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SYSTEM BREAKDOWN: THE ROLE OF MENTAL MODELS AND TRANSACTIVE MEMORY IN THE RELATIONSHIP BETWEEN ACUTE STRESS AND TEAM PERFORMANCE

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In an effort to extend theory and research on the effects of acute stress in teams, I examined the mediational role of mental models and transactive memory in the relationship between acute stress and team performance, using information-processing theory as an explanatory framework. Results for 97 teams working on a command-and-control simulation indicated that acute stress negatively affected mental models and transactive memory, which helped to explain why teams performed more poorly under acute stress.

On the morning of April 24, 1990, the space shuttle *Discovery* was successfully launched from Cape Canaveral with the Hubble Space Telescope in its cargo bay. The National Aeronautics and Space Administration hoped the mission would revitalize a struggling space program. Unfortunately, it would prove to be yet another costly exercise in space exploration. Soon after the telescope became operational, scientists began to notice that the data being transmitted were inaccurate. The only explanation was that the mirror at the heart of the telescope was the wrong shape. NASA immediately looked to the Perkin Elmer Corporation, which had been responsible for constructing the $70 million mirror. The people at Perkin Elmer thought they had done everything right. After designing a revolutionary system for polishing and measuring the mirror, they had assembled a team of technicians, engineers, and scientists to oversee the process. Initially, things progressed according to schedule. However, as the deadline approached, the team made several mistakes that needed to be corrected before the project could be completed. Suddenly the team was in the hot seat. Not only did they have to rush to meet the deadline—they also had to deal with increased scrutiny from Perkin Elmer, whose future rested solely on their shoulders. In the end, the team crumbled under the pressure, sending a faulty mirror into space (Capers & Lipton, 1993).

The situation that developed at Perkin Elmer reflected two major changes occurring in the workplace toward the end of the 20th century. First, organizations were shifting to team-based work structures, in which two or more employees, each assigned a specific role or function to perform, interact interdependently toward a common and valued goal or objective (e.g., Salas, Dickenson, Converse, & Tannenbaum, 1992). Second, the amount of stress placed on employees was increasing (Cooper, Dewe, & O'Driscoll, 2001). Stress can be defined as a sequence of events that includes the presence of a demand, the perception that the demand is significant and taxing on an individual's resources, and the generation of a response that typically affects the individual's well-being (Kahn & Byosiere, 1992). This definition encompasses acute stress, which is "sudden, novel, intense, and of relatively short duration, disrupts goal oriented behavior, and requires a proximate response" (Salas, Driskell, & Hughes, 1996: 6). By the time the *Discovery* was launched into space, nearly half (48%) of U.S. organizations were using teams (Devine, Clayton, Philips, Dunford, & Melner, 1999), and the number of employees reporting high levels of stress doubled from 1985 to 1990 (Northwestern National Life, 1991).

Since then, these changes have continued to take hold (see Kozlowski & Bell, 2003; Sonnentag & Frese, 2003), and teams have been forced to deal with acute stress, often at their own peril. Numer-

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ous incidents like the Hubble disaster have been reported, and researchers have attributed them all to one underlying cause: teams are unable to function properly under acutely stressful conditions (see Driskell & Johnston, 1998; Driskell, Salas, & Johnston, 1999). A number of studies have supported this proposition, consistently showing that acute stress negatively affects team performance (e.g., Cannon-Bowers & Salas, 1998; Driskell & Salas, 1991; Driskell et al., 1999). Although this finding may explain why NASA ended up with a misshapen mirror, organizations interested in designing interventions aimed at reducing the negative effects of acute stress in teams need to possess "a clear understanding of the processes by which this occurs" (Driskell et al., 1999: 299).

One process that has been examined in the literature is communication, and researchers have found that team members tend to interact less under acute stress (e.g., Driskell & Johnston, 1998; Gladstein & Reilly, 1985). However, while researchers have found that the *quality* of communication is related to team effectiveness (e.g., Campion, Medsker, & Higgs, 1993), communication *frequency* often exhibits no relationship with team performance (e.g., Smith, Smith, Olian, Sims, O'Bannon, & Scully, 1994) and merely represents a means for enabling more primary behavioral processes and cognitive states (Kozlowski & Bell, 2003). As a result, researchers feel that more attention needs to be paid to developing and evaluating theoretically derived links between acute stress and the specific duties and responsibilities of employees working in teams (Bliese & Jex, 1999; Driskell et al., 1999).

To address these issues, in this study I attempted to more effectively uncover the cognitive and behavioral mechanisms underlying the relationship between acute stress and team performance, using information-processing theory as an explanatory framework. Drawing on information-processing theory, I examine the role of mental models and transactive memory. *Mental models* have been defined as organized mental representations of knowledge regarding critical components of a team's task environment (Klimoski & Muhammed, 1994), and *transactive memory* has been defined as a cooperative division of labor for learning, remembering, and communicating relevant team knowledge (e.g., Wegner, 1987). Both mechanisms enable a team to collectively encode, store, and retrieve information (Hinsz, Tindale, & Vollrath, 1997). Because researchers suggest that acute stress alters information processing, I propose that it negatively affects mental models and transactive memory, which may help explain why teams perform more poorly under acute stress.

