (0.38)
Time	0.06* (0.01)	0.04* (0.01)	0.05* (0.01)	0.04 (0.03)
Trans1	-0.17 (0.13)	-0.06 (0.17)	-0.06 (0.13)	-0.03 (0.09)
Recovery1	-0.04† (0.02)	-0.04* (0.02)	0.01 (0.02)	0.01 (0.01)
Trans2	-0.62* (0.20)	-0.39* (0.15)	-0.01 (0.12)	0.03 (0.08)
Recovery2	-0.05* (0.02)	-0.05* (0.01)	0.02 (0.01)	0.01 (0.01)
Variance components				
Within-team (L1) variance	0.22	0.11	0.23	0.09
Intercept (L2) variance	0.98	0.94	0.97	1.27
Time slope (L2) variance		<0.001		0.01
Trans1 slope (L2) variance		0.17		0.02
Additional information				
-2 log-likelihood	430.56	283.80*	440.24	235.11*
Number of estimated parameters	8	13	8	13

*Note. Numbers for fixed parameters are beta coefficients based on standardized z scores with standard errors in parentheses, * = p < .05,* † = p < .1. *A * following the -2 log-likelihood indicates that the random slopes model is a better fit than the random intercepts model with the same fixed parameters. The random effects in the random slopes models are indicated in parentheses in the heading. Correlations between the random components have been left out of this table.*

Table 15

Discontinuous growth models for team mental model similarity, df = 261

	Relative Change		Absolute Change	
Level and Variable	Random Intercept	Random Slopes (Time and Trans1)	Random Intercept	Random Slopes (Time)
Level 1				
Intercept	-0.21 (0.32)	-0.19 (0.33)	-0.21 (0.32)	-0.19 (0.31)
Time	0.03* (0.01)	0.03* (0.01)	0.03* (0.01)	0.03 (0.03)
Trans1	0.09 (0.12)	0.12 (0.12)	0.12 (0.12)	0.13 (0.09)
Recovery1	-0.05* (0.02)	-0.05* (0.01)	-0.02 (0.02)	-0.02 (0.01)
Trans2	-0.34† (0.18)	-0.31* (0.01)	-0.06 (0.11)	-0.04 (0.09)
Recovery2	-0.02 (0.02)	-0.02† (0.01)	0.01 (0.01)	0.01 (0.01)
Variance components				
Within-team (L1) variance	0.18	0.09	0.18	0.11
Intercept (L2) variance	0.90	0.85	0.88	0.84
Time slope (L2) variance		0.001		0.006
Trans1 slope (L2) variance		0.05		
Additional information				
-2 log-likelihood	378.90	236.92*	379.62	275.76*
Number of estimated parameters	8	13	8	10

*Note. Numbers for fixed parameters are beta coefficients based on standardized z scores with standard errors in parentheses, * = p < .05,* † = p < .1. *A * following the -2 log-likelihood indicates that the random slopes model is a better fit than the random intercepts model with the same fixed parameters. The random effects in the random slopes models are indicated in parentheses in the heading. Correlations between the random components have been left out of this table.*

Table 16

Discontinuous growth models for shared vision (combined goals and challenges), df = 250

Level and Variable	Relative Change Random Intercept	Absolute Change Random Intercept
Level 1		
Intercept	0.19 (0.21)	0.18 (0.22)
Time	-0.02 (0.02)	-0.02 (0.03)
Trans1	0.24 (0.26)	0.21 (0.25)
Recovery1	-0.02 (0.04)	-0.04 (0.04)
Trans2	0.04 (0.40)	-0.16 (0.24)
Recovery2	0.05 (0.04)	0.03 (0.03)
Variance components		
Within-team (L1) variance	0.82	0.82
Intercept (L2) variance	0.17	0.17
Additional information		
-2 log-likelihood	731.88	731.90
Number of estimated parameters	8	8

Note. Numbers for fixed parameters are beta coefficients based on standardized z scores with standard errors in parentheses, * = $p < .05$, † = p < .1.

Table 17

Discontinuous growth models for shared vision (goals), df = 250

Level and Variable	Relative Change Random Intercept	Absolute Change Random Intercept
Level 1		
Intercept	0.15 (0.19)	0.15 (0.21)
Time	-0.02 (0.02)	-0.03 (0.03)
Trans1	0.58* (0.26)	0.55* (0.26)
Recovery1	-0.02 (0.04)	-0.05 (0.04)
Trans2	0.001 (0.40)	-0.24 (0.24)
Recovery2	0.09* (0.04)	0.06* (0.03)
Variance components		
Within-team (L1) variance	0.87	0.87
Intercept (L2) variance	0.11	0.12
Additional information		
-2 log-likelihood	743.14	731.90
Number of estimated parameters	8	8

Note. Numbers for fixed parameters are beta coefficients based on standardized z scores with standard errors in parentheses, * = *p* < *.05,* † = p < .1.

Table 18

Discontinuous growth models for shared vision (challenges), df = 250

Level and Variable	Relative Change Random Intercept	Absolute Change Random Intercept
Level 1		
Intercept	-0.07 (0.20)	-0.09 (0.21)
Time	0.01 (0.02)	0.01 (0.03)
Trans1	-0.17 (0.26)	-0.18 (0.26)
Recovery1	-0.02 (0.04)	-0.01 (0.04)
Trans2	-0.01 (0.41)	0.05 (0.25)
Recovery2	-0.01 (0.04)	-0.002 (0.03)
Variance components		
Within-team (L1) variance	0.87	0.87
Intercept (L2) variance	0.13	0.13
Additional information		
-2 log-likelihood	743.71	743.43
Number of estimated parameters	8	8

Note. Numbers for fixed parameters are beta coefficients based on standardized z scores with standard errors in parentheses, * = $p < .05$, † = $p < .1$.

Table 19

The impact of breadth of daily challenges on team cognitive similarity, df = 253

Level and Variable	Task Mental Mode Similarity	Team Mental Model Similarity	Shared Vision (Goals)
Level 1			
Intercept	-0.39 (0.32)	-0.13 (0.32)	0.27 (0.22)
Time	0.02* (0.003)	0.01 (0.002)	0 (0.01)
Breadth of daily challenges	-0.004 (0.02)	0.01 (0.02)	-0.06 (0.04)
Variance components			
Within-team (L1) variance	0.22	0.19	0.89
Intercept (L2) variance	0.83	0.87	0.12
Additional information			
ICC1	0.79	0.82	0.11
-2 log-likelihood	408.08	372.77	745.19
Number of estimated parameters	5	5	5
Pseudo R_2	0.15	0	0.001

Note. Breadth of daily challenges is the sole predictor in these models and each column represents a different dependent variable. Numbers for fixed parameters are beta coefficients based on standardized z scores with standard errors in parentheses, * = $p < .05$, † = $p < .1$. *Pseudo* R_2 *is the proportion of within team (L1) variance explained by the model.*

Table 20

The impact of status conflict on team cognitive similarity, df = 65

Level and Variable	Task Mental Mode Similarity	Team Mental Model Similarity	Shared Vision (Goals)	Shared Vision (Challenges)
Level 1				
Intercept	-0.42 (0.32)	-0.15 (0.32)	0.09 (0.18)	0.02 (0.18)
Time	0.09* (0.02)	0.05* (0.02)	-0.02 (0.03)	0 (0.03)
Status conflict	-0.07 (0.10)	-0.12 (0.09)	-0.003 (0.11)	-0.13 (0.11)
Variance components				
Within-team (L1) variance	0.21	0.19	0.66	0.40
Intercept (L2) variance	0.85	0.84	0.02	0.14
Additional information				
ICC1	0.76	0.79	0.03	0.22
-2 log-likelihood	135.35	128.51	194.45	165.21
Number of estimated parameters	5	5	5	5
Pseudo R^2	0.21	0.06	0	0.01

*Note. Status conflict is the sole predictor in these models and each column represents a different dependent variable. Numbers for fixed parameters are beta coefficients based on standardized z scores with standard errors in parentheses, * = p < .05,* † = p < .1. *Pseudo R^2 is the proportion of within team (L1) variance explained by the model.*

Table 21

The impact of hindrance network density on team cognitive similarity, df = 65

Level and Variable	Task Mental Mode Similarity	Team Mental Model Similarity	Shared Vision (Goals)	Shared Vision (Challenges)
Level 1				
Intercept	-0.14 (0.35)	-0.09 (0.33)	-0.15 (0.20)	0.04 (0.22)
Time	0.09* (0.02)	0.04* (0.02)	-0.03 (0.03)	-0.01 (0.03)
Hindrance network density	-1.18* (0.52)	-0.08 (0.52)	1.16† (0.60)	0.18 (0.65)
Variance components				
Within-team (L1) variance	0.19	0.19	0.65	0.41
Intercept (L2) variance	0.93	0.82	0	0.12
Additional information				
ICC1	0.76	0.79	0.03	0.22
-2 log-likelihood	127.62	126.43	187.59	162.92
Number of estimated parameters	5	5	5	5
Pseudo R_2	0.27	0.04	0	0

*Note. Hindrance network density is the sole predictor in these models and each column represents a different dependent variable. Numbers for fixed parameters are beta coefficients based on standardized z scores with standard errors in parentheses, * = p < .05,* † = p < .1. *Pseudo R_2 is the proportion of within team (L1) variance explained by the model*

Table 22

The impact of team cognitive similarity on execute task performance

Level and Variable	Task Mental Mode Similarity (*df* = 159)	Team Mental Model Similarity (*df* = 159)	Shared Vision (Goals) (*df* = 151)	Shared Vision (Challenges) (*df* = 151)	Social Role Agreement (*df* = 65)	Full Model (*df* = 148)
Level 1						
Intercept	-0.82* (0.28)	-0.85* (0.24)	-0.81* (0.27)	-0.79* (0.27)	-0.39 (0.36)	-0.80* (0.25)
Time	0.07* (0.01)	0.08* (0.01)	0.08* (0.01)	0.08* (0.01)	0.09* (0.03)	0.08* (0.01)
Task mental model similarity	0.07 (0.17)					-0.05 (0.12)
Team mental model similarity		0.21 (0.13)				0.28† (0.14)
Shared goals			0.06 (0.04)			0.05 (0.04)
Shared challenges				0.09† (0.05)		0.10* (0.05)
Social role agreement					0.10 (0.10)	
Variance components						
Within-team (L1) variance	0.24	0.25	0.26	0.26	0.41	0.23
Intercept (L2) variance	0.59	0.43	0.59	0.62	0.93	0.41
Task MM Slope (L2) variance	0.18					0.06
Team MM Slope (L2) variance		0.12				0.13
Additional information						
ICC1	0.58	0.58	0.58	0.58	0.58	0.58
-2 log-likelihood	294.74	285.99	286.77	285.37	179.57	274.30
Number of estimated parameters	7	7	5	5	5	13
Pseudo R_2	0.46	0.45	0.42	0.42	0.16	0.49

*Note. Numbers for fixed parameters are beta coefficients based on standardized z scores with standard errors in parentheses, * = p < .05,* † = p < .1. *Pseudo R_2 is the proportion of within team (L1) variance explained by the model. Only best fitting models are reported here so task and team mental model similarity models have random slopes while shared goals and challenges and social role agreement are random intercept model*

