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On Shifting from Autonomous to Interdependent Work

What we know and what we need to learn

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Executive Summary

Problem

A recent analysis of the team training needs of Long Duration Space Flight Crews (Smith-Jentsch et al., 2011) noted that ISS crews must shift to highly interdependent tasks after long periods of autonomous work. Interviews with former ISS crew members revealed that such shifts are believed to create risks with regard to crew performance. Although team adaptability and task interdependence have been studied for decades, the existing literature has a number of gaps that need to be attended to, in order to address the challenges ISS crews face when shifting from one level of task interdependence to another.

Objectives of This Report

- Synthesize the existing literature pertinent to the problem of ISS crews shifting from autonomous to highly interdependent work
- Identify research questions that remain to be answered in order to address this problem
- Identify operational implications with respect to crew performance and training.

Research Gaps

- Shifts in task interdependence over time have not been examined.
- The physiological, cognitive, and social impacts of autonomous work on crew members have not been examined simultaneously.
- The range of interdependence experienced by ISS crews is not reflected in prior studies.
- Few studies have investigated how objective task characteristics affect team members' perceptions of their interdependence and vice versa.

Operational Impacts of Research on Team Task Shifting

- Training and pre-debriefing strategies could be developed to facilitate team task shifts.
- Crew commanders, mission controllers, and others could be trained to monitor for symptoms signaling a potential problem in team task shifting.
- Task schedules could be designed to reduce the risks associated with team task shifting.
- Individuals' preferences/predispositions regarding interdependent work could be considered when composing crews.

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Introduction

A recent training needs analysis conducted for Long Duration Space Flight Crews, (Smith-Jentsch et al., 2011) noted that ISS crews must adapt to extreme shifts in task interdependence after long periods of social entrainment. Although team adaptability and task interdependence have been studied for decades, the existing literature has a number of gaps that need to be closed in order to address the challenges ISS crews face when shifting from one level of task interdependence to another. The following sections describe four methodological limitations in this regard. Throughout this report, quotations taken from the author's prior interviews with NASA astronauts are used to illustrate the points made.

The Need for Within-Subjects Designs

Task interdependence refers to the degree to which team members share materials, information, or expertise in order to achieve their goals (Cummings, 1978; Susman, 1976), whereas *goal interdependence* refers to the degree to which group members are assigned joint group goals and given group-level feedback (e.g., Thomas, 1957; Tjosvold, 1986). A substantial number of studies have compared the performance of teams working under conditions of high task and/or goal interdependence to those working under low task and/or goal interdependence using a between-subjects design (e.g., Cleavenger, Gardner, & Mhatre, 2007; Rico & Cohen, 2005). These studies have generally found that higher levels of interdependence are associated with desirable team attitudes (Ramamoorthy & Flood, 2004), shared team knowledge (Zhang, Hempel, Han, & Tjosvold, 2007), and coordination processes (De Dreu, 2007; Gonzales, 2011; Somechi, Desvilya, & Lidogoster, 2009; Van der Vegt & Janssen, 2003). Moreover, the impact of team attitudes, knowledge, and behavior on team performance is generally stronger under conditions of high interdependence than under conditions of low interdependence (Bachrach, Powell, Collins, & Richey, 2006). Thus, highly interdependent tasks appear to both lead to, and require, team-related *knowledge, skills, and attitudes (*KSAs*)* to a greater degree than do less interdependent tasks. However, results from between-subjects comparisons of interdependence do not necessarily generalize to the problem of shifting from one level of interdependence to another since patterns of team interaction tend to persist even after environmental changes make them maladaptive (e.g., Uitidewilligen, Waller, & Pitariu, 2013).

"I believe that the greatest danger [is in the] transition from laid back to dynamic ops."

In this regard, prior research has employed within-subjects designs to investigate shifts from one team structure to another (e.g., centralized-decentralized decision making). However, no *published* research has directly tested the impact of requiring teams to shift from one level of task interdependence to another. Such research is needed in order to answer the following research question.

Research Question:

- What are the specific types of coordination breakdowns that can occur when crews shift from autonomous to highly interdependent work?

Operational Impact:

- If research can determine the specific types of coordination breakdowns that threaten crews' ability to shift from autonomous to highly interdependent work, measures could be developed to help crews monitor for such risks.

Simultaneous Consideration of Multiple Forms of Entrainment

Entrainment, broadly defined, is a phenomenon in which two or more independent rhythmic processes synchronize with each other (McGrath, Kelly, & Machatka, 1984; McGrath & Rotchford, 1983). There are a number of different forms of entrainment that are relevant to the problem of shifting from low to high levels of interdependence on the ISS, and each has the potential to affect and interact with the other. First, s*ocial entrainment* refers to the development of self-reinforcing norms with respect to social interaction (Ancona & Chong, 1996). Studies of social entrainment have demonstrated that teams have difficulty shifting from one structure to another and that the strength of these effects depends on the direction of the shift. For instance, Johnson, Hollenbeck, Humphrey, Ilgen, Jundt, and Meyer (2006) found that it was easier for teams to shift from a cooperative to a competitive reward structure than to do the reverse.

Temporal entrainment occurs when teams synchronize the pacing and sequencing of their tasks to the same external pacer. Prior research has shown that temporal entrainment is associated with more effective team processes (Jansen & Kristof-Brown, 2005) and that it is task-specific (Mohammed & Nadkarni, 2011).

Lexical entrainment refers to the process by which individuals who are engaged in conversation progressively adopt the same terms as referents to a particular object or concept (Brennan & Clark, 1996; Levitan & Hirschberg, 2011; Reitter, Keller, & Moore, 2006). Lexical entrainment facilitates comprehension by accelerating recall and reducing misinterpretations, which in turn improves team member communication. However, similar to social entrainment, individuals have been shown to persist in using entrained language even when speaking to listeners who are unfamiliar with that language, leading to comprehension problems and communication delays (Engelhardt, Bailey, & Ferreira, 2006).

Cognitive entrainment among team members occurs when they adopt increasingly similar cognitive structures and processes over time. Prior research has shown that team members develop similar cognitive representations of their tasks, roles, and relative expertise after working together on interdependent tasks (e.g., transactive memory systems, TMS; Campion, Papper, & Medsker, 1996; Goodman & Leyden, 1991; Smith-Jentsch, Kraiger, Cannon-Bowers, & Salas, 2009) and that teams with such shared team cognition tend to be more effective (Austin, 2003; Lewis, 2004; Zhang et al., 2007). However, when teams fail to update their shared cognition in reaction to changes in their environment, performance suffers (e.g., Uitdewilligen et al., 2013).

Physiological entrainment refers to the process whereby individuals develop similar physiological patterns as a function of face-to-face contact. Prior research has shown that individuals who interact face-to-face develop similar heart rates (Watanabe, Okubo, & Kuroda, 1996), respiration (Watanabe & Okubo, 1997), sleeping patterns (Hida, Kitamura, & Mishima, 2012) and posture (Strang et al., 2011). Team members who demonstrate greater physiological entrainment have been shown to communicate more and report greater cohesion than do members who exhibit less physiological entrainment (Wheatley, Kang, Parkinson, & Looser, 2012).