LITERATURE REVIEW AND HYPOTHESES

Teams as Information Processors: The Role of Mental Models and Transactive Memory

Researchers define information processing as a sequence of operations within the human mind that takes in information, transforms it, and produces some sort of output (Hinsz et al., 1997). This sequence can take a number of different forms, although certain elements remain fairly consistent. An individual, when placed in a certain context, perceives information in the *attention* phase. The information is then evaluated, interpreted, and transformed through an *encoding* process that prepares it for *storage* within memory. The information can then be *retrieved* from memory when necessary.

Because work groups and teams are facing tasks of an increasingly intellectual and cognitive nature, performance relies on team members' information-processing capabilities (Salas et al., 1992). However, in teams, information processing is defined as "the degree to which information, ideas, or cognitive processes are *shared,* and are being shared, among the group members and how this sharing of information affects both individual- and group-level outcomes" (Hinsz et al., 1997: 53; emphasis added). Although the components remain the same, the unique nature of teamwork changes the way that each functions within the larger network as interactions and the interdependence between team members enter each phase of the process.

Mental models. In the encoding phase, mental models provide members with a heuristic to help them interpret information (Hinsz et al., 1997). Researchers view mental models as an emergent cognitive state (see Ilgen, Hollenbeck, Johnson, & Jundt, 2005; Marks, Mathieu, & Zaccaro, 2001) that taps qualities of a team that represent member cognitions rather than member interaction. In essence, each team member develops a *psychological map,* or organized structure of knowledge, depicting how the characteristics, duties, and needs of his or her teammates fit with one another (e.g., Mohammed, Klimoski, & Rentsch, 2000). These maps vary in terms of accuracy and in terms of similarity to other team members' maps. Team members need to hold accurate representations of their team performance environment to be effective, and they need to hold similar representations to be efficient (e.g., Smith-Jentsch, Campbell, Milanovich, & Reynolds, 2001).

A number of studies have supported the positive effects of mental model similarity and accuracy on team performance (e.g., Marks, Sabella, Burke, & Zaccaro, 2002; Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000). For example, Marks, Zaccaro, and Mathieu (2000) found that mental model similarity and accuracy each exhibited significant and positive unique relationships with team performance.

Transactive memory. In the storage and retrieval phases, transactive memory provides a team with a system for distributing and retrieving knowledge based on members' specific areas of expertise (Gibson, 2001; Hinsz et al., 1997). Wegner (e.g., 1987) originally conceived of transactive memory to explain the behavior of couples in close relationships. Since then, two different yet compatible conceptualizations of the construct have developed. These divergent perspectives reflect the fact that transactive memory has both cognitive and behavioral components. Organizational researchers have focused on *specialization, coordination,* and *credibility,* which are considered emergent cognitive manifestations of transactive memory (Ilgen et al., 2005). Specialization refers to the level of memory differentiation within a team; coordination refers to the ability of team members to work together efficiently; and credibility refers to team members' beliefs about the reliability of other members' knowledge (e.g., Lewis, 2003; Moreland & Myaskovsky, 2000).

Social psychological researchers have focused on directory updating, information allocation, and retrieval coordination, which are considered independent behavioral indicators of transactive memory. Through directory updating, team members learn about each other's areas of expertise and become more aware of "who knows what" by sharing or requesting information from their teammates. Through information allocation, information is communicated to the team member who possesses the relevant area of expertise, allowing team members to pass information to each other without storing anything into memory. Through retrieval coordination, team members use their "directory of directories" to request information known to be within a teammate's areas of expertise (e.g., Hollingshead, 1998a, 1998b). As such, the social-psychological conceptualization of transactive memory can be considered a particular manifestation of what Marks and colleagues (2001) called "action processes," which include activities such as systems monitoring and coordination behavior that lead directly to the accomplishment of specific team goals.

Both approaches represent viable conceptualizations of transactive memory (e.g., Lewis, 2003). However, because the teams examined in this study were formed for a short period and consisted of members with distinct areas of expertise, specialization, coordination, and credibility may be less relevant. For example, if team members' experiences with one another are limited, they may find it difficult to accurately gauge the reliability of their teammates' knowledge (i.e., credibility). As a result, I approached transactive memory from the social-psychological perspective.

Regardless of the approach, research suggests that transactive memory positively affects team performance (e.g., Austin, 2003; Cannon-Bowers & Salas, 2001; Hollingshead, 1998a; Lewis, 2003; Moreland & Myakovsky, 2000). For example, Hollingshead (1998b) found that individuals who knew each other performed significantly better because they more effectively used the retrieval coordination component of their transactive memory systems.

The Effects of Acute Stress

Researchers have 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).

Team members also narrow their breadth of attention under acute stress (e.g., Driskell et al., 1999; Gladstein & Reilly, 1985; Staw et al., 1981). However, instead of focusing less on secondary or peripheral tasks, team members become more self-focused and less team-focused (e.g., Driskell et al., 1999; Gladstein & Reilly, 1985). Because information processing relies on a team focus (see Hinsz et al., 1997), researchers suggest that this attentional shift can disrupt encoding, storage, and retrieval capabilities (Driskell et al., 1999), which may negatively affect mental models and transactive memory.