Table 23

The impact of team cognitive similarity slopes on generate task performance

Level and Variable	Task Mental Mode Similarity (df = 17)	Team Mental Model Similarity (df = 17)	Shared Vision (Goals) (df = 17)	Shared Vision (Challenges) (df = 17)	Full Model (df = 14)
Level 1					
Intercept	0.17 (0.25)	0.21 (0.25)	0.18 (0.25)	0.19 (0.25)	0.20 (0.26)
Time 1	0.03 (0.17)	0 (0.13)	0 (0.14)	-0.01 (0.14)	0.04 (0.17)
Time 2	-0.93* (0.15)	-0.98* (0.14)	-0.94* (0.15)	-0.94* (0.15)	-0.98* (0.15)
Time 3	0.36† (0.20)	0.32† (0.18)	0.35† (0.19)	0.33 (0.19)	0.34 (0.19)
Task mental model similarity	3.01 (7.96)				3.53 (8.74)
Team mental model similarity		-11.43 (7.34)			-12.16 (8.96)
Shared goals			-0.40 (0.72)		-0.74 (0.86)
Shared challenges				0.53 (0.73)	-0.10 (0.88)
Variance components					
Within-team (L1) variance	0.09	0.08	0.09	0.09	0.09
Intercept (L2) variance	0.46	0.50	0.46	0.46	0.51
Additional information					
ICC1	0.59	0.59	0.59	0.59	0.59
-2 log-likelihood	35.48	33.48	40.11	39.86	23.82
Number of estimated parameters	7	7	7	7	10
Pseudo R_2	0.74	0.77	0.74	0.74	0.74

Note. * = $p < .05$, † = $p < .1$. *Pseudo* R_2 *is the proportion of within team (L1) variance explained by the model. Only best fitting models are reported here and all of the best fitting models were random intercept models.*

Table 24

The impact of average team cognitive similarity on generate task performance

Level and Variable	Task Mental Mode Similarity (*df* = 17)	Team Mental Model Similarity (*df* = 17)	Shared Vision (Goals) (*df* = 17)	Shared Vision (Challenges) (*df* = 17)	Full Model (*df* = 14)
Level 1					
Intercept	0.12 (0.22)	0.16 (0.18)	0.19 (0.26)	0.14 (0.24)	0.09 (0.16)
Time 1	0.06 (0.15)	0.08 (0.15)	-0.04 (0.13)	0.06 (0.12)	0.18 (0.15)
Time 2	-0.85* (0.15)	-0.87* (0.16)	-0.95* (0.14)	-0.96* (0.13)	-0.85* (0.15)
Time 3	0.47* (0.20)	0.45* (0.21)	0.35† (0.18)	0.39* (0.16)	0.58* (0.19)
Task mental model similarity	-0.22 (0.13)				-0.10 (0.12)
Team mental model similarity		-0.36* (0.14)			-0.45* (0.13)
Shared goals			0.18 (0.10)		0.03 (0.11)
Shared challenges				-0.49* (0.18)	-0.52* (0.21)
Variance components					
Within-team (L1) variance	0.09	0.10	0.07	0.06	0.09
Intercept (L2) variance	0.34	0.19	0.54	0.50	0.12
Additional information					
ICC1	0.59	0.59	0.59	0.59	0.59
-2 log-likelihood	40.13	39.57	41.72	36.81	36.68
Number of estimated parameters	7	7	7	7	10
Pseudo R^2	0.74	0.70	0.78	0.82	0.76

*Note. Numbers for fixed parameters are beta coefficients based on standardized z scores with standard errors in parentheses, * = $p < .05$,* † = $p < .1$. *Pseudo R^2 is the proportion of within team (L1) variance explained by the model. Only best fitting models are reported here and all of the best fitting models were random intercept models.*

Table 25

The impact of team cognitive similarity on team viability

Level and Variable	Task Mental Mode Similarity (*df* = 65)	Team Mental Model Similarity (*df* = 65)	Shared Vision (Goals) (*df* = 65)	Shared Vision (Challenges) (*df* = 65)	Social Role Agreement (*df* = 65)	Full Model (*df* = 62)
Level 1						
Intercept	0.49† (0.30)	0.37 (0.28)	0.51† (0.29)	0.50† (0.29)	0.50† (0.29)	0.39 (0.29)
Time	-0.08* (0.02)	-0.06* (0.01)	-0.08* (0.01)	-0.09* (0.01)	-0.08* (0.01)	-0.06* (0.01)
Task mental model similarity	-0.02 (0.09)					0.03 (0.74)
Team mental model similarity		-0.20† (0.12)				-0.19 (0.13)
Shared goals			0.03 (0.05)			0 (0.05)
Shared challenges				0.05 (0.06)		0.04 (0.06)
Social role agreement					-0.03 (0.05)	0 (0.06)
Variance components						
Within-team (L1) variance	0.11	0.09	0.11	0.11	0.11	0.09
Intercept (L2) variance	0.72	0.63	0.72	0.72	0.71	0.65
Team MM Slope (L2) variance		0.06				0.07
Additional information						
ICC1	0.88	0.88	0.88	0.88	0.88	0.58
-2 log-likelihood	93.63	80.68	94.46	93.60	94.28	94.95
Number of estimated parameters	5	6	5	5	5	13
Pseudo R_2	0.33	0.46	0.33	0.34	0.33	0.43

Note. Numbers for fixed parameters are beta coefficients based on standardized z scores with standard errors in parentheses, * = $p < .05$, † = $p < .1$. *Pseudo* R_2 *is the proportion of within team (L1) variance explained by the model. Only best fitting models are reported here so team mental model similarity model has a random slope while the rest are random intercept modes.*

Table 26

The impact of team cognitive similarity slopes on choose task performance

Level and Variable	Task Mental Mode Similarity (*df* = 17)	Team Mental Model Similarity (*df* = 17)	Shared Vision (Goals) (*df* = 17)	Shared Vision (Challenges) (*df* = 17)	Full Model (*df* = 14)
Level 1					
Intercept	0.76* (0.30)	0.64* (0.28)	0.76* (0.30)	0.71* (0.27)	0.65* (0.28)
Time 1	-0.93* (0.41)	-0.89* (0.32)	-0.88* (0.36)	-0.77* (0.34)	-0.84* (0.38)
Time 2	-1.46* (0.38)	-1.27* (0.34)	-1.45* (0.38)	-1.39* (0.35)	-1.27* (0.35)
Time 3	-0.96† (0.49)	-0.92* (0.42)	-0.96† (0.48)	-0.85† (0.44)	-0.88† (0.43)
Task mental model similarity	-3.83 (17.34)				-3.59 (17.47)
Team mental model similarity		41.93* (17.02)			32.85 (19.47)
Shared goals			0.88 (1.63)		0.64 (1.76)
Shared challenges				-3.83* (1.62)	-2.51 (1.88)
Variance components					
Within-team (L1) variance	0.60	0.46	0.60	0.50	0.46
Intercept (L2) variance	0.20	0.22	0.21	0.15	0.22
Additional information					
ICC1	0.05	0.05	0.05	0.05	0.05
-2 log-likelihood	65.85	60.45	70.33	65.40	44.32
Number of estimated parameters	7	7	7	7	10
Pseudo R^2	0.36	0.51	0.37	0.47	0.51

*Note. * = p < .05,* † = p < .1. *Pseudo R^2 is the proportion of within team (L1) variance explained by the model. Only best fitting models are reported here and all of the best fitting models were random intercept models*

Table 27

The impact of average team cognitive similarity on choose task performance

Level and Variable	Task Mental Mode Similarity ($df = 17$)	Team Mental Model Similarity ($df = 17$)	Shared Vision (Goals) ($df = 17$)	Shared Vision (Challenges) ($df = 17$)	Full Model ($df = 14$)
Level 1					
Intercept	0.78* (0.30)	0.76* (0.29)	0.74* (0.30)	0.73* (0.30)	0.76* (0.31)
Time 1	-0.93* (0.37)	-0.93* (0.37)	-0.85* (0.37)	-0.86* (0.37)	-0.86* (0.38)
Time 2	-1.52* (0.39)	-1.49* (0.38)	-1.44* (0.38)	-1.46* (0.38)	-1.55* (0.39)
Time 3	-1.03* (0.49)	-0.95† (0.48)	-0.99† (0.48)	-0.91† (0.49)	-1.04† (0.49)
Task mental model similarity	0.14 (0.20)				0.15 (0.23)
Team mental model similarity		0.18 (0.21)			0.15 (0.25)
Shared goals			-0.18 (0.25)		-0.29 (0.28)
Shared challenges				-0.24* (0.39)	-0.36 (0.46)
Variance components					
Within-team (L1) variance	0.59	0.59	0.59	0.60	0.60
Intercept (L2) variance	0.20	0.18	0.21	0.19	0.25
Additional information					
ICC1	0.05	0.05	0.05	0.05	0.05
-2 log-likelihood	74.26	73.96	73.85	73.08	73.99
Number of estimated parameters	7	7	7	7	10
Pseudo R^2	0.36	0.51	0.37	0.47	0.51

Note. Numbers for fixed parameters are beta coefficients based on standardized z scores with standard errors in parentheses, $* = p < .05$, † = $p < .1$. *Pseudo R^2 is the proportion of within team (L1) variance explained by the model. Only best fitting models are reported here and all of the best fitting models were random intercept models*

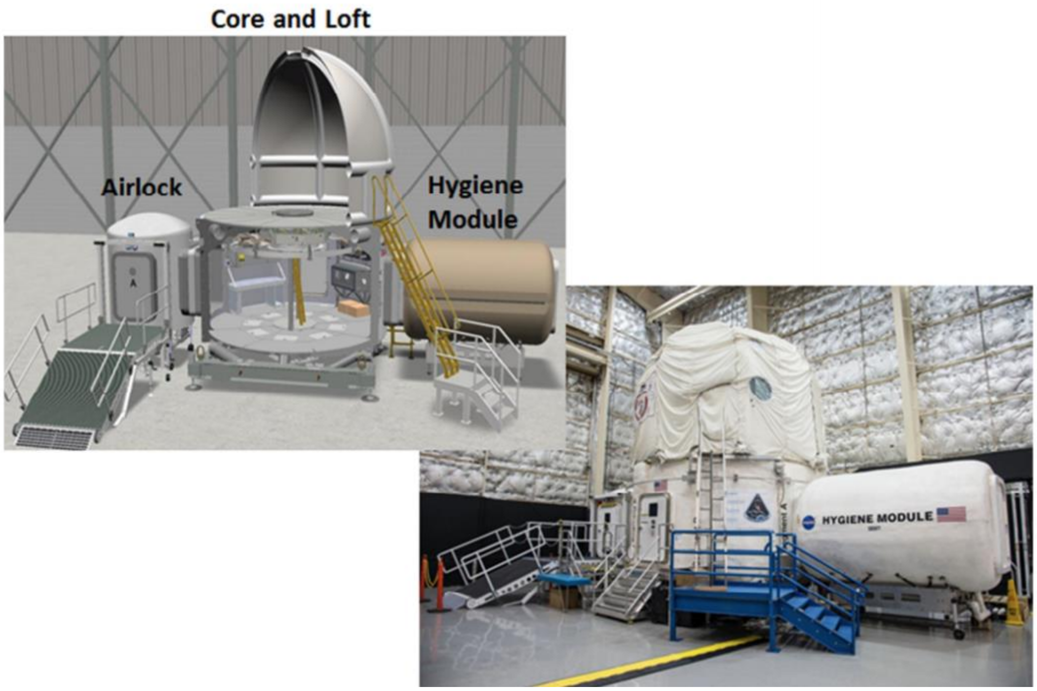

Figure 1. *Schematic representation of the HERA. Image taken from the Human Research Program Human Exploration Research Analog (HERA) Experiment Information Package (Cromwell & Neigut, 2014).*