Finally, e*motional entrainment* occurs when individuals begin to mirror one another's affective states; in other words, team members' moods become more similar over time. Drawing on evolutionary psychology (e.g., Cosmides & Tooby, 2000), Spoor and Kelly (2004) argued that emotional entrainment allows group members to quickly convey information regarding their perceptions of the team's environment (e.g., signaling danger) and fosters interpersonal bonds and group loyalty. Although the entrainment of positive mood states has been associated with improved cooperation and decreased conflict (Barsade, 2002); the entrainment of negative affective states (e.g., burnout) has also been shown to have negative effects on individual members (Bakker, van Emmerik, & Euwema, 2006).

In sum, there are a number of different forms of entrainment that are likely to affect ISS crews' ability to shift from periods of autonomous to highly interdependent work; and each may affect or interact with the other. For instance, long periods of autonomous work are likely to result in a loss of temporal, emotional, physiological, and lexical entrainment which, in turn, may cause crews to resist increasing their interdependence with one another (i.e., strengthening social entrainment to patterns associated with low interdependence). Prior published research has generally examined one form of entrainment independent of others. Additional research is needed in which multiple forms of entrainment are considered simultaneously so that their combined effects on team task shifting can be determined.

Research Questions:

- What is the rate at which crews develop and lose various forms of entrainment?
- Are there combinations of entrainment (e.g., lexical and cognitive) that are particularly problematic or helpful?

Operational Impact:

- If research can specify the length of time it tasks crews to gain and to lose entrainment, this information could be used to alert crew commanders and/or mission controllers to the potential for problems.
- If research can specify the manner in which various types of entrainment or lack of entrainment combine to affect performance, this crew commanders and mission controllers could be trained to monitor for related behaviors that indicate crews are particularly at risk for errors.

Range of Goal and Task Interdependence

> *"You are spread out most of the time, 75% of the time you're on your own."*

A third important gap in the literature is that prior studies have primarily focused on a limited range of interdependence that does not fully capture the range of interdependence experienced by ISS crews. First, most prior studies focus exclusively on levels of positive goal interdependence. *Positive goal interdependence* exists when there is a positive relationship between one's goal attainment and the goal attainment of others. *Goal independence*, in contrast, exists when the achievement of one's goals is unrelated to the goal achievement of others, whereas *negative goal interdependence* exists when there is a negative relationship between one's goals and the goals of others (i.e. a zero-sum game). Finally, a*symmetric interdependence* exists when only one member benefits (or benefits to a greater degree) from the other's success. Very few studies have investigated the impact of goal independence, negative interdependence, or asymmetric goal interdependence. This is an important gap because the sparse evidence that does exist indicates that these forms of interdependence have very different (and often negative) effects on team performance (e.g., Kumar, Scheer, & Steenkamp, 1995).

> *"If you don't work-out [on station], you're going to have bad bone loss; [it's also] a stress reliever. People have to get off the [exercise] equipment at times so somebody else can get on."*

Former ISS crew members interviewed by the present author reported that, for the majority of their mission, they had no positive goal interdependence other than the obvious goal to return safely and without damage to the station. However, they did describe instances of both *negative* and/or asymmetric *resource interdependence.* For instance, ISS crew members share finite resources such as food, exercise equipment, computing equipment, electrical power, etc. (as the above quotation demonstrates).

With respect to *task* interdependence, nearly all prior research has operationalized the low end of the continuum as being "pooled" or "additive" in nature where group performance is truly a sum of individual parts (e.g., Bachrach et al., 2006; Bachrach, Powell, Bendoly, & Richey, 2006). However, the low end of the continuum for ISS crews is no task interdependence at all. Thus, in order to capture the challenges that ISS crews face, research must examine extreme shifts from a complete absence of task interdependence to *intensive team interdependence* (Tesluk, Mathieu, Zaccaro, & Marks, 1997*),* characterized by a simultaneous, multi-directional workflow, to a complete lack of task interdependence. Such experiments are necessary in order to address NASA's need to understand the challenges involved in team task shifting on the ISS.

Research Question:

- To what degree does perceived asymmetric and/or negative task interdependence between crew members interfere with team performance when shifting from autonomous to interdependent work?

Operational Impact:

- If it is determined that asymmetric and/or negative task interdependence has a significantly detrimental effect on crew performance, crew commanders and mission planners could parse and assign tasks in such a way so as to minimize these problems.

Bi-directional Relationships between Actual and Perceived Interdependence

A fourth gap in the current literature is that interdependence is seldom manipulated *and* measured in the same study. Studies of goal and task interdependence involving real work teams almost exclusively *measure* individuals' *perceptions* and rarely report evidence of team members' perceptual agreement in this regard. Thus, it is unclear to what degree individuals' perceptions reflect actual interdependence or organizationally-intended levels of task interdependence and to what degree they reflect individual differences in preferences for interdependence. Laboratory experiments, on the other hand, almost exclusively manipulate goal and task interdependence and rarely measure team members' perceptions of such interdependence. Thus, it is unclear to what degree members view or perform their tasks with the level of interdependence intended. This is important since team members' preferences for interdependence have been shown to predict later levels of actual interdependence (e.g.,

Wageman & Gordon, 2005). For instance, Mihm and Smith-Jentsch (2013) demonstrated that participants scoring higher on the personality trait agreeableness tended to perceive greater positive goal interdependence between themselves and a teammate than did those scoring lower in agreeableness, even when objective levels of goal interdependence were held constant. Perceived interdependence, in turn, was associated with greater information exchange during the team task. Using the same experimental protocol, Sierra, Rico, Smith-Jentsch, and Mihm (2013) found that team members decreased their interdependence with another teammate if that teammate *perceived* negative goal interdependence between them. This effect was strongest if the teammate was experiencing stress at the time. Thus, individuals appear to learn how their teammates perceive interdependence and attempt to accommodate those perceptions.

There is also evidence that team members' level of agreement with respect to their interdependence plays an important role. In a study of air traffic control teams, Smith-Jentsch, Mathieu, and Kraiger (2005) found that teams whose members held more similar mental models of their position-specific goal interdependence out-performed those with less similar mental models, but only if they also agreed upon cue-strategy associations that would cause them to shift their strategy. For teams that did not share such cue-strategy associations, similar perceptions of goal interdependence were negatively related to performance.

Together, results from these studies suggest that perceived interdependence, agreement among team members with respect to interdependence, and the objective interdependence built into a task interact in complex ways to impact team performance. Additional laboratory research is needed in which goal and task interdependence is simultaneously manipulated (through task instructions and training) and measured (via perceptions, preferences, and behaviors). This type of research is necessary in order to answer the following research questions:

Research Questions:

- To what degree do individuals have stable versus malleable perceptions/preferences for task interdependence?
- In what ways do such individual differences influence team performance when the task environment requires a shift from low to high interdependence?

Operational Impacts:

- If it is determined that individual differences in preferences for and predispositions toward task interdependence are stable over time and have a consistently positive or negative impact on team performance, such preferences/predispositions could be measured and used to screen out candidates with extreme scores as part of the *selection* process.
- If it is determined that individual differences in preferences for and predispositions toward task interdependence have a consistently positive or negative impact on team performance, however these are malleable, *training* can be developed to address this.
- If it is determined that *crew compatibility* in terms of preferences for and predispositions toward task interdependence is critical, this could become a factor considered when making decisions about *crew composition*.

Contextual Moderators

There are at least three moderating conditions that should make shifting from autonomous to interdependent work particularly difficult for ISS crews: (1) the timing of the autonomous period with respect to a crew's development, (2) the length of the autonomous period, and (3) the degree to which intra-crew fault-lines exist. The following sections describe the manner in which these factors are expected to exacerbate the problem of team task shifting.