Mental models. To ensure that similar and accurate mental models are available for efficient and effective information encoding, team members are required to focus on the characteristics, duties, and needs of their teammates. However, when unusual task circumstances such as acute stress present themselves, team members tend to lose their focus. For example, Driskell and colleagues (1999) found that acute stress negatively affected team perspective, which consists of two components. The first relates to a sense of "we-ness," or the perception that there is a common team identity. The second relates to a collective representation of the team task, or the perception that the task requires an interdependent team effort. Driskell et al. suggested that when this perception is present, team members hold a common understanding of their interactive responsibilities and the team's resources, goals, and performance strategies, or similar mental models regarding the job/task, the team, and so forth (see Mathieu et al., 2000).

Although Driskell and colleagues' (1999) results suggest that acute stress may negatively affect mental models, certain types may be affected more than others. Cannon-Bowers, Salas, and Converse (1993) identified four types of mental models held by team members: technology/equipment mental models, job/task mental models, team mental models, and team interaction mental models. Other types of mental models focus on factors such as equipment functioning and environmental constraints, but team interaction mental models focus on members' roles and responsibilities and interaction patterns within a team. Because team interaction mental models focus primarily on team-related aspects of a situation, while other types of mental models focus on task-related aspects of the situation, team interaction models require teamwork rather than "taskwork" behavior (see Mathieu et al., 2000) and may be particularly susceptible to shifts in attention. As evidence, researchers have discovered that, under acute stress, individuals find it significantly more difficult to differentiate among people with different areas of expertise (Rotten, Olszewski, Charleton, & Soler, 1978) and often confuse their roles and responsibilities (Torrence, 1954). This uncertainty may result in less similar and less accurate team interaction mental models, which leads to the following hypothesis:

Hypothesis 1. Acute stress negatively affects team interaction mental model (a) similarity and (b) accuracy.

Transactive memory. For the members of a team to use transactive memory to store and retrieve information, they need to focus attention on the team, as they expend a significant amount of their cognitive resources to request and share expertise (Hinsz et al., 1997). A shift in attention may reduce team members' willingness and ability to interact with their teammates in such a manner. Groupthink theory (Janis, 1982) supports this idea, suggesting that team members insulate themselves and search for and share significantly less information under acute stress. Threat rigidity theory takes a similar perspective, suggesting that teams behave rigidly in threatening situations by simplifying information codes and using fewer information channels. This restriction results in a system that is not sufficiently diversified or flexible, an insufficiency that can be maladaptive during radical environmental shifts (Staw et al., 1981).

In support of these contentions, research has shown that individuals tend to neglect social and interpersonal cues under acute stress, failing to recognize situations that require interaction (Cohen, 1980). Even if team members are aware that interaction is required, acute stress significantly reduces both the number of communication channels they use (Gladstein & Reilly, 1985) and the likelihood that they will provide needed information to their teammates (e.g., Isen & Levin, 1972; Mathews & Canon, 1975), compromising their willingness and ability to engage in directory updating, information allocation, and retrieval coordination. To engage in directory updating, team members need to recognize that information regarding their roles and responsibilities needs to be distributed within the team. To engage in information allocation, team members need to be aware of who needs what information, and they need to be willing to share the information with their teammates. To engage in retrieval coordination, team members must be aware of who holds what information, and they need to be willing to use the appropriate communication channels to get it. Thus, I hypothesize that:

Hypothesis 2. Acute stress negatively affects transactive memory through diminished use of (a) directory updating, (b) information allocation, and (c) retrieval coordination.

On the basis of my first two hypotheses, I expect that acute stress will negatively affect team interaction mental models and transactive memory, which have been linked to team performance (e.g., Salas & Fiore, 2004). Given that acute stress has also been linked to team performance (e.g., Cannon-Bowers & Salas, 1998; Salas et al., 1996), I suggest that team interaction mental models and transactive memory together represent the cognitive and behavioral mechanisms through which acute stress affects team performance. This formulation is consistent with the idea that emergent cognitive states and behavioral processes such as team interaction mental models and transactive memory intervene and transmit the influence of more distal inputs such as acute stress to outcomes such as team performance (Ilgen et al., 2005; Marks et al., 2001). Therefore, I hypothesize that:

Hypothesis 3. The effects of acute stress on team performance are partially mediated by (a) team interaction mental model similarity and accuracy and (b) transactive memory through the use of directory updating, information allocation, and retrieval coordination.

The Relationship between Mental Models and Transactive Memory

Because team interaction mental models and transactive memory are both expected to partially mediate the relationship between acute stress and team performance, it is important to determine the amount of overlap between the two constructs. The relationship between team interaction mental models and transactive memory could have implications for the design and implementation of specific organizational intervention programs.

Researchers have provided evidence that team interaction mental models and transactive memory are conceptually and empirically distinct constructs (see Austin, 2003; Kozlowski & Bell, 2003; Lewis, 2003; Mohammed & Dumville, 2001). For example, Lewis noted that "members' agreement about member expertise associations is related to transactive memory systems, but does not reflect the entirety of the construct" (Lewis, 2003: 590). Team interaction mental models do not reflect whether team members choose to draw upon and combine their teammates' knowledge by allocating information to, and retrieving information from, the correct team members. Team interaction mental models primarily serve to integrate team members' perceptions, while transactive memory primarily serves to capitalize on differences among team members' roles and responsibilities. In other words, team interaction mental models have an *integrative* function, whereas transactive memory has a *differentiation* function. Lewis (2003) supported these assertions empirically, finding that transactive memory systems were distinct from members' agreement about who knew what within teams.