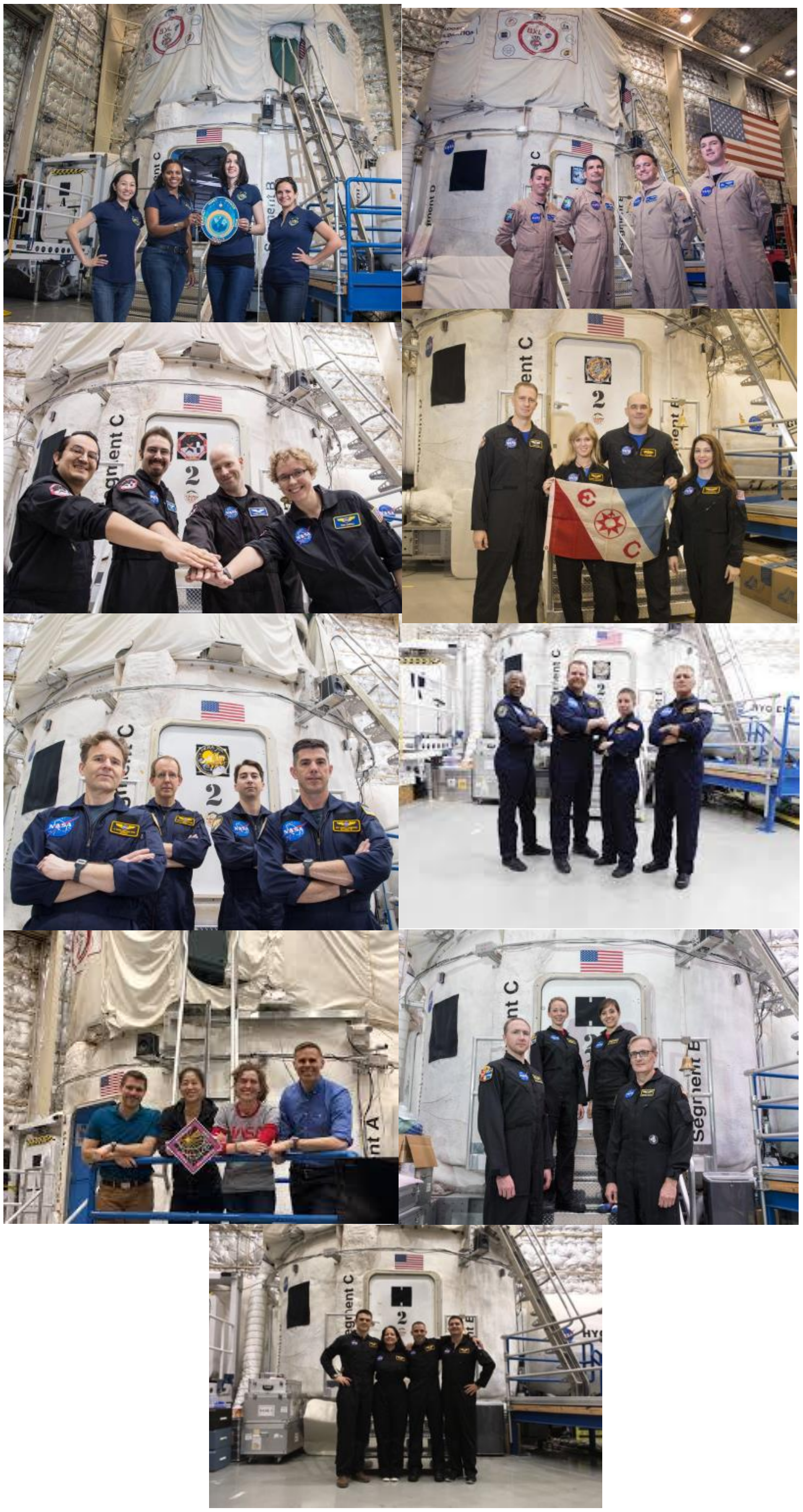

Figure 2. The nine HERA crews that participated in these studies. The top four spent 30 days inside the habitat and the next four spent 45 days inside. The bottom crew was intended to spend 45 days inside, but their mission was aborted on day 22 due to a hurricane. Chapter 2 includes only the top four crews while Chapters 3 and 4 include all nine crews

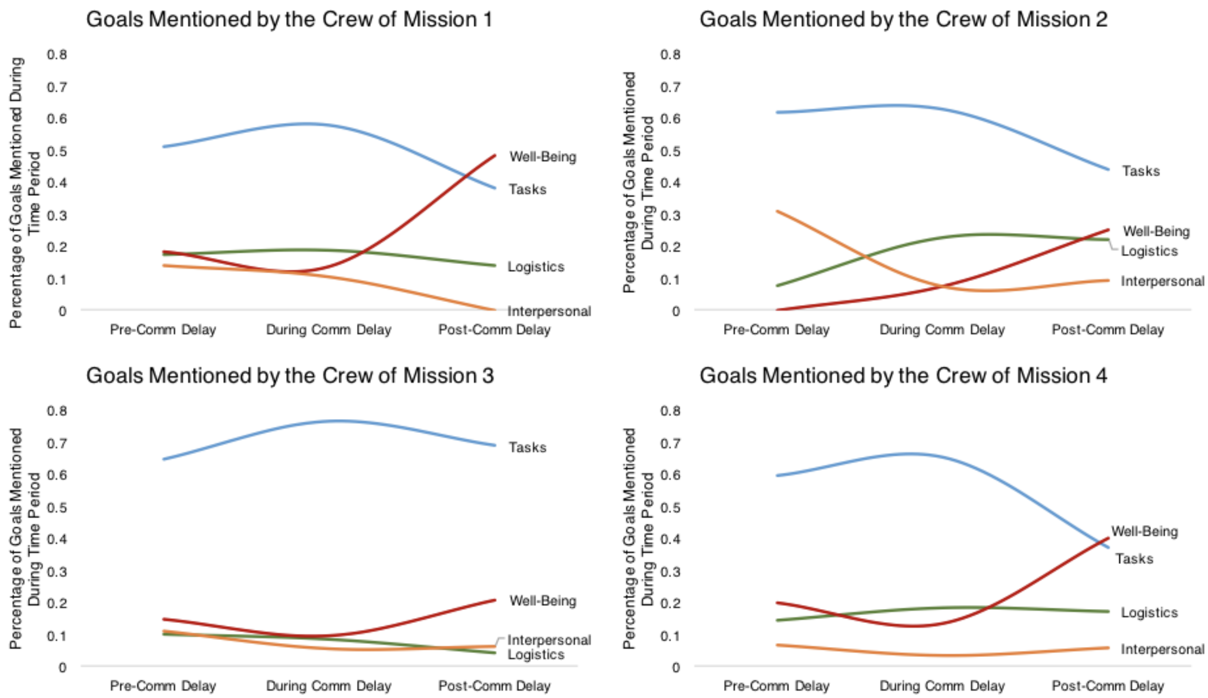

Figure 3. Proportion of second order category goals over time.

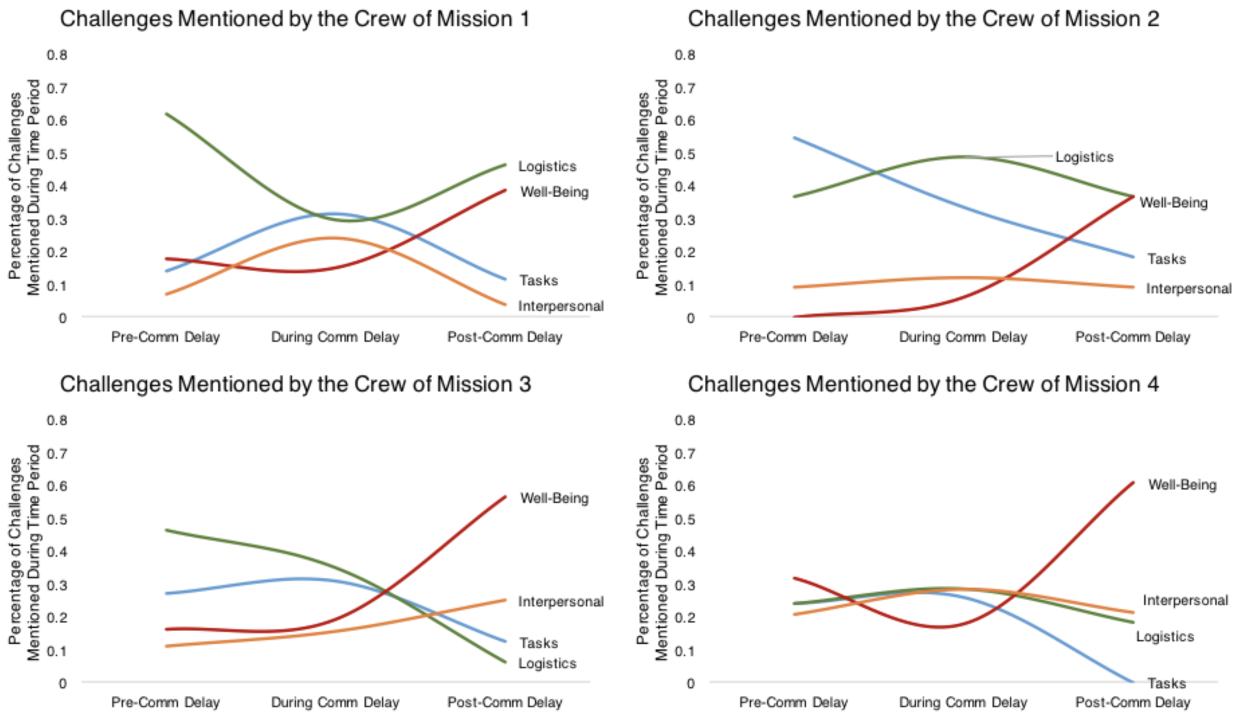

Figure 4. Proportion of second order category challenges over time.

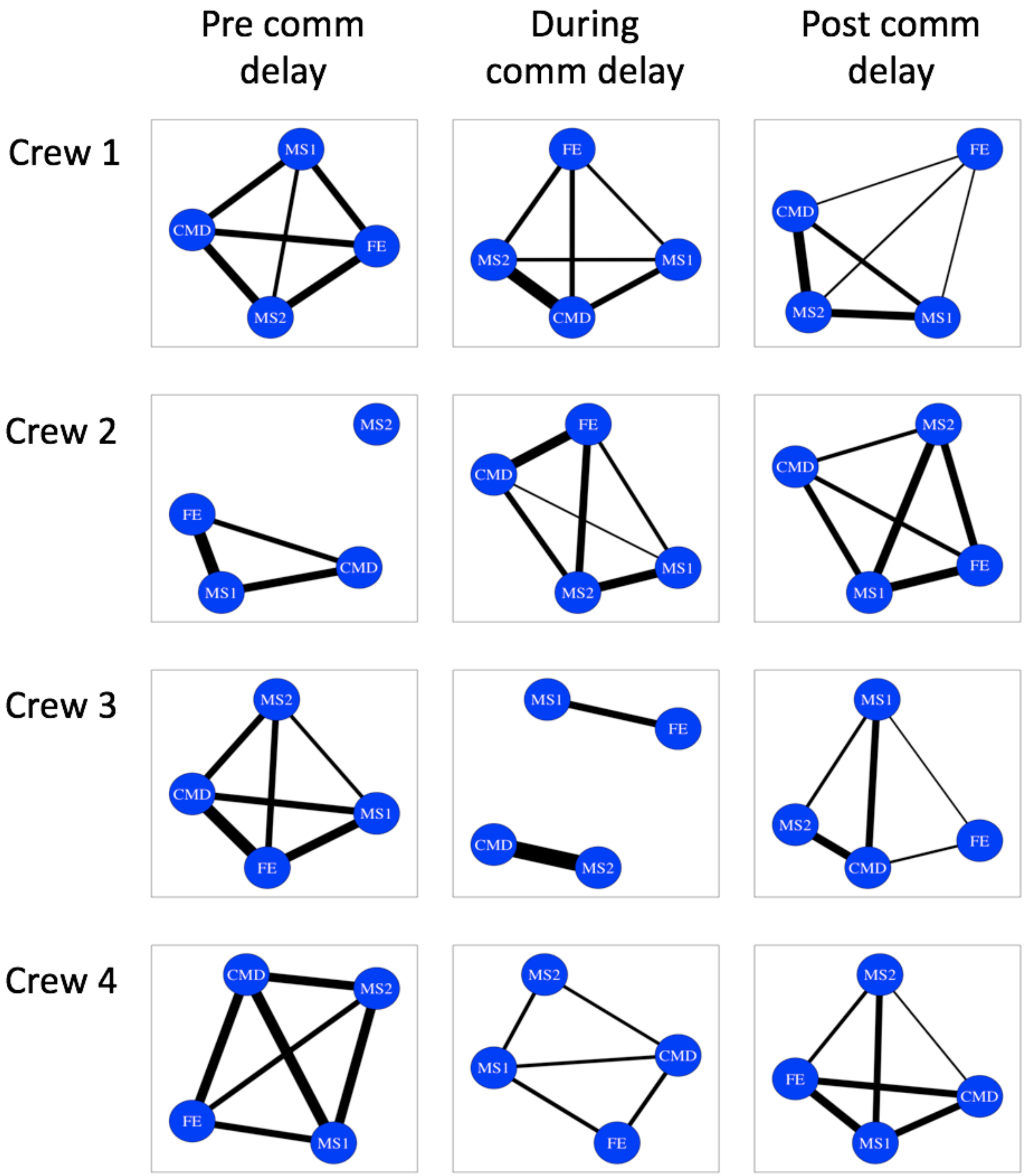

Figure 5 Crews 1-4 challenge similarity networks for pre, during, and post communication delay.