Phase of Team Development

Tuckman's (1965) model of group development maintains that all teams go through the same necessary and inevitable stages as they develop (i.e., forming, storming, norming, and performing). During the *forming* stage, members are motivated by a desire to be accepted by the others and to avoid contention. This stage is followed by a *storming* stage characterized by conflict as members clash due to their discrepant points of view on team functioning. If a team makes it through this stage intact, they proceed to the *norming* phase where members focus on coming to agreement on expectations and roles and are motivated to compromise. It is during

this phase that team members develop social, cognitive, lexical, and emotional entrainment with one another. Finally, in the *performing* stage, positive attitudes and shared knowledge that were developed in the norming stage allow teams to coordinate efficiently, resolve conflicts effectively, and maximize the use of their collective expertise.

> *"People and personalities that you're familiar with …that totally changes. [And] It's not like it gradually changes, it entirely changes when the hatch closes."*

The current practice on the ISS is for six crew members to be on the ISS at all times. Every three months, three of the six crew members leave and three new crew members arrive. This means that each three-person crew must go through the forming-storming-norming-performing developmental process twice during the six month period they are on the ISS (i.e., once when they arrive and once when their crew changes after three months). Switching from autonomous to highly interdependent tasks should be more difficult for crews the earlier the tasks occur in the lifespan of a particular six-person crew. Specifically, prior to completing the norming phase, crews will not have developed positive attitudes (e.g., cohesion, collective efficacy) and shared knowledge (e.g., about teammates' expertise) that they can refresh and build upon after a shift from autonomous to interdependent work.

Moreover, such crews are likely to become "stuck" at the forming or storming phases. Progression from the forming to the storming stage requires a stimulus to incite members to discuss and negotiate their points of view. Thus, if a crew experiences a period of autonomous work while they are still in the forming stage (immediately or shortly after a partial crew change), there will be little to stimulate a progression to the storming stage. If a crew has begun but not yet passed through the storming stage when they experience a period of autonomous work, they are less likely to ignore rather than work through their conflicting expectations. Consistent with this notion, prior research has shown that teams with low interdependence tend to engage in less cooperative conflict management (Somechi et al., 2009). Moreover, teams tend to react to conflict by *reducing* rather than increasing their interdependence (Langfred, 2007). It follows that the intra-crew conflict associated with the storming stage should undermine the crew's ability to shift to higher levels of interdependence.

Research Question:

- Can we specify when during a team's developmental process they are best and least prepared to effectively make shifts from low to high levels of interdependence?

Operational Impact:

- If there is a fairly predictable length of time since crews need to have worked together to develop a capacity to effectively shift from low to high task interdependence, and this can be specified, mission planners could use this information when creating task schedules.

Length of Autonomous Work Period

A second factor that is likely to hamper shifts from autonomous to interdependent work is the length of the autonomous period. Research has shown that knowledge and knowledge structures are more easily retrieved when they have been frequently or recently activated (Higgins, Bargh, & Lombardi, 1985; Wyer & Srull, 1986). When crew members are performing independent tasks, they have little need to activate knowledge about their teammates' expertise or knowledge about the nature of teamwork itself. Moreover, long periods of physical separation are likely to make crew members' collective identity less salient. Self-categorization theory (Turner, Oakes, Haslam, & McGarty, 1994) emphasizes that the manner in which one categorizes him-/herself is highly dependent on contextual shifts in his/her frame of reference and that information about the one's personal self and one's collective self are stored in different locations within long-term memory. Consistent with this notion, when individuals are primed with the words "us" or "we," they are more likely to retrieve information associated with their collective identity and are more likely to be swayed by social norms, whereas the reverse is true when they are primed with the words "I" or "me" (Higgins, King, & Marvin, 1982; Markus, Smith, & Moreland, 1985).

> *"When you are very focused on something... [, for example,] an experiment, you forget about all the stuff that's around you."*

During periods of autonomous work on the ISS, the contextual cues crew members are exposed to should increase the degree to which cognitions related to their independent selves are activated and should decrease the degree to which team-related cognitions are activated. Thus, the longer the period of autonomous work, the less accessible team-related cognitions should be to them. As such, additional research is needed to answer the following research questions.

Research Questions:

- At what rate does team-related knowledge decay/become less accessible to crew members?
- Can refresher training be used to prevent or to slow the decay of team-related knowledge during periods of autonomous work?

Operational Impacts:

- If there is a predictable rate at which crew members' teammate-related knowledge decays during autonomous work periods, mission planners could use this information as a factor to consider when making task schedules.
- If refresher training can be demonstrated to regain or to slow the decay of teammate-related knowledge during autonomous work periods, such training could be provided to crews.

Team Composition and the Potential for Fault-lines

A third factor that should interfere with shifts from autonomous to interdependent tasks involves crew composition and team fault-lines. Team fault-lines are "hypothetical dividing lines that split a group into subgroups based on one or more attributes" (e.g., Russian and American; Lau & Murnighan, 1998; p. 328). Team fault-lines have been shown to reduce information sharing among teammates (Homan, van Knippenberg, Van Kleef, & De Dreu, 2007) and to lower team performance (Thatcher & Patel, 2011). It is important to note that perceived fault-lines may or may not develop within a team of diverse members. They are most likely to occur when sets of at least two members share multiple attributes (e.g., nationality and education) that are not shared by the rest of a team.

> *"It makes a difference whether or not … [crew members] have the background or the same language…in terms of camaraderie...comfort level."*

Perceived fault-lines may become more salient during periods of autonomous work, ultimately interfering with the inevitable shift back to interdependent tasks. Specifically, crew members have fewer formal demands for communication during periods of low interdependence and thus they have the freedom to communicate less with out-group members and more with in-group members. Consistent with this notion, previous research has shown that fault-lines are particularly problematic for less interdependent teams (Rico, Molleman, Sánchez-Manzanares, & Van der Vegt, 2007). On the ISS, crew members who choose to work in close proximity with in-group members are more likely to develop physiological, lexical, and emotional entrainment with these members, increasing their similarity with in-group members (and to their common dissimilarity from out-group members). In this way, autonomous work periods on the ISS should strengthen and/or to create perceived crew fault-lines. ISS crews have been and will likely always be multi-cultural/multi-national in composition. Moreover, sections of the ISS are owned by different countries and during autonomous work periods, individual crew members primarily perform their tasks in their own country's segment. Thus, one cannot ignore the possibility that cultural fault-lines may develop and/or become stronger during periods of autonomous work and that this may interfere with team task shifting. Specifically, perceived fault-lines have been shown to reduce the degree to which members elaborate on one another's task-related information (Homan et al., 2007). In this way, such fault-lines may prevent a crew from integrating their diverse perspectives and expertise after a shift to interdependent work when such integration is critical.

Research Question:

- Do cultural fault-lines develop and/or become stronger during periods of autonomous work on the ISS?
- If so, how long does it take for this to occur?

Operational Impact:

- If it is determined that fault-lines do in fact become stronger during autonomous work periods, crew members from different countries could be intentionally paired to perform housekeeping/maintenance tasks or to participate in refresher training together during such periods to alleviate the problem.

Unique Impact on Distinct Teamwork Processes

A recent NASA advisory meeting was convened in order to review and edit the Space Flight Resource Management (SFRM) criteria. On the basis of this meeting, a set of four dimensions were defined and will be trained and measured in the most recent update of NASA's SFRM program. These four dimensions (Leadership/Followership, Supporting Behavior, Information Exchange, and Communication Delivery) have been demonstrated to predict team performance in earlier empirical work (Smith-Jentsch, Johnston, & Payne 1998). Thus, the following sections are organized around this model.