However, differentiation and integration likely represent complementary processes. Team interaction mental models and transactive memory are both mechanisms that teams can use when processing information (Hinsz et al., 1997) and are likely related to one another (Austin, 2003; Lewis, 2003). Smooth, efficient coordinated action is inherently a part of transactive memory (Lewis, 2003) and relies on team members possessing a good understanding of who has what knowledge and how that knowledge fits together (e.g., Hinsz et al., 1997). Lacking a similar and accurate directory of directories (e.g., Hollingshead, 1998a, 1998b), team members will not know whom to allocate information to and whom to retrieve information from (Wegner, 1987). In addition, through information allocation and retrieval coordination, team members can help their teammates more efficiently and effectively identify who knows what and who needs to talk to whom, refining team interaction mental model similarity and accuracy (Austin, 2003). Therefore, I expect team interaction mental models and transactive memory to be positively correlated, leading to the following hypothesis:

> *Hypothesis 4. Team interaction mental model (a) similarity and (b) accuracy are positively related to transactive memory through the use of (a) directory updating, (b) information allocation, and (c) retrieval coordination.*

METHODS

Research Participants and Task

Participants included 388 students from an introductory management course at a large midwestern university who were arrayed into 97 four-person teams. Of the 388 students, 223 (57.5%) were male and 342 (88.1%) were white. The average age was 21 years. In exchange for participation, each student earned class credit, and all were eligible for cash prizes ($400 per team) based upon team performance. Participants were randomly assigned to either the acute stress experimental condition or to the control condition.

Participants engaged in a modified version of the Distributed Dynamic Decision-Making Simulation (the DDD; see Miller, Young, Kleinman, & Serfaty, 1998). The DDD is a computerized, dynamic command-and-control simulation requiring team members to monitor a geographic region and defend it against invasion from unfriendly tracks, which are radar representations of unfriendly forces moving through the region. The objective is to maximize the number of team points, which can be accomplished by identifying tracks, determining whether they are friendly or unfriendly, and keeping unfriendly tracks out of restricted areas.

Geographic region. The geographic region is partitioned into four quadrants of equal size (one per team member). In the center of the computer screen is a 4×4 square designated the "highly restricted zone," which is nested within a larger 12×12 square labeled the "restricted zone." Outside the restricted zone is neutral space.

Bases and vehicles. To monitor the geographic region, each team member has a base of operations surrounded by a detection ring that detects the presence or absence of tracks within its radius. To detect tracks outside of their bases' detection rings, team members can rely on their teammates or on the vehicles located at their bases.

Vehicles are semi-intelligent agents that can automatically perform certain functions during the task. There are four different types of vehicles: (1)

AWACS (surveillance) planes, (2) tanks, (3) helicopters, and (4) jets. Although each type can detect targets, they vary in capability along five major dimensions: (1) range of vision, (2) speed of movement, (3) duration of operability, (4) weapons capacity, and (5) identification capacity. Capabilities are distributed among the vehicle types so that each has both strengths and weaknesses, as shown in Table 1.

Tracks. When tracks enter a detection ring, they show up as unidentified. Once a team member has identified the track using an AWACS plane, he or she can engage it with a tank, helicopter, or jet. If the engaging vehicle has the correct level of power, the track is disabled. In this study, teams faced four different types of tracks: A, B, C, and D. Each track had a power of 0 (friendly), 1, 3, or 5, depending on whether it appeared during the training or the experimental task (see Table 1).

Team member specialties. During DDD training, team members did *not* have specific areas of expertise. Each team member owned a tank, an AWACS plane, a helicopter, and a jet and knew that the A, B, C, and D tracks corresponded to power levels 0, 1, 3, and 5, respectively.

During the experimental task, team members *did* have specific areas of expertise. I created the specific areas of expertise by splitting up knowledge regarding the tracks and possession of the four different vehicles. Each team member (DM) knew the power level of one track and was responsible for one type of vehicle. DM4 knew that track A had a power of 1 and had four jets; DM3 knew that track C had a power of 3 and had four helicopters; DM2 knew that track B had a power of 5 and had four tanks; and DM1 knew that track D had a power of 0 and had four AWACS planes. Each team member was *only* aware of his or her area of expertise at the start of the experimental task.

Procedures

Team members were first trained on declarative and procedural knowledge regarding the various aspects of the task for approximately 60 minutes. Participants then performed a 45-minute practice task, in which they learned how to launch and move vehicles, identify tracks, and engage tracks *without* specific areas of expertise. After training, team members performed a 45-minute experimental task *with* specific areas of expertise. Each team encountered 140 tracks consisting of 35 of each of the four types (A, B, C, and D) that were evenly distributed across the task. For the duration of the experiment, participants could only communicate verbally with one another.

In order to ensure that the acute stress manipulation (see below) was sudden, intense, and disruptive to goal-oriented behavior, I introduced it at the 15-minute mark. Transactive memory and team performance were measured during the final 30 minutes. At the end of the 45-minute task, team members completed the manipulation checks for the acute stress manipulation and the team interaction mental models measure.