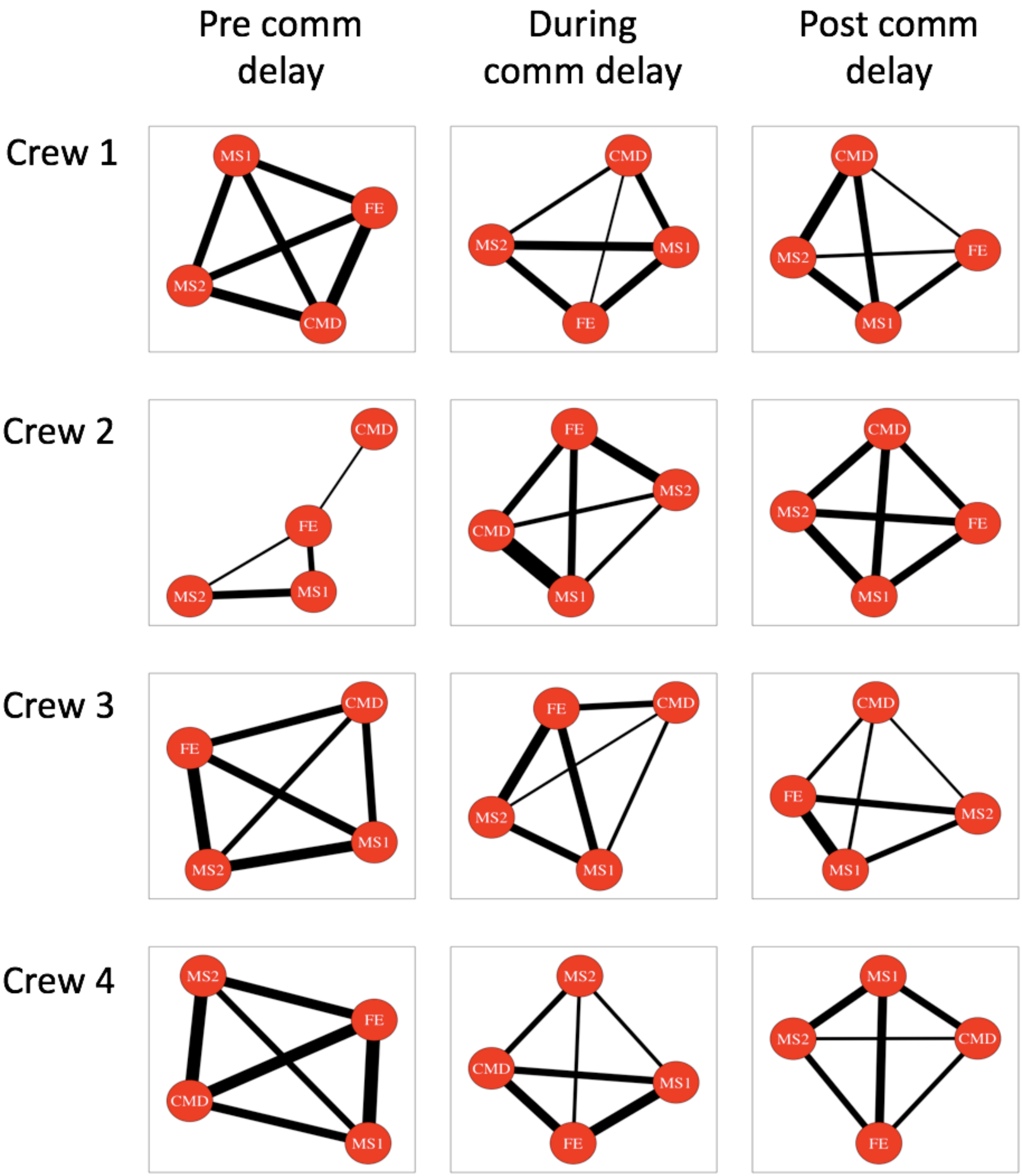

Figure 6 Crews 1-4 goal similarity networks for pre, during, and post communication delay.

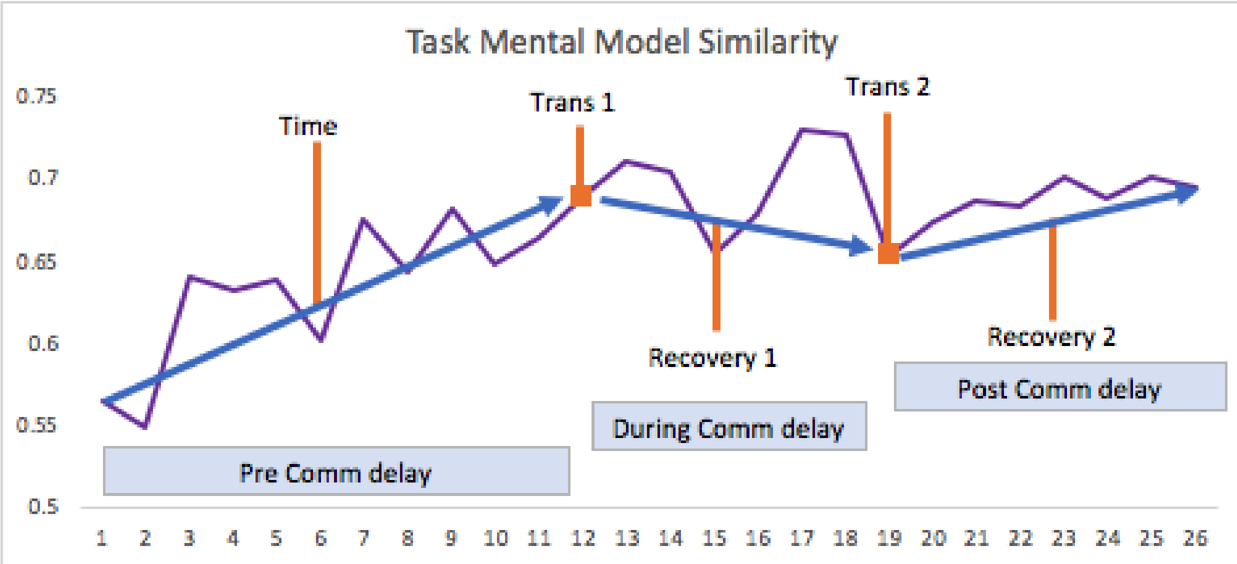

Figure 7 An example diagram of the discontinuous growth model terms laid out for mission 1 task mental model similarity

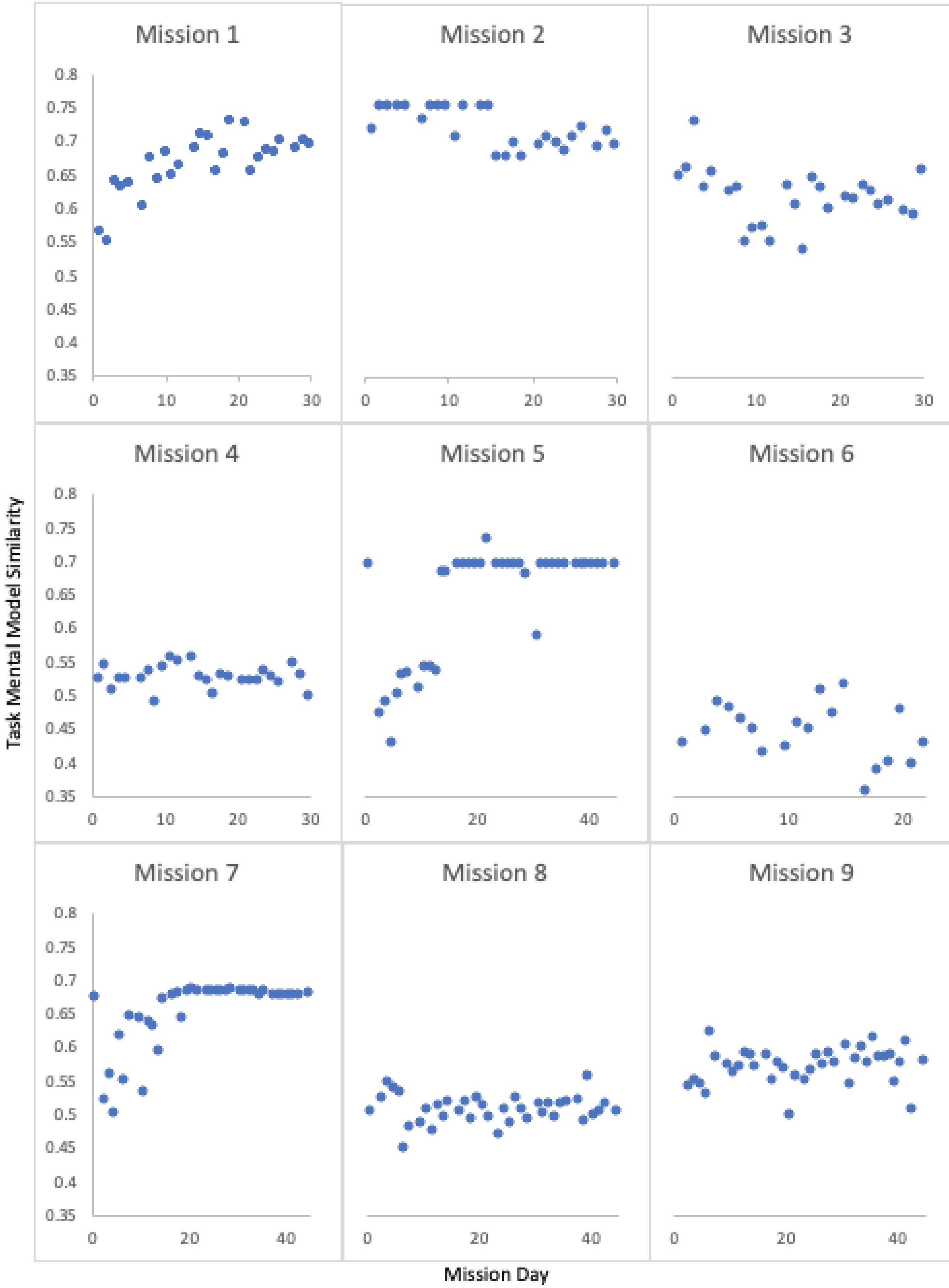

Figure 8 Crews 1-9 shared task mental model similarity over time.