Leadership/Followership

> *"You have to be a follower or a leader, you're going to be doing both."*
> *"At any given time, the commander [is not] the one who has the knowledge to carry out that part of the mission."*

Effective *leadership/followership* is one of the critical dimensions of effective flight crew teamwork defined in the current instantiation of SFRM. Given the diversity in functional expertise, experience, backgrounds, and complementary knowledge of its crew members, shared leadership is an expectation on the ISS and is needed in order to act in accordance with sudden situational demands. Shared leadership has been defined as the practice of "broadly sharing power and influence among a set of individuals rather than centralizing it in the hands of a single individual who acts in the clear role of a dominant superior" (Pearce, Manz, & Sims, 2009, p. 234). Prior research has shown that managers of subordinates with less interdependent goals make greater use of directive influence and less use of collaborative influence (Tjosvold, Andrews, & Struthers, 1992). Moreover, members of less interdependent teams view leaders as having greater status when they adopt a powerful speech style, whereas the reverse is true in highly interdependent tasks (Fragale, 2006). A formal leader's ability to exert influence through sources of person power (i.e., the leader's knowledge, skills, and abilities) is limited in tasks with low interdependence (e.g., Ellyson & Dovidio, 1985; Mast, 2010). Specifically, followers are less susceptible to emotional contagion from a leader when they perceive lower interdependence

(Eberly & Fong, 2013). This means that the formal leader is less able to leverage *referent power* (based on follower's loyalty, respect, admiration, affection; French & Raven, 1959) in order to gain compliance. Although crew commanders have a greater ability to exert referent power when a crew shifts to interdependent work, there is a danger that *social entrainment* processes may prevent them from making a shift to a more collaborative leadership style. Prior studies have demonstrated that individuals respond to dominant behavior by adopting a more compliant approach (Sadler & Woody, 2003). Over time during a period of autonomous work, such a pattern of dominant leadership and more compliant followership should lead to an increase in perceived p*ower distance* (i.e., the expectation that power is not distributed equally) between the leader and the rest of the crew (Hofstede, 1980). Perceived power distance has been negatively associated with followers' willingness to express constructive challenges to a status quo (Botero & Van Dyne, 2009). The SFRM definition of effective leadership/followership states that when filling the role of the "situational leader," crew members are expected to offer recommendations but should defer to the formal leader when a recommended action is overruled, unless there is a threat to safety or mission success. During relatively autonomous work periods, it is less likely that deference to the commander will pose a threat to safety or mission success. Thus, adopting a more compliant approach is not necessarily a problem. However, during highly interdependent tasks, performance decrements are likely to occur if power distance norms, developed during a prior period of autonomous work, inhibit crew members from constructively challenging the formal commander.

Shared leadership requires a perceptual differentiation among team members' individual bases of "expert power" in varying domains. *Expert power* refers to the "ability to influence other parties based on expertise and knowledge" (French & Raven, 1953, p. 163). When crew members hold shared knowledge about their relative strengths and weaknesses, this should motivate them to utilize and to accept technical leadership based on the unique expertise of crew members. However, the independence of their tasks during autonomous periods makes it less likely that members will engage in the type of task-related discussions that are necessary in order to build or make salient such knowledge. If knowledge about one another's expertise is not shared, accurate, and salient to crew members, this should inhibit their willingness to participate actively in shared leadership even after a shift to more interdependent work makes shared leadership critical. In sum, additional research is needed to investigate the following research questions.

Research Questions:

- Does perceived power distance increase during periods of autonomous work and does this interfere with shared leadership when a crew shifts to a more interdependent task?
- Does teammate-specific knowledge become less accessible over time during autonomous work periods and does this hinder increases in shared leadership when a crew shifts to a more interdependent task?

Operational Impacts:

- If power distance does in fact increase over time during autonomous work periods and this impairs shifts to higher levels of interdependence, crew commanders could be trained in ways to explicitly communicate expectations for shared leadership and reminded to do so prior to a task shift.
- If decay in teammate-specific knowledge during autonomous periods is shown to interfere with shifts to higher levels of shared leadership, pre-briefings could be structured to explicitly make salient each crew members' unique expertise.

Supporting Behavior

Supporting behavior is the second dimension within the latest SFRM framework. Supporting behavior is defined as actions taken by team members that enable them to effectively compensate for one another. This involves taking actions to prevent errors, making team members aware when an error has occurred (including the admission of one's own errors), and correcting errors. It also involves providing or requesting assistance when needed, and managing the distribution of workload effectively.

> *"You have to have the ability to … sense your teammates" [It's important to] "look out for other people who are excessively tired, rushing, making mistakes."*

Previous research has shown that supporting behavior can either facilitate or hinder team performance depending on the degree to which a backup provider has the ability to provide support without neglecting his/her own task responsibilities (Barnes, Hollenbeck, Wagner, DeRue, Nahrgang, & Schwind, 2008; Porter, Gogus, & Yu, 2010). Moreover, shifting workload effectively requires some degree of coordination as members determine what sort of support is needed and who among them is best suited to provide it. Consistent with this notion, team

members are more willing to ask for and to accept backup and error correction when they hold shared knowledge regarding the distribution of expertise among them and report higher levels of collective efficacy (Smith-Jentsch et al., 2009). Highly interdependent teams show greater levels of both collective efficacy and shared teammate knowledge (Alavi & McCormick, 2008; Yuan, Fulk, Monge, & Contractor, 2010). Thus, ISS crews may engage in less supporting behavior after a shift to a highly interdependent task because they did not develop or did not activate knowledge about one another's unique expertise during a preceding period of autonomous work. Further, prior research has shown that physical separation from one's teammates lowers their collective orientation (Smith-Jentsch, Kraiger, Salas, & Cannon-Bowers, 1999), and that those low in collective orientation pay less attention to their teammates than do those with higher collective orientation (Driskell & Salas, 1992). This means that crew members are less likely to have a collective awareness of one another's dynamic internal states (e.g., physical health, fatigue, level of frustration; Daassi & Favier, 2005) following a period of autonomous work. This should interfere with their ability to distribute the workload effectively and monitor one another effectively when they shift to a highly interdependent task. Thus, future research should investigate the following research questions:

Research Questions:

- Does crew members' level of collective awareness with respect to one another's physical and emotional states decrease during autonomous work periods, and does this interfere with their ability to manage the distribution of workload after a shift to more interdependent work?
- Are crews better able to engage in effective supporting behavior after a shift to interdependent work if they hold shared and highly accessible knowledge about one another's relative strengths and weaknesses?

Operational Impacts:

- If it is found that supporting behavior is impaired after a shift from autonomous to interdependent work due to the decay of teammate-specific knowledge, training and pre-briefing strategies could be developed specifically to alleviate this problem.
- If it is found that crew members lose collective awareness during autonomous periods and that this hinders their ability to manage workload effectively, structured pre-briefings could be explicitly designed so members re-develop a collective awareness of one another's states (e.g., fatigue, health).

Information Exchange

Team information exchange is a third teamwork dimension defined in the most recent set of SFRM skills. Information exchange involves pushing and pulling information to and from the right people at the right time. Specifically, crew members are expected to fully utilize all possible sources of information, to pass information proactively to others, and to integrate information to provide teammates with situational updates. Effective shifts from autonomous to interdependent work require crews to increase the degree to which they exchange information. However, their ability to do so will be impaired by a lack of *temporal entrainment* and *shared temporal cognition*.