TABLE 1
Summary of Vehicles and Tracks[a]

	Vehicles					Tracks			
Game Component	**Duration**	**Speed**	**Vision**	**Power?**	**Identify Ring?**	**Speed**	**Power, Experimental Tasks**	**Power, Training Tasks**	**Nature**
Vehicles									
Tank	8:00	Slow	Very limited	Yes (5)	No				
Helicopter	4:00	Medium	Limited	Yes (3)	No				
Jet	2:00	Very fast	Far	Yes (1)	No				
AWACs	6:00	Fast	Very far	No	Yes				
Tracks									
A						Slow	Low (1)	None	Enemy
B						Slow	High (5)	Low (1)	Enemy
C						Slow	Medium (3)	Medium (3)	Enemy
D						Slow	None	High (5)	Friendly

[a] "Duration" is the number of minutes a vehicle may stay away from the base before needing to refuel. "Speed" is how fast a vehicle travels across the task screen. "Vision" refers to a vehicle's range of vision for seeing and identifying tracks. "Power" is a vehicle's ability to engage enemy tracks. "Identify ring" refers to a vehicle's ability to identify tracks. "Speed" is how fast a track travels across the task screen. "Power" is the level of power needed to successfully engage a track. "Nature" is a track's identity as enemy or friend.

Measures

Transactive memory. To measure transactive memory, this study employed direct measures of verbal behavior based on the team members' areas of expertise (see Hollingshead, 1998a, 1998b). Because variance in team members' verbal behavior was of no theoretical or operational concern, I used an additive index (i.e., a sum) to represent directory updating, information allocation, and retrieval coordination at the team level (Chan, 1998). Directory updating occurred when team members shared expertise with, or requested expertise from, their teammates (e.g., "I'm DM2 and I have the tanks" or "Who knows what the D track is?"). Sharing expertise and requesting expertise ($r = .54$, $p < .01$) were summed as the index of directory updating. Information allocation occurred when team members sent information to the person with the correct track or vehicle specialty (e.g., "DM3, I have several C tracks in my restricted zone"). Retrieval coordination occurred when team members requested information known to be part of someone's track or vehicle specialty (e.g., "DM3, what is the C track again?").

Two experimenters were in charge of coding. Both experimenters participated in a two-hour training session intended to ensure that the coding was accurate and consistent; it included a review of the construct definitions for each dimension as well as the coding of two practice teams. The experimenters then coded 17 (17%) of the teams together. Cohen's (1960) kappa provided an index of interrater agreement. In this study, kappa was .76 for directory updating, .76 for information allocation, and .72 for retrieval coordination, values that indicated acceptable levels of agreement (see Landis & Koch, 1977). Therefore, the remaining 82 teams were divided equally between the two experimenters.

Team interaction mental models. According to Kozlowski and Klein (2000), team interaction mental models represent a configural construct whose properties capture an array of divergent contributions to the whole rather than convergent perceptions among the members of a unit. Several techniques for measuring team interaction mental models have been developed (see Mohammed et al., 2000); in this study, I adapted Marks et al.'s (2000) concept-mapping technique. Team members were given two separate task scenarios. Each task scenario was accompanied by eight blank spaces (two per team member) that needed to be filled with one of ten concepts that represented different aspects of the task domain. Team members completed the maps by placing concepts that best represented the actions of each team member on the map, a process allowing for more than one correct response.

Two concept maps were constructed specifically for this study and based on team members' specialties during the experimental task. The first concept map was designed to assess whether team members understood their teammates' roles and responsibilities; for example, when the highly restricted area contained two of each type of track, DM2 should (1) launch two tanks and (2) disable the two B tracks. The second concept map was designed to assess whether team members understood interaction patterns within the team; for instance, when DM4 had two B tracks and two C tracks in his or her restricted zone, he or she should (1) ask DM2 to send two tanks and (2) ask DM3 to send two helicopters.

To calculate the similarity between team members' concept maps, the experimenters gave one point when two team members shared two linked concepts (A-B), three points when three team members shared two linked concepts, and nine points when all four team members shared two linked concepts. Two judges who were subject matter experts in the DDD command-and-control simulation assessed the accuracy scores; this assessment resembled a technique used by Marks et al. (2000). Each team member's concept map was rated from 1 ("inaccurate") to 7 ("highly accurate"). Judges paid particular attention to (1) the critical DDD functions, (2) the appropriate role assignments for each team member, and (3) a reasonable sequence of actions for successful completion of the task. The two judges' evaluations were highly correlated for both the first ($r = .95$, $p < .01$) and the second ($r = .94$, $p < .01$) concept maps. Thus, I formed team accuracy scores by averaging the two judges' ratings and then taking the sum of the four scores. Finally, similarity scores for the two concept maps were highly correlated with one another ($r = .66$, $p < .01$), as were accuracy scores ($r = .81$, $p < .01$). I combined them to form team interaction mental model similarity and accuracy.

Team performance. The measure of team performance in this study was adapted from Ellis, Hollenbeck, Ilgen, Porter, West, and Moon (2003) and focused on the teams' main objective, which was to maximize the number of team points represented by offensive and defensive scores. The offensive score started at 1,000 points and went up 5 points every time an enemy track was disabled in a restricted zone. If an enemy track was disabled in the neutral space or a friendly track was disabled, the offensive score dropped by 25 points. The defensive score started at 50,000 and decreased 1 point for every second an enemy resided within the restricted zone and 2 points for every second an enemy resided within the highly restricted zone. I measured team performance by standardizing and combining offensive and defensive scores.