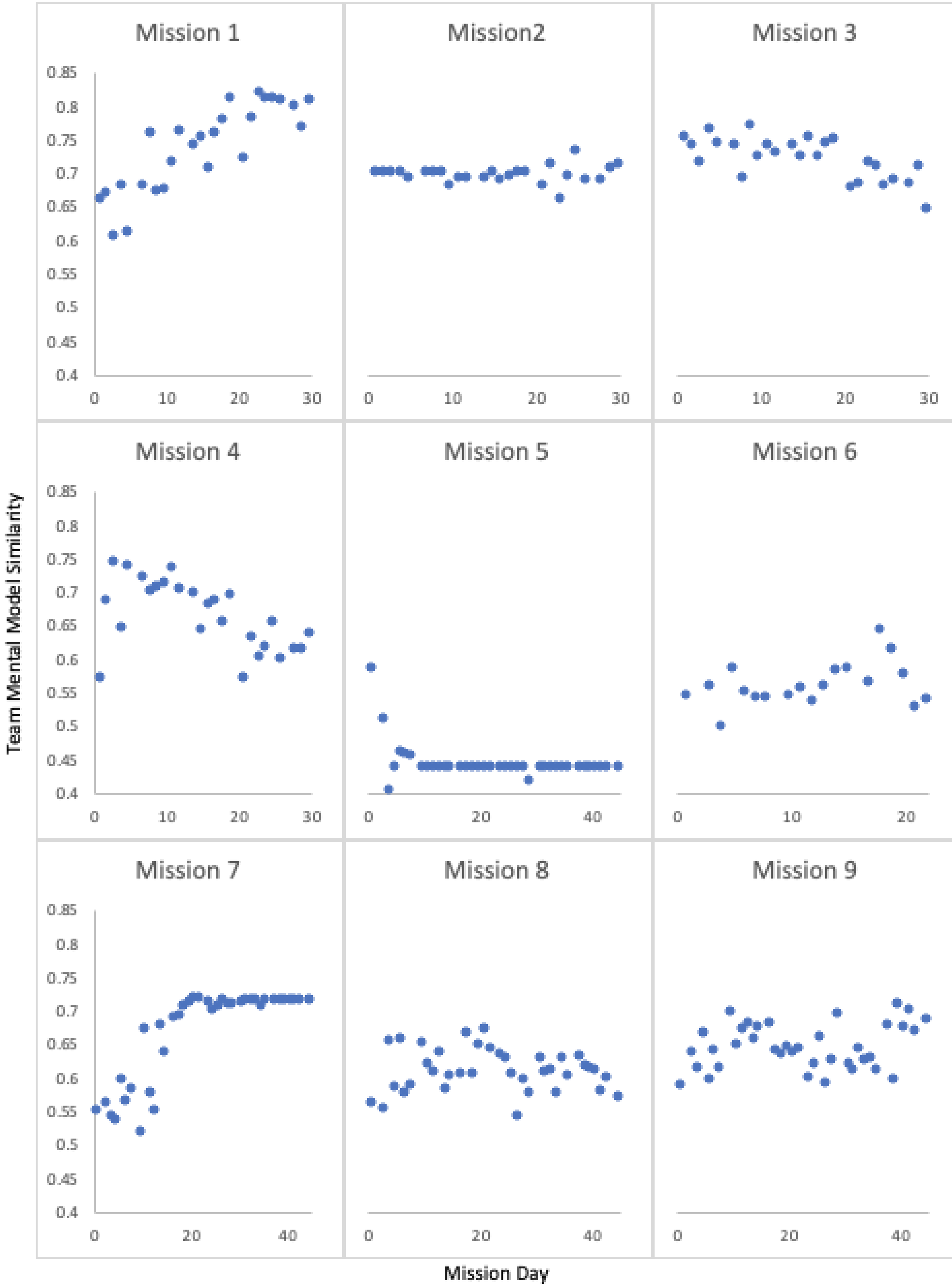

Figure 9 Crews 1-9 shared team mental model similarity over time.

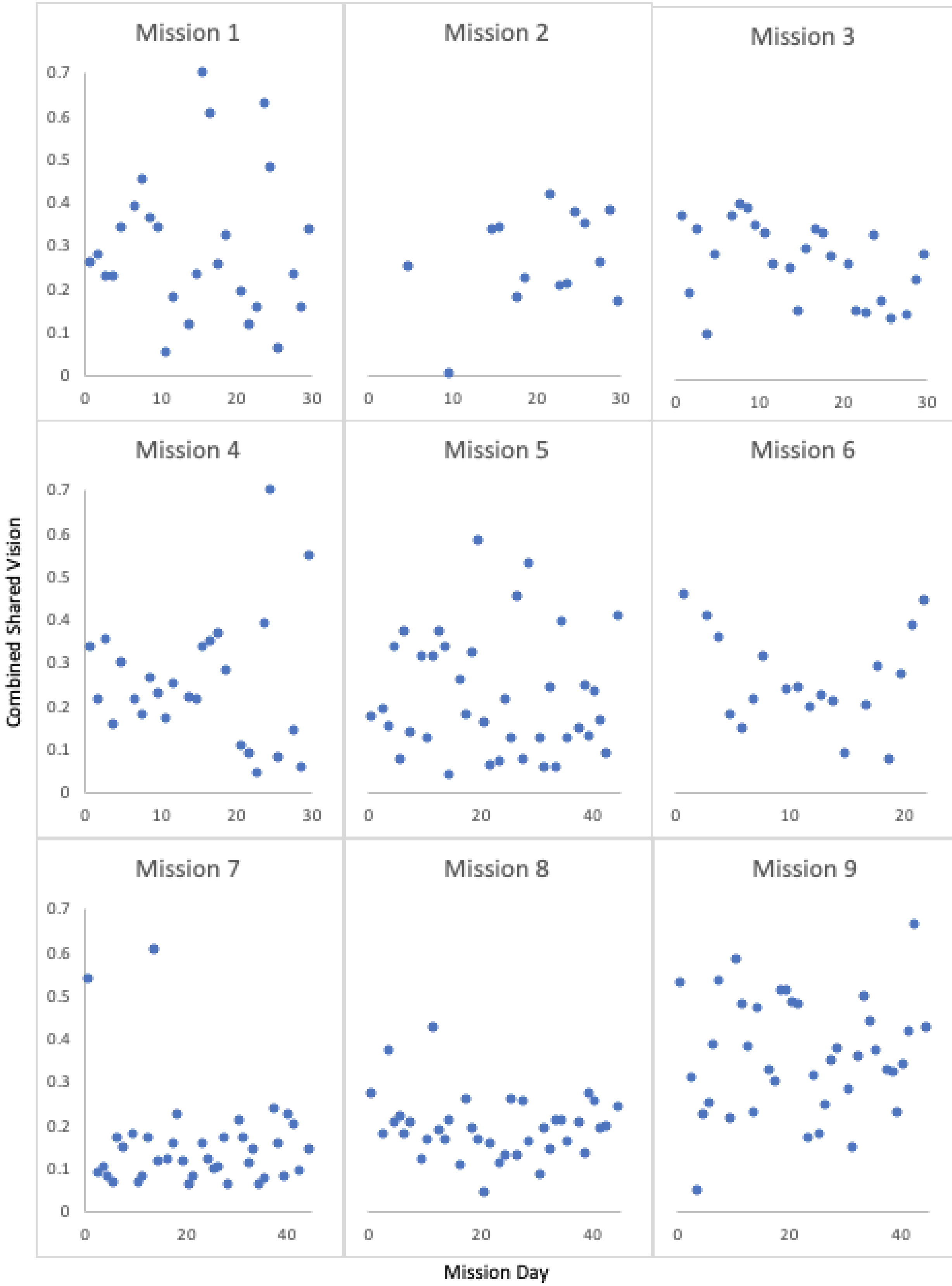

Figure 10 Crews 1-9 combined shared vision over time.

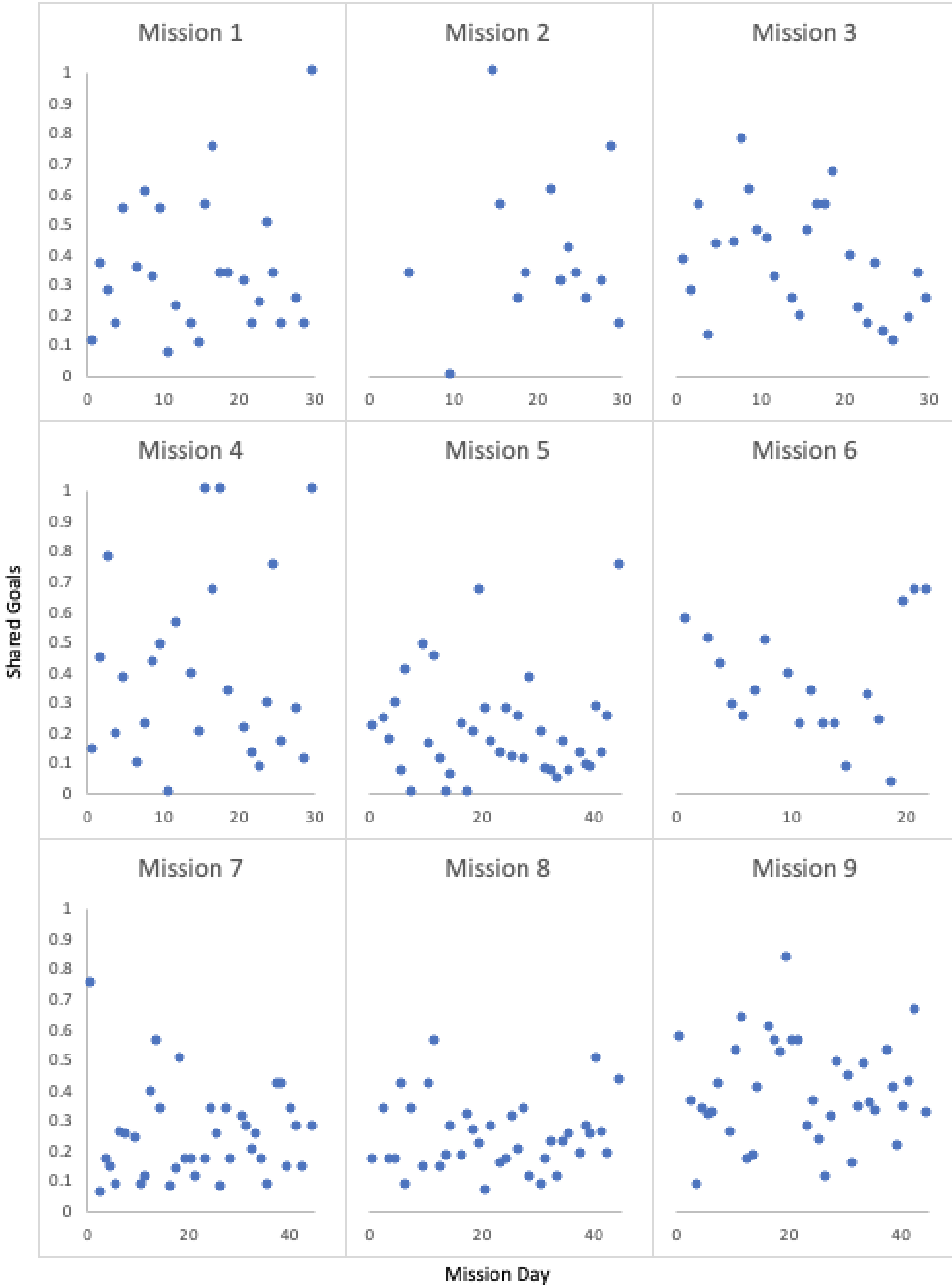

Figure 11 Crews 1-9 shared goals over time.