> *"We're going to have another vehicle coming' and so should you sleep shift right, or should you sleep shift left? Should you take meds? Not everybody adapts at the same pace"*

Crew members' tasks and schedules are largely independent from one another during autonomous work periods. As such, they are likely to become highly entrained to their own temporal orientation (e.g., in pacing and time urgency). Consistent with this notion, astronauts describe having diverse sleeping, eating, and work schedules. Such temporal diversity should also have a negative impact on information exchange after a shift to interdependent work. Prior research has demonstrated that diversity with respect to team members' temporal orientations is negatively associated with team performance (Mohammed & Nadkarni, 2011), particularly when it is coupled with a lack of shared temporal cognition which is a common understanding of time-related aspects of a team's task (Mohammed & Nadkarni, 2014). Like other dimensions of team-related cognition, shared temporal cognition, if it had been previously developed, is likely to have decayed and/or become less accessible after a long period of autonomous work. This means that when shifting from autonomous to highly interdependent work, crew members are both more likely to be temporally out of sync and less likely to hold shared temporal cognition. This could result in ambiguity and/or conflict regarding when information is available and when it is expected to be exchanged (McGrath, 1991; McGrath & Kelly, 1986; McGrath & Rotchford, 1983). Previous research has shown that team members tend to react to conflict by loosening rather than increasing their interdependencies with one another (Langfred, 2007). Thus, there is a

risk that crews shifting from autonomous to more interdependent tasks may resist increasing their information exchange in order to alleviate conflicts. In sum, the following research questions should be addressed in future research.

Research Questions:

- Does temporal diversity increase over time during autonomous work periods, and does this impair a crew's ability to exchange information after a shift to interdependent work?
- Do crews hold less shared temporal cognition after a period of autonomous work, and does this interfere with information exchange following a shift to more interdependent work?

Operational Impacts:

- If it is found that crew members become increasingly diverse with respect to their sleeping, eating, working schedules during periods of autonomous work, and that this impairs information exchange after a shift to highly interdependent work, crews could be scheduled/instructed to gradually synchronize themselves in this respect leading up to a planned task shift. Crews could also use structured pre-briefings to develop/re-develop shared temporal cognition.

Communication Delivery

A fourth dimension of teamwork defined in the current instantiation of SFRM skills is c*ommunication delivery.* Whereas information exchange involves knowing what to pass to whom and when, communication delivery refers to techniques designed to ensure messages are understood as intended. This includes using proper terminology, packaging calls in a clear, complete, and efficient manner, asking questions for clarification, and knowing what to do with the information. This section details some of the challenges associated with communication delivery that crews face when shifting from autonomous to highly interdependent tasks.

> *"He knew if we had to stop and explain something that might slow [us] down"*

During periods of autonomous work, crew members engage in much less task-related communication with one another than they do during interdependent periods. However, they do communicate with team members on the ground regarding their individual projects and, as such, may develop lexical entrainment with ground crew members, especially in situations immediately following a long period of autonomous work. Numerous studies have found that once an individual has entrained to a particular reference, they tend to persist in using that reference even when it is unnecessarily specific and even when their audience is unfamiliar with it (e.g., referring to an incident that occurred prior to a crew shift when some members were not present; Brennan & Clark, 1996; Deutsch & Pechmann, 1982; Mangold & Pobel, 1988; Van Der Wege, 2009). This occurs because it is difficult to suppress the retrieval of linguistic information that is highly accessible in memory (Wardlow, Lane, & Ferreira, 2008; Wardlow, Lane, & Liersch, 2012). Since listeners expect speakers to use descriptions that most efficiently convey a concept, the use of an over-specified, unfamiliar description can slow comprehension (Engelhardt et al., 2006; Gann & Barr, 2012). *Recipient design* (Sacks, Schegloff, & Jefferson, 1974) or *audience design* (Clark & Murphy, 1982) are terms used to describe the processes whereby speakers adapt their language to the unique characteristics of listeners. Self-prompted audience design relies on knowledge the speaker holds about their partner's social identity and their common experiences (Clark & Marshall, 1981), whereas other-prompted adaptations are made in response to feedback from the listeners themselves. Research has shown that speakers rely most heavily on other-prompted audience design when they know that it is available to them but that this becomes increasingly inefficient as the number of listeners increases (Rogers, Fay, & Maybery, 2013). Such inefficiencies may not be problematic during periods of autonomous work but could have more serious effects during highly interdependent work. It has been argued earlier in this report that crew members' teammate-specific knowledge becomes less accessible to them during periods of autonomous work. This should inhibit their ability to engage in self-prompted audience design, leading them to rely more heavily on the less efficient method of other-prompted audience design. As such, future research should investigate the following research questions:

Research Questions:

- Does lexical entrainment with team members on the ground lead crew members to use phraseology that is not recognized by all crew members and does this lead to comprehension problems after a shift to more interdependent work?
- Does the inaccessibility of teammate-specific knowledge lead to less efficient communication delivery after a shift from autonomous to interdependent work?

Operational Impacts:

- If it is found that communication delivery is impaired by the decay of teammate-specific knowledge during periods of autonomous work (e.g., remembering which terms are familiar to which team members), training and pre-briefing strategies could be developed to explicitly refresh such knowledge in preparation for a pre-planned shift to interdependent work.

Summary

The objective of the current report was to identify potential problems crews face when shifting from autonomous to interdependent work, to summarize lessons learned from existing literature in this regard, to identify research questions that remain unanswered, recommend research to answer those questions, and predict the operational impacts that such research could have. To summarize, the most glaring gaps in the literature stem from the fact that (1) few studies have employed longitudinal designs to explore the impacts of task shifts, (2) prior research has failed to consider the impact of multiple forms of entrainment (e.g., physiological, lexical, social) simultaneously, (3) experimental conditions in prior studies do not reflect the range and type of interdependence flight crews face (e.g., complete autonomy, negative or asymmetric interdependence).

I have also proposed three contextual factors that should make shifts from autonomous to interdependent work particularly challenging for crews: (1) the point in a crew's development that a shift is required (more challenging early), (2) the length of the autonomous work period preceding a shift (longer periods more challenging), and (3) the degree to which potential crew fault-lines exist (e.g., cultural, educational). I have argued that research in this area should investigate the moderating effects of these three factors.

Finally, I have offered some initial hypotheses with regard to the impact of shifts in task interdependence on four teamwork dimensions that are listed among the Space Flight Resource Management criteria: (1) Leadership/Followership, (2) Supporting Behavior, (3) Information Exchange, and (4) Communication Delivery. I have argued that each of these processes could break down in the event of a shift in task interdependence, and I have specified the cognitive and affective mechanisms (i.e., mediators) that are likely to explain these performance effects. I have organized the research questions and related operational impacts described in this report within Table 1 on the following pages. The final two columns of this table indicate the relative difficulty and investment required to conduct the research necessary to answer each question, and the investment and potential pay-offs expected by each operational impact.