Acute Stress Manipulation

Because combining stressors has been shown to result in an exponentially greater response (Kahn & Byosiere, 1992), I manipulated acute stress using time pressure and threat. Time pressure, defined as the perception that there is not enough time to complete a given amount of work (Cooper et al., 2001), has been shown to increase arousal and psychological stress (e.g., Driskell et al., 1999; Salas et al., 1996). The time pressure manipulation was adapted from Driskell et al. (1999). At the 15-minute mark, the first warning was given. Team members were told, "You now have only 30 minutes left to work on the task, which is not a lot of time. In order to perform well, you need to hurry up and work harder at keeping the restricted zones free from enemy tracks." Similar warnings were given at 5-minute intervals throughout the remainder of the task.

Threat, which has been broadly defined "as an environmental event that has impending negative or harmful consequences for the entity" (Staw et al., 1981: 502), represents a significant cause of psychological and physiological stress and strain (see Cooper et al., 2001). The threat manipulation in this study was adapted from Turner, Pratkanis, Probasco, and Leve (1992). At the 15-minute mark, a video camera was placed in the corner of the room, the "record" button was pressed, and team members were told the following:

> Each semester, we notice that there are a few teams that seem to lag far behind the others. We feel that this is due to a lack of motivation among certain students. Right now, there are almost 600 students enrolled in your class. In order to make sure you give us your full attention and effort for the next 30 minutes, we are going to videotape your team's performance. If your team is one of the three lowest performers, your professor will show the tape to the entire class the last week of the semester as an example of ineffective teamwork.

RESULTS

Manipulation Checks

To examine the effectiveness of the acute stress manipulation, I first had participants complete the pressure/tension scale from the Intrinsic Motivation Inventory (e.g., Deci, Eghrari, Patrick, & Leone, 1994). Coefficient alpha for this study was .85. Results indicated that team members in the acute stress condition felt tenser ($\bar{x} = 4.62$, s.d. = 1.31) than team members in the control condition ($\bar{x} = 4.29$, s.d. = 1.28; $t[386] = 2.53$, $p < .05$). Participants then completed the 20-item state anxiety scale (e.g., Spielberger, 1983). Coefficient alpha was .92 in this study. Results indicated that team members in the acute stress condition reported higher levels of state anxiety ($\bar{x} = 1.99$, s.d. = 0.56) than team members in the control condition ($\bar{x} = 1.79$, s.d. = 0.49; $t[386] = 3.78$, $p < .01$). Finally, participants completed four items designed to assess reactions to the specific manipulation used in this study; a sample item is, "The idea that other students may be aware of my performance on this task was very stressful." Coefficient alpha reached .82. Results indicated that team members in the acute stress condition felt more time pressure and more threatened ($\bar{x} = 4.00$, s.d. = 1.40) than team members in the control condition ($\bar{x} = 3.05$, s.d. = 1.31; $t[386] = 6.85$, $p < .01$). A number of team members also verbally supported the effectiveness of the manipulation, with comments such as "I'm starting to sweat. This is stressing me out!"

Tests of Hypotheses

Table 2 presents means, standard deviations, and correlations for all the variables of interest. The team performance, transactive memory, and team interaction mental model measures were first subjected to a multivariate analysis of variance (MANOVA) comparing the acute stress and control conditions. Significant multivariate effects emerged for the acute stress manipulation (multivariate $F[6, 90] = 10.35$, $p < .01$, partial $\eta^2 = .41$). The transactive memory and team interaction mental model measures were then subjected to a MANOVA comparing the acute stress and control conditions. Significant multivariate effects again emerged for the acute stress manipulation (multivariate $F[5, 91] = 11.71$, $p < .01$, partial $\eta^2 = .39$). Univariate follow-up analyses of variance (ANOVAs) revealed a number of significant differences (see Table 2).

The first and second hypotheses propose that acute stress negatively affects team interaction mental models and transactive memory. As shown in Table 2, acute stress negatively affected team interaction mental model similarity ($F[1, 96] = 26.91$, $p < .01$, partial $\eta^2 = .22$) and accuracy ($F[1, 96] = 37.62$, $p < .01$, partial $\eta^2 = .28$), supporting Hypothesis 1. Acute stress also negatively affected directory updating ($F[1, 96] = 11.00$, $p < .01$, partial $\eta^2 = .10$), information allocation ($F[1, 96] =$

TABLE 2
Means, Standard Deviations, and Correlations[a]

Variable	1	2	3	4	5	6	Whole Sample		Acute Stress Condition		Control Condition	
							Mean	s.d.	Mean	s.d.	Mean	s.d.
1. Acute stress							0.49	0.50	1.00	0.00	0.00	0.00
2. Directory updating	−.32**						16.78	7.84	14.24**	7.13	19.27	7.78
3. Information allocation	−.32**	.10					14.20	11.31	10.61**	10.80	17.70	10.77
4. Retrieval coordination	−.49**	.49**	.23*				1.59	2.06	0.58**	0.94	2.58	2.37
5. Team interaction mental model similarity	−.47**	.32**	.24*	.48**			35.00	20.25	25.44**	15.65	46.96	5.77
6. Team interaction mental model accuracy	−.53**	.29**	.29**	.42**	.85**		43.31	6.96	39.58**	6.07	46.96	5.77
7. Team performance	−.43**	.24*	.25*	.35**	.43**	.47**	−0.04	1.70	−0.77**	1.74	0.67	1.32

[a] $n = 97$; for the acute stress condition, $n = 48$; for the control condition, $n = 49$. Acute stress was coded 0 if absent and 1 if present.
* $p < .05$
** $p < .01$

10.48, $p < .01$, partial $\eta^2 = .10$), and retrieval coordination (F[1, 96] = 29.45, $p < .01$, partial $\eta^2 = .24$), supporting Hypothesis 2.