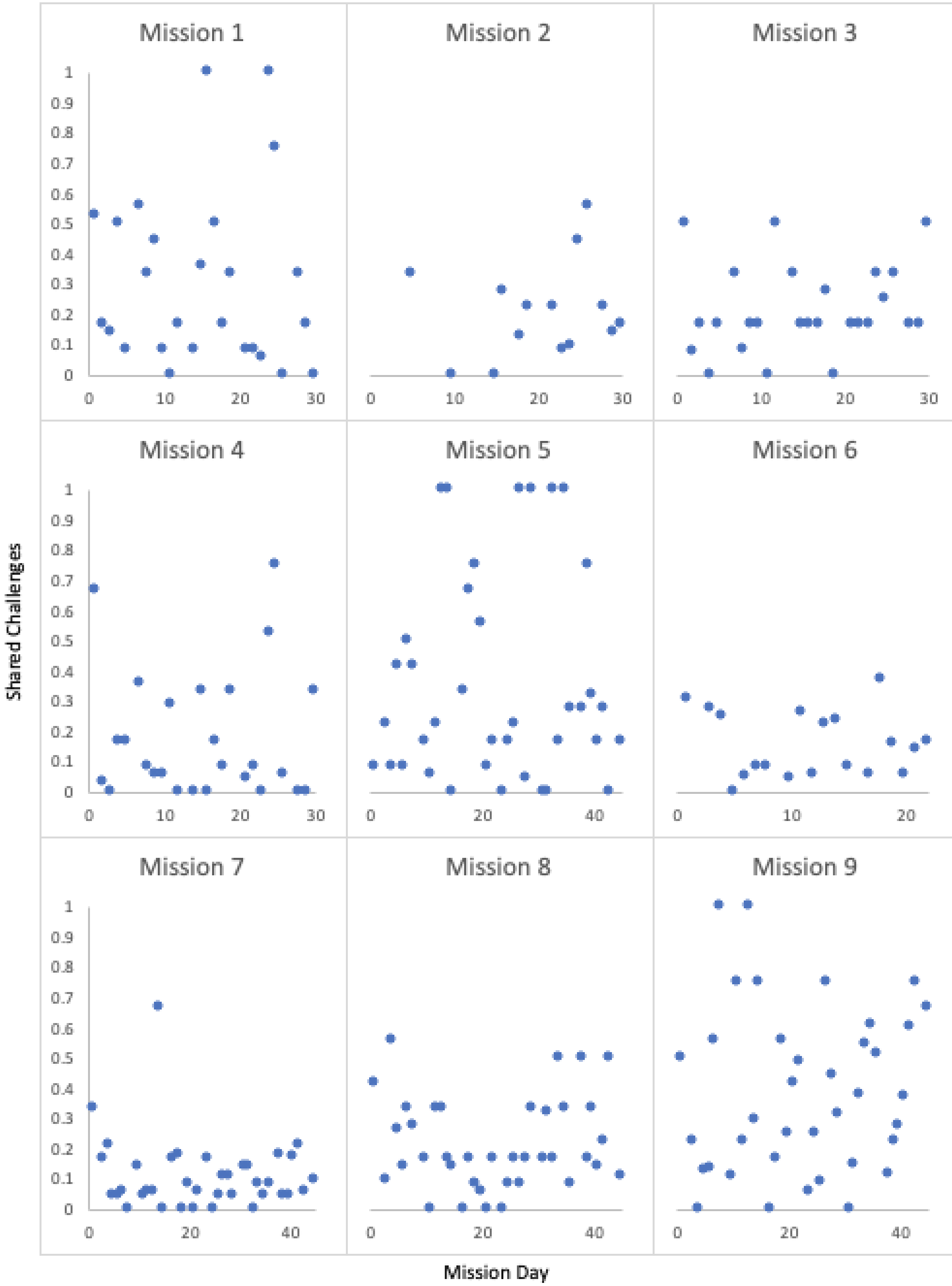

Figure 12 Crews 1-9 shared challenges over time.

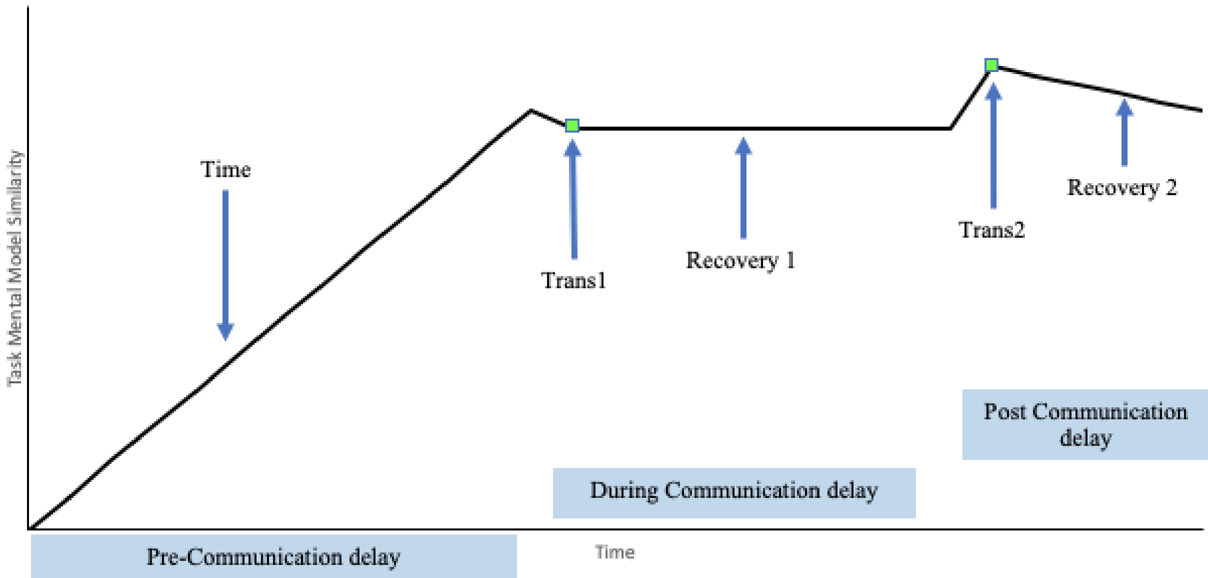

Figure 13 A summary diagram of the discontinuous growth model parameters for task mental model similarity (parameters based on the random slopes relative change model in Table 14 on page 145).

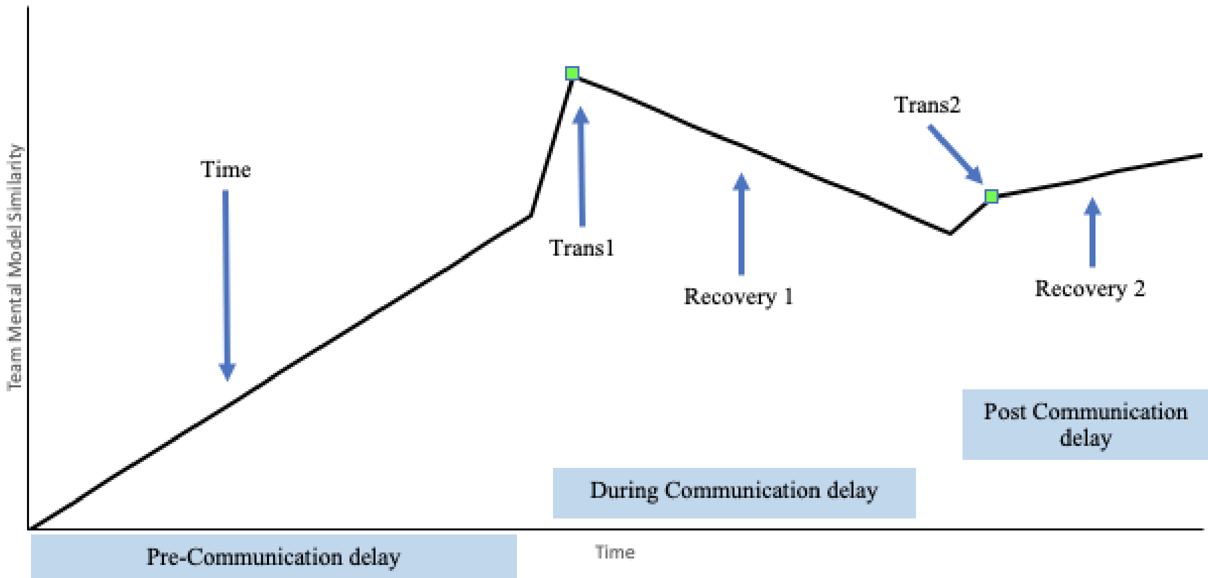

Figure 14 A summary diagram of the discontinuous growth model parameters for team mental model similarity (parameters based on the random slopes relative change model in Table 15 on page 146).

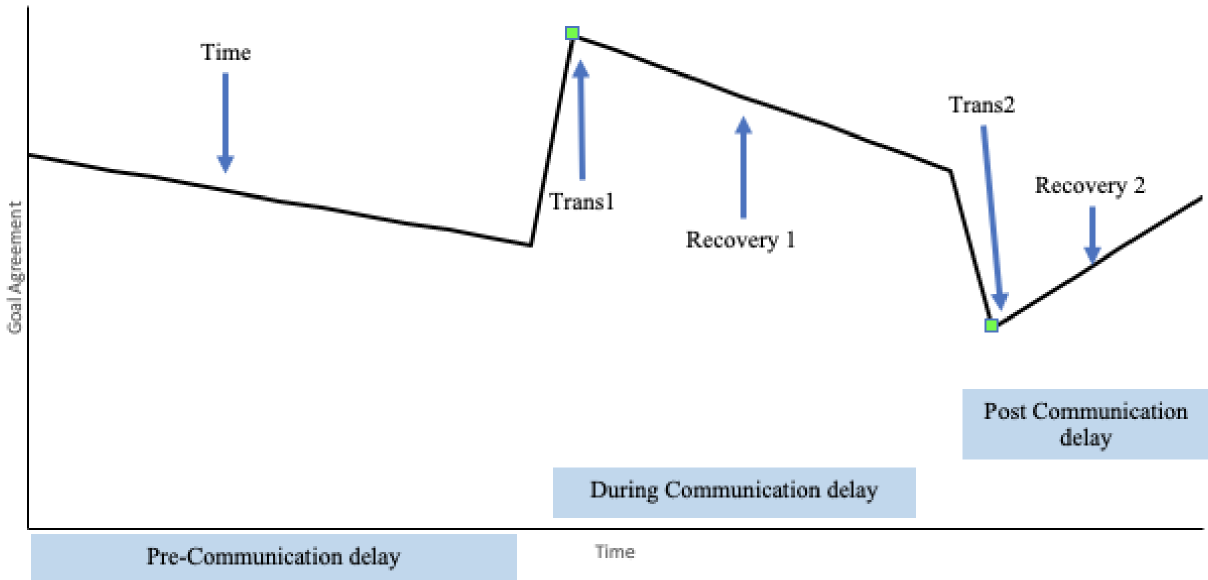

Figure 15 A summary diagram of the discontinuous growth model parameters for shared goals (parameters based on the random intercept relative change model in Table 17 on page 148).

References

Amabile, T. M. (1983). The social psychology of creativity: A componential conceptualization. *Journal of Personality and Social Psychology*, *45*(2), 357-376.

Bales. R. F., & Slater, P. (1955). Role differentiation in small decision-making groups. In T. Parsons & R. F. Bales (Eds.), *Family Socialization and Interaction Processes* (pp. 259-306). Glencoe, IL: Free Press.

Bechtel, R. B., & Berning, A. (1991). The third-quarter phenomenon: do people experience discomfort after stress has passed?. In *From Antarctica to outer space* (pp. 261-265). Springer, New York, NY.

Becker, H. S., & Geer, B. (1960). Latent culture: A note on the theory of latent social roles. *Administrative Science Quarterly*, *5*(2), 304-313.

Bell, S. T., Brown, S. G., Abben, D. R., & Outland, N. B. (2015). Team composition issues for future space exploration: A review and directions for future research. *Aerospace Medicine and Human Performance, 86*(6), 548-556.

Bell, S. T., & Marentette, B. J. (2011). Team viability for long-term and ongoing organizational teams. *Organizational Psychology Review*, *1*(4), 275-292.

Bliese, P. D. (2000). Within-group agreement, non-independence, and reliability: Implications for data aggregation and analysis. In K. J. Klein & S. W. J. Kozlowski (Eds.), *Multilevel theory, research, and methods in organizations: Foundations, extensions, and new directions* (pp. 349-381). San Francisco, CA, US: Jossey-Bass.

Bliese, P. D. (2016). multilevel: Multilevel Functions. R package version 2.6. https://CRAN.R-project.org/package=multilevel

Bliese, P. D., & Lang, J. W. (2016). Understanding relative and absolute change in discontinuous growth models: Coding alternatives and implications for hypothesis testing. *Organizational Research Methods*, *19*(4), 562-592.