Table 1. *Listing and Brief Description of Research Questions*

Research Q's	**Difficulty/ Investment**	**Operational Impacts**	**Difficulty/ Investment**
What are the specific types of coordination breakdowns that can occur when crews shift from autonomous to highly interdependent work?	Could be tested in lab or analogue	Measures could be developed monitor for indications that a crew is not effectively shifting from autonomous to interdependent work.	Moderate to high difficulty and cost (depending on type of measures)
To what degree does perceived asymmetric and/or negative task interdependence between crew members interfere with team performance when shifting from autonomous to interdependent work?	Could be tested in lab or analogue	Crew commanders and mission planners could parse and assign tasks in such a way so as to minimize asymmetric and/or negative task interdependencies.	Low to moderate complexity Low cost
What is the rate at which crews develop and lose various forms of entrainment? Are there combinations of entrainment (e.g., lexical and cognitive) that are particularly problematic or helpful?	Long-term Repeated Data collection On ISS	Mission controllers could use this information when scheduling crew tasks. Crew commanders could be trained to monitor for indicators of various forms of entrainment and/or lack thereof.	Moderate complexity Low cost Low difficulty Low cost
Contextual Moderators			
Can we specify when during a team's developmental process they are best and least prepared to effectively make shifts from low to high levels of interdependence?	Long-term Repeated Data collection On ISS	Mission planners could use this information when scheduling crew tasks.	Moderate complexity Low cost
At what rate does team-related knowledge decay/become less accessible to crew members during periods of autonomous work?	Long-term Repeated Data collection On ISS	Mission controllers could use this information when scheduling crew tasks.	Low difficulty Low cost
Do cultural fault-lines develop and/or become stronger during periods of autonomous work on the ISS?	Long-term Repeated Data collection On ISS	Crew members from different cultures could be assigned to perform maintenance / housekeeping tasks and/or refresher training together during autonomous periods.	Low difficulty Low Cost

Table 1 (cont.). *Listing and Brief Description of Research Questions*

Leadership/Followership			
Does perceived power distance increase during periods of autonomous work and does this interfere with shared leadership when a crew shifts to a more interdependent task?	Could be tested in lab or analogue	Crew commanders could be trained in ways to explicitly communicate expectations for shared leadership and reminded to do so prior to a task shift.	Low Difficulty Low cost
Does teammate-specific knowledge become less accessible over time during autonomous work periods and does this hinder increases in shared leadership when a crew shifts to a more interdependent task?	Could be tested in lab or analogue	Pre-briefings could be structured to explicitly make salient each crew members' unique expertise.	Low difficulty Low cost
Supporting Behavior			
Does crew members' level of collective awareness with respect to one another's physical and emotional states decrease during autonomous work periods, and does this interfere with their ability to manage the distribution of workload after a shift to more interdependent work?	Long-term Repeated Data collection On ISS	Structured pre-briefings could be explicitly designed so members re-develop a collective awareness of one another's states (e.g., fatigue, health) and refresh their knowledge about one another's unique expertise.	Low Difficulty Low cost
Are crews better able to engage in effective supporting behavior after a shift to interdependent work if they hold shared and highly accessible knowledge about one another's relative strengths and weaknesses?	Long-term Repeated Data collection On ISS		

Table 1 (cont.). *Listing and Brief Description of Research Questions*

Information Exchange			
Does temporal diversity increase over time during autonomous work periods, and does this impair a crew's ability to exchange information after a shift to interdependent work? Do crews hold less shared temporal cognition after a period of autonomous work, and does this interfere with information exchange following a shift to more interdependent work?	Long-term data collection Repeated measures Real ISS crews	Crews could be scheduled/instructed to gradually synchronize themselves in this respect leading up to a planned task shift. Crews could also use structured pre-briefings to develop/re-develop shared temporal cognition.	Moderate to low complexity Low cost Low difficulty Low cost
Communication Delivery			
Does lexical entrainment with team members on the ground lead crew members to use phraseology that is not recognized by all crew members and does this lead to comprehension problems after a shift to more interdependent work? Does the inaccessibility of teammate-specific knowledge lead to less efficient communication delivery after a shift from autonomous to interdependent work?	Long-term Repeated Data collection On ISS Long-term Repeated Data collection On ISS	Training and pre-briefing strategies could be developed to explicitly refresh teammate-specific lexical knowledge in preparation for a pre-planned shift to interdependent work.	Low Difficulty Low cost

References

Alavi, S., & McCormick, J. (2008). The roles of perceived task interdependence and group members' interdependence in the development of collective efficacy in university student group contexts. *British Journal of Educational Psychology*, *78*(3), 375-393.

Ancona, D., & Chong, C. (1996). Entrainment: Pace, cycle, and rhythm in organizational behavior. In B. M. Staw & L. L. Cummings (Eds.), *Research in organizational behavior: An annual series of analytical essays and critical reviews, 18* (pp. 251-284).

Austin, J. R. (2003). Transactive memory in organizational group: the effects of content, consensus, specialization and accuracy on group performance. *Journal of Applied Psychology, 88*, 866-878.

Bachrach, D. G., Powell, B. C., Bendoly, E. & Richey, R. G. (2006). Organizational citizenship behavior and performance evaluations: Exploring the impact of task interdependence. *Journal of Applied Psychology, 91*, 193-201.

Bachrach, D. G., Powell, B. C., Collins, B. J., & Richey, R. G. (2006). Effects of task interdependence on the relationship between helping behavior and group performance. *Journal of Applied Psychology*, *91*(6), 1396.

Bakker, A. B., van Emmerik, H., & Euwema, M. C. (2006). Crossover of burnout and engagement in work teams. *Work and Occupations, 33*(4), 464-489.

Barnes, C. M., Hollenbeck, J. R., Wagner, D. T., DeRue, D., Nahrgang, J. D., & Schwind, K. M. (2008). Harmful help: the costs of backing-up behavior in teams. *Journal of Applied Psychology*, *93*(3), 529.

Barsade, S. G. (2002). The ripple effects: Emotional contagion and its influence on group behavior. *Administrative Science Quarterly*, *47*(4), 644-675.

Botero, I. C., & Van Dyne, L. (2009). Employee voice behavior: Interactive effects of LMX and power distance in the United States and Colombia. *Management Communication Quarterly, 23*, 84-104.

Brennan, S.E., & Clark, H.H. (1996). Conceptual pacts and lexical choice in conversation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22*, 1482-1493.

Campion, M. A., Papper, E. M., & Medsker, G. J. (1996). Relations between work team characteristics and effectiveness: a replication and extension. *Personnel Psychology, 49*, 429-452.

Clark, H. H., & Marshall, C. R. (1981). Definite reference and mutual knowledge. In A. K. Joshi, B. Webber, & I. Sag (Eds.), *Elements of discourse understanding* (pp. 10-63). Cambridge: Cambridge University Press.

Clark, H. H., & Murphy, G. L. (1982). Audience design in meaning and reference. In J.F. LeNy & W. Kintsch (Eds.), *Language and comprehension*. Amsterdam: North-Holland.

Cleavenger, D., Gardner, W. L., & Mhatre, K. (2007). Help-seeking: Testing the effects of task interdependence and normativeness on employees propensity to seek help. *Journal of Business and Psychology, 21*(3), 331-359.

Cosmides, L. & Tooby, J. (2000). Evolutionary psychology and the emotions. In M. Lewis & J. M. Haviland-Jones (Eds.), *Handbook of Emotions, 2nd Edition.* (pp. 91-115.) NY: Guilford.

Cummings, T.G. (1978). Self-regulation work groups: A socio-technical synthesis. *Academy of Management Review, 3,* 625-634.