The third hypothesis proposes that team interaction mental models and transactive memory partially mediate the effects of acute stress on team performance. According to Baron and Kenny (1986), several steps are necessary to demonstrate mediation. First, the independent variable needs to significantly affect the dependent variable. As shown in Table 2, acute stress negatively affected team performance (F[1, 96] = 21.04, $p < .01$, partial $\eta^2 = .18$). Second, the independent variable needs to significantly affect the mediators, which was supported in testing Hypotheses 1 and 2. Third, the mediators need to significantly affect the dependent variable. Fourth, the direct effects of the independent variable on the dependent variable need to be reduced with the inclusion of the mediators.

To test the third and fourth requirements for mediation, I conducted an analysis of covariance (ANCOVA) in which team interaction mental models and transactive memory were covariates. Results indicated that each was related to team performance, including team interaction mental model similarity (F[1, 96] = 8.83, $p < .01$, partial $\eta^2 = .09$), team interaction mental model accuracy (F[1, 96] = 4.28, $p < .05$, partial $\eta^2 = .05$), directory updating (F[1, 96] = 7.22, $p < .01$, partial $\eta^2 = .07$), information allocation (F[1, 96] = 6.21, $p < .05$, partial $\eta^2 = .07$), and retrieval coordination (F[1, 96] = 6.16, $p < .05$, partial $\eta^2 = .06$). Results also indicated that the effects of acute stress on team performance became nonsignificant when team interaction mental models and transactive memory were partialed out (F [1, 96] = 2.55, n.s., partial $\eta^2 = .03$). An ANCOVA was then conducted with team interaction mental models as a covariate. Results indicated that the effects of acute stress on team performance were reduced when team interaction mental models were partialed out (F[1, 96] = 5.32, $p < .05$, partial $\eta^2 = .05$). Finally, an ANCOVA was then conducted with transactive memory as a covariate. Results again indicated that the effects of acute stress on team performance were reduced when transactive memory was partialed out (F[1, 96] = 7.55, $p < .01$, partial $\eta^2 = .07$). In sum, these results support Hypothesis 3.

The final hypothesis, Hypothesis 4, proposes that team interaction mental models and transactive memory are positively related to one another. Multivariate tests indicated that team interaction mental model similarity was significantly related to directory updating (F[1, 96] = 10.89, $p < .01$, partial $\eta^2 = .10$), information allocation (F [1, 96] = 5.62, $p < .05$, partial $\eta^2 = .06$), and retrieval coordination (F[1, 96] = 28.02, $p < .01$, partial η^2 = .23). Results also indicated that team interaction mental model accuracy was significantly related to directory updating (F[1, 96] = 8.38, $p < .01$, partial η^2 = .08), information allocation (F[1, 96] = 8.37, $p < .01$, partial η^2 = .08), and retrieval coordination (F[1, 96] = 20.55, $p < .01$, partial η^2 = .18). These results fully support Hypothesis 4.

DISCUSSION

Following the Hubble disaster, researchers uncovered a number of teamwork issues that might have contributed to the eventual failure of the telescope's mirror. When pressured during the later stages of the construction process, team members frequently squandered their teammates' knowledge and expertise. For instance, when several technicians needed to mount the mirror lens on a bracket, they installed three household washers as spacers instead of getting them custom-made. Abe Offner, the original designer, was surprised that the technicians failed to ask for his expertise, noting this: "These things are made so they would not need washers. I would have expected any questions to be referred to me" (Capers & Lipton, 1993: 45). Roderic Scott, who acted as a scientific advisor on the project, was also surprised to find that he was never told of problems that came up during construction, even though he had voiced misgivings about the lack of independent testing on the mirror (Capers & Lipton, 1993). These examples suggest that team members may have been unaware of, or unwilling to use, their teammates' expertise under intense levels of stress.

The problems that occurred within the team at Perkin Elmer are not unusual. Similar breakdowns in teamwork have been observed in a number of other organizations (see Driskell & Johnston, 1998; Driskell et al., 1999). Such incidents have prompted scholars to call for research aimed at uncovering the specific factors underlying the relationship between acute stress and team performance (Driskell et al., 1999). Using information-processing theory as an explanatory framework, this study examined the role of mental models and transactive memory. Results indicated that acute stress negatively affected team performance, supporting previous research (e.g., Driskell et al., 1999). However, acute stress also negatively affected team interaction mental models and transactive memory, which mediated the relationship between acute stress and team performance. More specifically, when examined separately, team interaction mental models and transactive memory partially mediated the effects of acute stress on team performance. When examined together, team interaction mental models and transactive memory fully mediated the effects of acute stress on team performance, indicating that that it is important to consider team interaction mental models together with transactive memory to fully capture the cognitive and behavioral mechanisms through which acute stress affects team performance. These findings extend previous research by clarifying the specific mechanisms underlying the negative effects of acute stress in teams and by providing more precise prescriptive information that can aid organizations in developing interventions aimed at reducing those effects.