Bliese, P. D., & Ployhart, R. E. (2002). Growth modeling using random coefficient models: Model building, testing, and illustrations. *Organizational Research Methods*, *5*(4), 362-387.

Borgatti, S. P., Everett, M. G., & Freeman, L. C. (2002). Ucinet for Windows: Software for social network analysis.

Burke, C. S., Priest, H. A., Salas, E., Sims, D., & Mayer, K. (2008). Stress and teams: How stress affects decision making at the team level. In P. A. Hancock & J. L. Szalma (Eds.), *Performance under stress* (pp. 181-208). New York, NY: Routledge.

Burke, C. S., Stagl, K. C., Salas, E., Pierce, L., & Kendall, D. (2006). Understanding team adaptation: A conceptual analysis and model. *Journal of Applied Psychology*, *91*(6), 1189-1207.

Cannon-Bowers, J. A., Salas, E., & Converse, S. A. (1990). Cognitive psychology and team training: Training shared mental models and complex systems. *Human Factors Society Bulletin*, *33*(12), 1-4.

Cannon-Bowers, J. A., Salas, E., & Converse, S. (1993). Shared mental models in expert team decision making. In N. J. Castellan, Jr. (Ed.), *Individual and Group Decision Making: Current Issues* (pp. 221-246). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Cannon-Bowers, J. A., Tannenbaum, S. I., Salas, E., & Volpe, C. E. (1995). Defining competencies and establishing team training requirements. In R. Guzzo & E. Salas (Eds.), *Team effectiveness and decision making in organizations* (pp. 333–380). San Francisco, CA: Jossey-Bass.

Carsten, M. K., Uhl-Bien, M., West, B. J., Patera, J. L., & McGregor, R. (2010). Exploring social constructions of followership: A qualitative study. *The Leadership Quarterly*, *21*(3), 543-562.

Cooke, N. J., Kiekel, P. A., & Helm, E. E. (2001). Measuring team knowledge during skill acquisition of a complex task. *International Journal of Cognitive Ergonomics*, *5*(3), 297-315.

Cooke, N. J., Kiekel, P. A., Salas, E., Stout, R., Bowers, C., & Cannon-Bowers, J. (2003). Measuring team knowledge: A window to the cognitive underpinnings of team performance. *Group Dynamics: Theory, Research, and Practice*, *7*, 179-199.

Cromwell, R. L., & Neigut, J. S. (2014) Human Research Program Human Exploration Research Analogue (HERA) Experiment Information Package. Retrieved at: https://www.nasa.gov/sites/default/files/files/HRP-HERA-Experiment-Information-Package.pdf

DeChurch, L. A., & Mesmer-Magnus, J. R. (2010a). The cognitive underpinnings of effective teamwork: A meta-analysis. *Journal of Applied Psychology*, *95*(1), 32-53.

DeChurch, L. A., & Mesmer-Magnus, J. R. (2010b). Measuring shared team mental models: A meta-analysis. *Group Dynamics: Theory, Research, and Practice*, *14*(1), 1-14.

Dietz, A. S., Weaver, S. J., Sierra, M. J., Bedwell, W. L., Salas, E., Fiore, S. M., ... & Driskell, J. E. (2010, September). Unpacking the temporal and interactive effects of stress on individual and team performance. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 54, No. 13, pp. 1017-1021). Los Angeles, CA: SAGE Publications.

Driskell, J. E., Salas, E., & Johnston, J. (1999). Does stress lead to a loss of team perspective?.

Group dynamics: Theory, research, and practice, 3(4), 291-302.

Edwards, B. D., Day, E. A., Arthur Jr, W., & Bell, S. T. (2006). Relationships among team ability composition, team mental models, and team performance. *Journal of Applied Psychology, 91*(3), 727-736.

Ellis, A.P.J. 2006. System breakdown: The role of mental models and transactive memory in the relationship between acute stress and team performance. *Academy of Management Journal, 49*(3), 576-589.

Freeman, L. C., Roeder, D., & Mulholland, R. (1979). Centrality in social networks II: Experimental results. *Social Networks, 2*(2), 119-141.

Gehman Jr, H. W., Barry, J. L., Deal, D. W., Hallock, J. N., Hess, K. W., Hubbard, G. S., ... & Tetrault, R. E. (2003). *Columbia Accident Investigation Board Report,* (Volume 1). Washington DC: NASA.

Gladstein, D. L. (1984). Groups in context: A model of task group effectiveness. *Administrative Science Quarterly*, *29*(4), 499-517.

Gladstein, D. L., & Reilly, N. P. (1985). Group decision making under threat: The tycoon game. *Academy of Management Journal*, *28*(3), 613-627.

Goodman, P. (1986). The impact of task and technology on group performance. In P. Goodman (Ed.), *Designing effective work groups* (pp. 198–216). San Francisco, CA: Jossey-Bass.

Gouldner, A. W. (1957). Cosmopolitans and locals: Toward an analysis of latent social roles .I. *Administrative Science Quarterly*, *2*(3), 281-306.

Gouldner, A. W. (1958). Cosmopolitans and locals: toward an analysis of latent social roles. II. *Administrative Science Quarterly*, *2*(4), 444-480.

Grand, J. A., Braun, M. T., Kuljanin, G., Kozlowski, S. W., & Chao, G. T. (2016). The dynamics of team cognition: A process-oriented theory of knowledge emergence in teams. *Journal of Applied Psychology*, *101*(10), 1353-1385.

Griffith, J., & Vaitkus, M. (1999). Relating cohesion to stress, strain, disintegration, and performance: An organizing framework. *Military Psychology*, *11*(1), 27-55.

Guilford, J. P. (1967). Creativity: Yesterday, today and tomorrow. *The Journal of Creative Behavior*, *1*(1), 3-14.

Guzzo, R. A., & Dickson, M. W. (1996). Teams in organizations: Recent research on performance and effectiveness. *Annual Review of Psychology*, *47*(1), 307-338.

Hackman JR. (1987). The design of work teams. In J. W. Lorsch (Ed.), *Handbook of organizational behavior* (pp. 315-342). Englewood Cliffs, NJ: Prentice-Hall.

Hackman, J. R. (1992). Group influences on individuals in organizations. In M. D. Dunnette & L. M. Hough (Eds.), *Handbook of industrial and organizational psychology* (pp. 199-267). Palo Alto, CA: Consulting Psychologists Press.

Hackman, J. R., & Morris, C. G. (1975). Group tasks, group interaction process, and group performance effectiveness: A review and proposed integration. In L. Berkowitz (Ed.), *Advances in experimental social psychology Vol 8* (pp. 45-99).

Hall, R. L. (1955). Social influence on the aircraft commander's role. *American Sociological Review*, *20*(3), 292-299.

Hall, J., & Watson, W. H. (1970). The effects of a normative intervention on group decision-making performance. *Human Relations*, *23*(4), 299-317.

Hare, A. P. (1976). *Handbook of Small Group Research*. New York, NY: Free Press.

Hegel, P. T. (1807). *The Phenomenology of Mind*. London: Allen and Unwin.

Hollingshead, A. B. (1998a). Retrieval processes in transactive memory systems. *Journal of*

Personality and Social Psychology, *74*(3), 659-671.

Hollingshead, A. B. (1998b). Communication, learning, and retrieval in transactive memory systems. *Journal of Experimental Social Psychology*, *34*(5), 423-442.

Janis, I. L., & Janis, I. L. (1982). *Groupthink: Psychological Studies of Policy Decisions and Fiascoes Vol. 349*. Boston, MA: Houghton Mifflin.

Jex, S. M., & Thomas, J. L. (2003). Relations between stressors and group perceptions: Main and mediating effects. *Work & Stress*, *17*(2), 158-169.

Johnson, J. C., Boster, J. S., & Palinkas, L. A. (2003). Social roles and the evolution of networks in extreme and isolated environments. *Journal of Mathematical Sociology*, *27*(2-3), 89-121.

Johnson, J. C., Palinkas, L.A. & Boster, J. S. (2003). Informal social roles and the evolution and stability of social networks. In R. Breiger, K. Carley, & P. Pattison (Eds.), *Dynamic social network modeling and analysis* (pp. 121-132). Washington, DC: The National Academies Press.

Johnson, J. & Weller, S. (2001). Elicitation techniques for interviewing. In J. F. Gubrium & J. A. Holstein (Eds.), *Handbook of interview research* (pp. 491-514). SAGE Publications, Inc.

Kanas, N. (1998). Psychosocial issues affecting crews during long-duration international space missions. *Acta astronautica*, *42*(1-8), 339-361.

Kanas, N. (2014) *The New Martians: A Scientific Novel.* New York, NY: Springer.

Katz, R. (1982). The effects of group longevity on project communication and performance. *Administrative Science Quarterly*, *27*(1), 81-104.

Katz, R. and Allen, T.J. (1988), Investigating the not invented here syndrome: A look at the performance, tenure, and communication patterns of 50 R&D project groups, in M. L. Tushman, and W. L. Moore (Eds.), *Readings in the management of innovation, 2nd ed*., New York, NY: Ballinger.

Kaufman, J. C., & Sternberg, R. J. (Eds.). (2010). *The Cambridge handbook of creativity*. Cambridge, MA: Cambridge University Press.

Kintz, N. M., Chou, C. P., Vessey, W. B., Leveton, L. B., & Palinkas, L. A. (2016). Impact of communication delays to and from the International Space Station on self-reported individual and team behavior and performance: A mixed-methods study. *Acta Astronautica*, *129*, 193-200.

Klimoski, R., & Mohammed, S. (1994). Team mental model: Construct or metaphor?. *Journal of Management*, *20*(2), 403-437.

Kouzes, J. M., & Posner, B. Z. (1987). *The Leadership Challenge: How to get Extraordinary Things Done in Organizations*. San Francisco: Jossey-Bass.

Kozlowski, S. W. J., & Bell, B. S. (2003). Work groups and teams in organizations. In W. C. Borman, D. R. Ilgen, & R. J. Klimoski (Eds.), *Handbook of psychology: Industrial and organizational psychology* (Vol. 12, pp. 333-375). London: Wiley

Kozlowski, S., & Bell, S. B. (2013). Work groups and teams in organizations: Review update. In N. Schmitt & S, Higghouse (Eds.), *Handbook of psychology*: *Industrial and organizational psychology 2nd edition* (vol. 12 pp. 412-469). Hoboken, NJ: Wiley.

Kozlowski, S. W., & Ilgen, D. R. (2006). Enhancing the effectiveness of work groups and teams. *Psychological Science in the Public Interest*, *7*(3), 77-124.

Kozlowski, S. W. J., & Klein, K. J. (2000). A multilevel approach to theory and research in organizations: Contextual, temporal, and emergent processes. In K. J. Klein & S. W. J.

Kozlowski (Eds.), *Multilevel theory, research, and methods in organizations: Foundations, extensions, and new directions* (pp. 3-90). San Francisco, CA, US: Jossey-Bass.

Kraiger, K., & Wenzel, L. H. (1997). A framework for understanding and measuring shared mental models of team performance and team effectiveness. In E. Salas, M. T.

Brannick,

& C. Prince (Eds.), *Team performance assessment and measurement: Theory, methods, and applications* (pp. 63-84). Hillsdale, NJ: Erlbaum.

Landon, L. B., Vessey, W. B., & Barrett, J. D. (2016). Evidence report: Risk of performance and behavioral health decrements due to inadequate cooperation, coordination, communication, and psychosocial adaptation within a team. *NASA: Houston*.

Lantis, M. (1968). Environmental stresses on human behavior: Summary and suggestions. *Archives of Environmental Health: An International Journal*, *17*(4), 578-585.

Lazarus, R. S., & Folkman, S. (1984). *Stress, appraisal, and coping*. New York, NY: Springer

Lee, T. W. (1999). *Using Qualitative Methods in Organizational Research*. Thousand Oaks, Ca: Sage.

Lieberman, H. R., Castellani, J. W., & Young, A. J. (2009). Cognitive function and mood during acute cold stress after extended military training and recovery. *Aviation, Space, and Environmental Medicine*, *80*(7), 629-636.