Daassi, M., & Favier, M. (2005). Groupware and team aware. In S. Dasgupta (Ed.), *Encyclopedia of Virtual Communities and Technologies,* (pp. 279-284). Hershey, PA: IGI Global.

De Dreu, C. W. (2007). Cooperative outcome interdependence, task reflexivity, and team effectiveness: A motivated information processing perspective. *Journal of Applied Psychology, 92*(3), 628-638.

Deutsch, W., & Pechmann, T. (1982). Social interaction and the development of definite descriptions. *Cognition, 11*, 159-184.

Driskell, J. E., & Salas, E. (1992). Collective behavior and team performance. *Human Factors, 34*(3), 277-288.

Eberly, M. B., & Fong, C. T. (2013). Leading via the heart and mind: The roles of leader and follower emotions, attributions and interdependence. *The Leadership Quarterly, 24*, 696-711.

Ellyson, S. L., & Dovidio, J. F. (1985). Power, dominance, and nonverbal behaviour: Basic concepts and issues. In S. L. Ellyson & J. F. Dovidio (Eds.), *Power, Dominance, and Nonverval Behaviour* (pp. 1-27). New York, NY: Springer.

Engelhardt, P. E., Bailey, K. D., & Ferreira, F. (2006). Do speakers and listeners observe the Gricean Maxim of Quantity? *Journal of Memory and Language, 54*(4), 554-573.

Fragale, A.R. (2006). The power of powerless speech: The effects of speech style and task interdependence on status conferral. *Organizational Behavior and Human Decision Processes, 108*, 53-65.

French, J. R. P., & Raven, B. (1953). 1960. The bases of social power. *Group dynamics*, 259-69.

French, J. R. P., Jr., & Raven, B. H. (1959). *The bases of social power*. In D. Cartwright (Ed.), *Studies in Social Power* (pp. 150-167). Ann Arbor, MI: Institute for Social Research.

Gann, T.M., Barr, D.J. (2012). Speaking from experience: Audience design as expert performance. *Language and Cognitive Processes, 29,* 744-760.

Gonzales, R. A. (2011). *Health care team effectiveness: The relationship between team task interdependence and group emotional competence* (Doctoral dissertation). University of Phoenix, USA.

Goodman, P. S., & Leyden, D. P. (1991). Familiarity and group productivity. *Journal of Applied Psychology, 76,* 578-586.

Hida, A., Kitamura, S., & Mishima, K. (2012). Pathophysiology and pathogenesis of circadian rhythm sleep disorders. *Journal of Physiological Anthropology*, *31*(7), 1-5.

Higgins, E., Bargh, J. A., & Lombardi, W. J. (1985). Nature of priming effects on categorization. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 11*(1), 59-69.

Higgins, E., King, G. A., & Mavin, G. H. (1982). Individual construct accessibility and subjective impressions and recall. *Journal of Personality and Social Psychology, 43*(1), 35-47.

Hofstede, G. (1980). *Culture's consequences: International differences in work-related values*. Beverly Hills, CA: Sage.

Homan, A. C., van Knippenberg, D., Van Kleef, G. A., & De Dreu, C. K. W. (2007). Bridging faultlines by valuing diversity: Diversity beliefs, information elaboration, and performance in diverse work groups. *Journal of Applied Psychology, 92*, 1189-1199.

Jansen, K. J., & Kristof-Brown, A. L. (2005). Marching to the beat of a different drummer: Examining the impact of pacing congruence. *Organizational Behavior and Human Decision Processes, 97*(2), 93-105.

Johnson, M. D., Hollenbeck, J. R., Humphrey, S. E., Ilgen, D. R., Jundt, D., & Meyer, C. J. (2006). Cutthroat cooperation: Asymmetrical adaptation of team reward structures. *Academy of Management Journal, 49*, 103-119.

Kumar, N., Scheer, L. K., & Steenkamp, J. M. (1995). The effects of perceived interdependence on dealer attitudes. *Journal of Marketing Research, 32*(3), 348-356.

Langfred, C. W. (2007). The downside of self-management: A longitudinal study of the effects of conflict on trust, autonomy, and task interdependence in self-managing teams. *Academy of Management Journal, 50,* 885-900.

Lau, D.C., & Murninghan, J.K. (1998). Demographic diversity and faultlines: The compositional dynamics of organizational groups. *The Academy of Management Review, 23*(2), 325-340.

Levitan, R., & Hirschberg, J. (2011). Measuring acoustic-prosodic entrainment with respect to multiple levels and dimensions. *Proceedings of Interspeech 2011*, Florence, Italy.

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

Mangold, R., & Pobel, R. (1988). Informativeness and instrumentality in referential communication. Journal of Language and Social Psychology, 7(3-4), 181-191.

Markus, H., Smith, J., & Moreland, R. L. (1985). Role of the self-concept in the perception of others. *Journal of Personality and Social Psychology, 49*(6), 1494-1512.

Mast, M. S. (2010). Interpersonal behaviour and social perception in a hierarchy: The interpersonal power and behaviour model. *European Review of Social Psychology, 21*(1), 1-33.

McGrath, J. E. (1991). Time, interaction and performance (TIP): A theory of groups. *Small Group Research, 22*, 147-174.

McGrath, J. E., & Kelly, J. R. (1986). *Time and human interaction: Toward a social psychology of time.* New York, NY: Guilford.

McGrath, J. E., Kelly, J. R., & Machatka, D. E. (1984). The social psychology of time: Entrainment of behavior in social and organizational settings. *Applied Social Psychology Annual, 5*, 521-44.

McGrath, J. E., & Rotchford, N. L. (1983). Time and behavior in organizations. *Research in Organizational Behavior, 5*, 557-101.

Mihm, D. & Smith-Jentsch, K.A. (2013, July). Personality configuration and mental model formation in teams. In *Mental models, centrality, and conflict.* Symposium conducted at the 8th Interdisciplinary Network for Group Research Conference, Atlanta, GA.

Mohammed, S., & Nadkarni, S. (2011). Temporal diversity and team performance: The moderating role of team temporal leadership. *Academy of Management Journal, 54*(3), 489-508.

Mohammed, S., & Nadkarni, S. (2014). Are we all on the same temporal page? The moderating effects of temporal team cognition on the polychronicity diversity-team performance relationship. *Journal of Applied Psychology, 99*, 404-422.

Pearce, C. L., Manz, C. C., & Sims, H. P., Jr. (2009). Where do we go from here?: Is shared leadership the key to team success? *Organizational Dynamics, 38*, 234-238.

Porter, C. O. L. H., Gogus, C. I., & Yu, R. C. (2010). When does teamwork translate into improved team performance? A resource allocation perspective. *Small Group Research, 41*, 221-248.

Ramamoorthy, N., & Flood, P. C. (2004). Individualism/collectivism, perceived task interdependence and teamwork attitudes among Irish blue-collar employees: A test of the main and moderating effects. *Human Relations, 57*(3), 347-366.

Reitter, D., Keller, F., & Moore, J.D. (2006). Computational modeling of structural priming in dialogue. *Conference proceedings of the Human Language Technology Conference of the NAACL, Companion Volume: Short Papers*, New York, New York (121-124).

Rico, R., & Cohen, S. G. (2005). Effects of task interdependence and type of communication on performance in virtual teams. *Journal of Managerial Psychology, 20*(3-4), 261-274.

Rico, R., Molleman, E., Sánchez-Manzanares, M., & Van der Vegt, G. S. (2007). The effects of diversity faultlines and team task autonomy on decision quality and social integration. *Journal of Management, 33*, 111-132.