Levesque, L. L., Wilson, J. M., & Wholey, D. R. (2001). Cognitive divergence and shared mental models in software development project teams. *Journal of Organizational Behavior: The International Journal of Industrial, Occupational and Organizational Psychology and Behavior*, *22*(2), 135-144.

Levine, J. M., & Moreland, R. L. (1990). Progress in small group research. *Annual review of psychology*, *41*(1), 585-634.

Levine, J. M., Resnick, L. B., & Higgins, E. T. (1993). Social foundations of cognition. *Annual Review of Psychology*, *44*, 585-612.

Lewis, K. (2004). Knowledge and performance in knowledge-worker teams: A longitudinal study of transactive memory systems. *Management Science*, *50*(11), 1519-1533.

Liang, D. W., Moreland, R., & Argote, L. (1995). Group versus individual training and group performance: The mediating role of transactive memory. *Personality and Social Psychology Bulletin*, *21*(4), 384-393.

Lim, B. C., & Klein, K. J. (2006). Team mental models and team performance: A field study of the effects of team mental model similarity and accuracy. *Journal of Organizational Behavior: The International Journal of Industrial, Occupational and Organizational Psychology and Behavior*, *27*(4), 403-418.

Lu, J. G., Akinola, M., & Mason, M. F. (2017). “Switching on” creativity: Task switching can increase creativity by reducing cognitive fixation. *Organizational Behavior and Human Decision Processes*, *139*, 63-75.

MacKenzie, K. D. (1976). *A Theory of Group Structures. Vols. I and II*. New York, NY: Gordon and Breach.

Marks, M. A., Mathieu, J. E., & Zaccaro, S. J. (2001). A temporally based framework and taxonomy of team processes. *Academy of Management Review*, *26*(3), 356-376.

Marks, M. A., Sabella, M. J., Burke, C. S., & Zaccaro, S. J. 2002. The impact of cross-training on team effectiveness. *Journal of Applied Psychology*, *87*(1), 3-13.

Marks, M. A., Zaccaro, S. J., & Mathieu, J. E. (2000). Performance implications of leader briefings and team-interaction training for team adaptation to novel environments. *Journal of Applied Psychology*, *85*(6), 971-986.

Mathieu, J. E., Heffner, T. S., Goodwin, G. F., Cannon-Bowers, J. A., & Salas, E. (2005). Scaling the quality of teammates' mental models: Equifinality and normative comparisons. *Journal of Organizational Behavior: The International Journal of Industrial, Occupational and Organizational Psychology and Behavior*, *26*(1), 37-56.

Mathieu, J. E., Heffner, T. S., Goodwin, G. F., Salas, E., & Cannon-Bowers, J. A. (2000). The influence of shared mental models on team process and performance. *Journal of Applied Psychology*, *85*(2), 273-283.

Mathieu, J., Maynard, M. T., Rapp, T., & Gilson, L. (2008). Team effectiveness 1997-2007: A review of recent advancements and a glimpse into the future. *Journal of Management*, *34*(3), 410-476.

McDougall, W. (1920). *The group mind: A Sketch of the Principles of Collective Psychology, with Some Attempt to Apply Them to the Interpretation of National Life and Character*. New York, NY: GP Putnam's Sons.

McGrath, J. E. (1984). *Groups: Interaction and Performance*. Englewood Cliffs, NJ: Prentice-Hall.

Mell, J. N., Van Knippenberg, D., & Van Ginkel, W. P. (2014). The catalyst effect: The impact of transactive memory system structure on team performance. *Academy of Management Journal*, *57*(4), 1154-1173.

Mesmer-Magnus, J., Niler, A. A., Plummer, G., Larson, L. E., & DeChurch, L. A. (2017). The cognitive underpinnings of effective teamwork: A continuation. *Career Development International*, *22*(5), 507-519.

Mohammed, S., Ferzandi, L., & Hamilton, K. (2010). Metaphor no more: A 15-year review of the team mental model construct. *Journal of Management*, *36*(4), 876-910.

Mohammed, S., Klimoski, R., & Rentsch, J. R. (2000). The measurement of team mental models: We have no shared schema. *Organizational Research Methods*, *3*(2), 123-165.

Moreland, R. L., & Myaskovsky, L. (2000). Exploring the performance benefits of group training: Transactive memory or improved communication?. *Organizational Behavior and Human Decision Processes*, *82*(1), 117-133.

Moreland, R. L., & Thompson, L. (2006). Transactive memory: Learning who knows what in work groups and organizations. In J. M. Levine & R. L. Moreland (Eds.), *Small groups: Key readings* (pp. 327-346). New York, NY: Psychology Press.

Mundell, I. (1993, April). Stop the rocket, I want to get off. *New Scientist*, *138*(1869), 34-37.

Nanus, B. (1992). *Visionary Leadership: Creating a Compelling Sense of Direction for Your Organization*. San Francisco, CA: Jossey-Bass Inc.

Palinkas, L.A. (2001). Psychosocial issues in long-term space flight: Overview. *Gravitational and Space Biology Bulletin*, *14*(2), 25-33.

Palinkas, L. A., Gunderson, E., Holland, A. W., Miller, C., & Johnson, J. C. (2000). Predictors of behavior and performance in extreme environments: The Antarctic space analogue program. *Aviation, space, and environmental medicine 71*(6), 619-625.

Patton, M. Q. (2002) *Qualitative Research and Evaluation Methods (3rd edition)*, Thousand Oaks, CA: Sage.

Pearce, C. L., & Ensley, M. D. (2004). A reciprocal and longitudinal investigation of the innovation process: The central role of shared vision in product and process innovation teams (PPITs). *Journal of Organizational Behavior*, *25*(2), 259-278.

Pultarova, T. (2012). Diego Urbina - Mars 500. Interview available online at: http://www.3eyesobserver.com/articles/astronautscosmonauts/diego-urbina-mars-500.

Rentsch, J. R., & Klimoski, R. J. 2001. Why do "great minds" think alike? Antecedents of team member schema agreement. *Journal of Organizational Behavior, 22*(2), 107-120.

Rentsch, J. R., Small, E. E., & Hanges, P. J. (2008). Cognitions in organizations and teams: What is the meaning of cognitive similarity? In B. Smith (Ed), *The people make the place: Exploring dynamic linkages between individuals and organizations* (pp. 127-155). New York, NY: Erlbaum.

Resick, C. J., Dickson, M. W., Mitchelson, J. K., Allison, L. K., & Clark, M. A. (2010). Team composition, cognition, and effectiveness: Examining mental model similarity and accuracy. *Group Dynamics: Theory, Research, and Practice*, *14*(2), 174-191.

Rouse, W. B., & Morris, N. M. (1986). On looking into the black box: Prospects and limits in the search for mental models. *Psychological Bulletin*, *100*(3), 349-363.

Salas, E.M., Driskell, J.E., & Hughes, S. (1996). Introduction: The study of stress and human performance. In J.E. Driskell & E. Salas (Eds.), Stress and human performance (pp. 1-46). Hillsdale, NJ: Erlbaum.

Salas, E., Rosen, M. A., Burke, C. S., & Goodwin, G. F. (2009). The wisdom of collectives in organizations: An update of the teamwork competencies. In E. Salas, G. F. Goodwin, & C. S. Burke (Eds.), *Team effectiveness in complex organizations: Cross-disciplinary perspectives and approaches* (pp. 39-79). New York, NY: Taylor and Francis Group.

Salas, E., Tannenbaum, S. I., Kozlowski, S. W., Miller, C. A., Mathieu, J. E., & Vessey, W. B. (2015). Teams in space exploration: A new frontier for the science of team effectiveness. *Current Directions in Psychological Science, 24*(3), 200-207.

Sandal, G. M., Leon, G. R., & Palinkas, L. (2006). Human challenges in polar and space environments. In R. Amils, C. Ellis-Evans, & H. Hinghofer-Szalkay (Eds.), *Life in extreme environments* (pp. 399-414). Dordrecht: Springer.

Santos, C. M., Uitdewilligen, S., & Passos, A. M. (2015). Why is your team more creative than mine? The influence of shared mental models on intra-group conflict, team creativity and effectiveness. *Creativity and Innovation Management*, *24*(4), 645-658.

Schneider, B., & Bowen, D. E. (1985). Employee and customer perceptions of service in banks: Replication and extension. *Journal of Applied Psychology*, *70*(3), 423-433.

Sikora, P. B., Beaty, E. D., & Forward, J. (2004). Updating theory on organizational stress: The asynchronous multiple overlapping change (AMOC) model of workplace stress. *Human Resource Development Review*, *3*(1), 3-35.

Skilton, P. F., & Dooley, K. J. (2010). The effects of repeat collaboration on creative abrasion. *Academy of Management Review*, *35*(1), 118-134.

Slack, K. J., Williams, T. J., Schneiderman, J. S., Whitmire, A. M., Picano, J. J., Leveton, L. B., ... & Shea, C. (2016). Risk of adverse cognitive or behavioral conditions and psychiatric disorders: Evidence report. *NASA: Houston*

Smith-Jentsch, K. A., Mathieu, J. E., & Kraiger, K. 2005. Investigating linear and interactive effects of shared mental models on safety and efficiency in a field setting. *Journal of Applied Psychology*, *90*(3), 523-535.

Staal, M. A. (2004). Stress, cognition, and human performance: A literature review and conceptual framework. Evidence report. *NASA: Houston*

Staw, B. M., Sandelands, L. E., & Dutton, J. E. (1981). Threat rigidity effects in organizational behavior: A multilevel analysis. *Administrative Science Quarterly 26*(4), 501-524.

Straus, S. G. (1999). Testing a typology of tasks: An empirical validation of McGrath's (1984) group task circumplex. *Small Group Research*, *30*(2), 166-187.

Stuster, J. (2010). *Behavioral Issues Associated with Long-duration Space Expeditions: Review and Analysis of Astronaut Journals: Experiment 01-E104 (Journals)*. National Aeronautics and Space Administration, Johnson Space Center.

Tadmor, C. T., Galinsky, A. D., & Maddux, W. W. (2012). Getting the most out of living abroad: Biculturalism and integrative complexity as key drivers of creative and professional success. *Journal of Personality and Social Psychology*, *103*(3), 520-542.

The Rogers Commission (1986). *Report of the Presidential Commission on the Space Shuttle Challenger Accident*, (Vols. I- V). Washington, D.C.: U.S. GPO

Thoms, P., & Greenberger, D. B. (1995). Training business leaders to create positive organizational visions of the future: is it successful? In D. Moore (Ed.), *Academy of management: Best paper proceedings* (pp. 212–216). Madison, WI: Omnipress.

Uitdewilligen, S., Waller, M. J., & Pitariu, A. H. (2013). Mental model updating and team adaptation. *Small Group Research*, *44*(2), 127-158.

Wegner, D. M. (1987). Transactive memory: A contemporary analysis of the group mind. In B. Mullen & G. G. Goethals (Eds.), *Theories of group behavior* (pp. 185-208). New York, NY: Springer

Wegner, D. M. (1995). A computer network model of human transactive memory. *Social Cognition*, *13*(3), 319-339.

Wegner, D. M., Erber, R., & Raymond, P. (1991). Transactive memory in close relationships. *Journal of Personality and Social Psychology*, *61*(6), 923-929.

Wegner, D. M., Giuliano, T., & Hertel, P. T. (1985). Cognitive interdependence in close relationships. In W. Ickes (Ed.), *Compatible and incompatible relationships* (pp. 253-276). New York, NY: Springer.

Wildman, J. L., Thayer, A. L., Pavlas, D., Salas, E., Stewart, J. E., & Howse, W. R. (2012). Team knowledge research: Emerging trends and critical needs. *Human Factors, 54*(1), 84-111.

Wood, J., Lugg, D. J., Hysong, S. J., & Harm, D. L. (1999). Psychological changes in hundred-day remote Antarctic field groups. *Environment and Behavior*, *31*(3), 299-337.