Rogers, S. L., Fay N., & Maybery, M. (2013). Audience design through social interaction during group discussion. *PLoS ONE 8*(2): e57211.

Sacks, H, Schegloff, E., & Jefferson, G. (1974). A simplex systematics for the organization of turn-taking for conversation. *Language, 50*, 696-735.

Sadler, P., & Woody, E. (2003). Is who you are who you're talking to? Interpersonal style and complementarity in mixed-sex interactions. *Journal of Personality and Social Psychology, 84*, 80-96.

Sierra, M. J., Rico, R., Smith-Jentsch, K. A., & Mihm, D. (2013, August). *Antecedents and outcomes of team situational models.* Paper presented at the 73rd Academy of Management Annual Meeting, Orlando, FL.

Smith-Jentsch, K.A., Sierra, M.J., Weaver, S.J., Bedwell, W.L., Dietz, A., Carter-Berenson, D., Oglesby, J., Fiore, S., & Salas, E. (2011). Team training needs analysis for long-duration space flight crews. White paper submitted under NASA grant Project Pegasus-#NNX09AK48G.

Smith-Jentsch, K. A., Johnston, J. H., & Payne, S. C. (1998). Measuring team-related expertise in complex environments. In J. A. Cannon-Bowers, E. Salas (Eds.) *Making decisions under stress: Implications for individual and team training* (pp. 61-87). Washington, DC US: American Psychological Association.

Smith-Jentsch, K. A., Kraiger, K., Cannon-Bowers, J. A., & Salas, E. (2009). Do familiar teammates request and accept more backup? Transactive memory in air traffic control. *Human Factors, 51,* 181-192.

Smith-Jentsch, K. A., Kraiger, K., Salas, E., & Cannon-Bowers, J. A. (1999). *Teamwork in the control tower: How does it differ from cockpit resource management*. Proceedings of the 10th International Symposium on Aviation Psychology, Columbus, OH.

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.

Somechi, Desivilya, & Lidogoster (2009). Team conflict management and team effectiveness: The effects of task interdependence and team identification. *Journal of Organizational Behavior, 30*(3), 359-378.

Spoor, J. R., & Kelly, J. R. (2004). The evolutionary significance of affect in groups: Communication and group bonding. *Group Processes & Intergroup Relations, 7*(4), 398-412.

Strang, A. J., Knott, B. A., Funke, G. J., Russell, S. M., Miller, B. T., Dukes, A. W., & ... Bolia, R. S. (2011). Collaboration technologies improve performance and communication in air battle management. *Military Psychology, 23*(4), 390-409.

Susman, G.I. (1976). *Autonomy at Work.* New York: Praeger.

Tesluk, P., Mathieu, J. E., Zaccaro, S. J., & Marks, M. (1997). Task and aggregation issues in the analysis and assessment of team performance. In M. T. Brannick, E. Salas, C. Prince (Eds.),*Team performance assessment and measurement: Theory, methods, and applications* (pp. 197-224). Mahwah, NJ: Lawrence Erlbaum Associates.

Thatcher, S. B., & Patel, P. C. (2011). Demographic faultlines: A meta-analysis of the literature. *Journal of Applied Psychology, 96*(6), 1119-1139.

Thomas, E.J. (1957). Effects of facilitative role interdependence on group functioning. *Human Relations, 10,* 347-366.

Tjosvold, D. (1986). Dynamics and outcomes of goal interdependence in organizations. *Journal of Psychology: Interdisciplinary and Applied, 120*(2), 101-112.

Tjosvold, D., Andrews, I., & Struthers, J. T. (1992). Leadership influence: goal interdependence and power. *Journal of Social Psychology, 132(1),* 39-50.

Tuckman, B. W. (1965). Developmental sequence in small groups. *Psychological Bulletin, 63*(6), 384-399.

Turner, J. C., Oakes, P. J., Haslam, S., & McGarty, C. (1994). Self and collective: Cognition and social context. *Personality and Social Psychology Bulletin, 20*(5), 454-463.

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

Van der Vegt, G. S., & Janssen, O. (2003). Joint impact of interdependence and group diversity on innovation. *Journal of Management, 29*(5), 729-751.

Van Der Wege, M. M. (2009). Lexical entrainment and lexical differentiation in reference phrase choice. Journal of Memory And Language, 60(4), 448-463.

Wageman, R., & Gordon, F. M. (2005). As the twig is bent: How group values shape emergent task interdependence in groups. *Organization Science, 16*(6), 687-700.

Wardlow Lane, L., & Ferreira, V. S. (2008). Speaker-external versus speaker-internal forces on utterance form: Do cognitive demands override threats to referential success?. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 34*(6), 1466-1481.

Wardlow Lane, L., & Liersch, M. J. (2012). Can you keep a secret? Increasing speakers' motivation to keep information confidential yields poorer outcomes. *Language and Cognitive Processes, 27*(3), 462-473.

Watanabe, T., & Okubo, M. (1997). Evaluation of the entrainment between a speaker burst-pause of speech and respiration and a listener respiration in face-to-face communication. *Proceedings of 6th IEEE International Workshop on Robot and Human Communication (RO-MAN 7)*, 392-397.

Watanabe, T., Okubo, M. & Kuroda, T. (1996). Analysis of entrainment in face-to-face interaction using heart rate variability. *Proceedings of 5th IEEE International Workshop on Robot and Human Communication (RO-MAN 6)*, 141-145.

Wheatley, T., Kang, O., Parkinson, C., & Looser, C. E. (2012). From mind perception to mental connection: Synchrony as a mechanism for social understanding. *Social and Personality Psychology Compass, 6*(8), 589-606.

Wyer, R. S., & Srull, T. K. (1986). Human cognition in its social context. *Psychological Review, 93*(3), 322-359.

Yuan, Y., Fulk, J., Monge, P. R., & Contractor, N. (2010). Expertise directory development, shared task interdependence, and strength of communication network ties as multilevel predictors of expertise exchange in transactive memory work groups. *Communication Research, 37*(1), 20-47.

Zhang, Z., Hempel, P. S., Han, Y., & Tjosvold, D. (2007). Transactive memory system links work team characteristics and performance. *Journal of Applied Psychology, 92,* 1722-1730.

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A recent training needs analysis conducted for Long Duration Space Flight Crews, (Smith-Jentsch et al., 2011) noted that ISS crews must adapt to extreme shifts in task interdependence after long periods of entrainment. Entrainment, broadly defined, is a phenomenon in which two or more independent rhythmic processes synchronize with each other (McGrath, Kelly, & Machatka, 1984; McGrath & Rotchford, 1983). This report describes three situations in which such shifts should be particularly difficult: 1) when the prior entrainment period was long, 2) when the shift takes place early in a team's development, and 3) when team fault-lines (subgroups based on one or more demographic attributes) exist (e.g., cultural). Hypotheses regarding specific types of coordination breakdowns that are likely to occur when shifting from low to high task interdependence are offered and supported using both theory and quotations taken from the author's interviews with NASA astronauts. It is proposed that in order to test these hypotheses future research must 1) employ longitudinal designs, 2) examine multiple forms of entrainment simultaneously (e.g., physiological, lexical, social), 3) expand the range of interdependence examined to include negative interdependence, asymmetric interdependence, and autonomy, and 4) examine bi-directional relationships between actual and perceived interdependence.

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