Theoretical Implications

The results of this study support information-processing theory as a viable framework that can help explain the negative effects of acute stress in teams (e.g., Gladstein & Reilly, 1985; Staw et al., 1981) and support the idea that information processing is a fluid system in which deficiencies in one area (i.e., attention) can disrupt the operation of other facets of the system (i.e., encoding, storage, and retrieval) (e.g., Driskell et al., 1999). This view was further supported by the fact that team interaction mental models were related to transactive memory. Although researchers have indirectly established a link between transactive memory and mental models in teams (e.g., Austin, 2003; Lewis, 2003), this is the first study to directly establish a relationship between the two constructs. Given the role of information-processing theory and the interrelatedness of its components, future research would benefit from examining the effects of acute stress on other aspects of information processing, such as how a team makes a *response*. For example, when there is a choice among several alternatives, acute stress may affect the decisions teams make (see Cannon-Bowers & Salas, 1998; Driskell & Salas, 1991).

In addition, the specific results regarding team interaction mental models and transactive memory have the potential to address a major shortcoming within the organizational literature. From the few studies that have been done, it is still unclear why "group coordination become[s] more problematic under stress or emergency conditions" (Driskell et al., 1999: 291). This study expanded upon previous conceptualizations, indicating that acute stress does not simply reduce the amount of communication between team members, but rather disrupts team interaction mental models and transactive memory. Lending further support, I found that teams in the acute stress condition did not evidence significantly lower levels of communication unrelated to directory updating, information allocation, and retrieval coordination ([1, 96] = 1.18, n.s.; $\bar{x}_{\text{stress}}$ = 129.31, s.d = 47.16; $\bar{x}_{\text{control}}$ = 140.41, s.d. = 53.08). These results qualify conclusions made in previous research and offer a more refined conceptualization of the acute stress process in teams.

Managerial Implications

Organizations can use the results of this study to design specific interventions aimed at reducing the negative effects of acute stress in teams. One option may be to restructure teams so that members do not need to allocate attention to their team, negating the importance of team interaction mental models and transactive memory. According to structural contingency theory, a team's structure needs to externally fit its environment. In unstable and unpredictable environments, divisional structures, in which team members have broad and independent roles, have been shown to outperform function structures, where team members have narrow and specialized roles (Hollenbeck et al., 2002). Divisional structures promote flexiblity because team members have broader capacities, helping them react more quickly to local, idiosyncratic threats and opportunities by allowing them to focus on their task duties without needing to coordinate an exchange of information. As a result, shifting to more divisional team structures may be beneficial for teams operating in acutely stressful environments.

Unfortunately, restructuring teams may not be feasible. Another option may be to enhance or strengthen team interaction mental models and transactive memory through team training. For example, a number of studies support the benefits of cross-training (e.g., Marks et al., 2002; Volpe, Cannon-Bowers, Salas, & Spector, 1996), which has been defined as "an instructional strategy in which each team member is trained in the duties of his or her teammates" (Volpe et al., 1996: 87). Researchers suggest that cross-training offers informational and instrumental support by providing team members with practical knowledge regarding the roles and responsibilities of their teammates, reducing attentional requirements in team-related areas (Pearsall, Ellis, & West, 2004). Although the issue needs direct a priori confirmation from future research, cross-training represents one of a number of forms of team training that may buffer the negative effects of acute stress in teams (Cannon-Bowers & Salas, 1998; Marks et al., 2002).

Limitations and Future Research

A few limitations should be highlighted, including the fact that this study focused on one type of team. The teams examined in this study closely resembled action teams, which are teams whose members are brought together for a short period of time and possess distinct areas of expertise. Although Sundstrom (1999) noted that action teams remain a popular choice for organizations, the effects of acute stress observed in this study may be much different in teams with longer work cycles and less within-team specialization. For example, Kozlowski, Gully, Nason, and Smith's (1999) compilation theory suggests that teams "progress through a series of learning stages during which their knowledge and skills compile into qualitatively different forms" (Kozlowski et al., 1999: 242). Different factors become relevant at different points along the developmental continuum. During later stages, team members begin to explore transaction alternatives to avoid miscoordination, which may lessen the importance of team interaction mental models and transactive memory. Team members' roles also become routinized, which may enable teams to better withstand the effects of acute stress. Cannon-Bowers and Salas (1997) suggested that, when team members' mental representations reach maturity, they are much less malleable than in the initial stages of team development.

I should also note a few caveats regarding the team interaction mental models examined in this study and their relationship with transactive memory. As in previous research (e.g., Marks et al. 2000), team interaction mental model similarity and accuracy were highly related to one another. However, given the simplicity of the measure used here (team members' expertise was rather limited) and given the fact that it was difficult to have both highly accurate and highly dissimilar mental models (the amount of variance in team interaction mental model similarity was almost six times greater when accuracy was low than when it was high), reducing variance within and between similarity and accuracy, this relationship was not unexpected. Furthermore, although it appears that conceptually one could argue that team interaction mental models represent a necessary but not sufficient condition for transactive memory, the exact nature of the relationship needs to be specified in future research. In addition, it should be noted that two factors strengthened the relationship between the two constructs. First, this study investigated team interaction mental models, which are closely intertwined with the concept of transactive memory. Mental models focusing on the technology or equipment used by a team may exhibit less of a relationship with transactive memory. Second, I focused on positive instances of directory updating, information allocation, and retrieval coordination. The relationship may have been very different had I focused on negative behaviors, such as sharing incorrect information with team members (see Hinsz et al., 1997).

Finally, one potential weakness of this study's design was that team interaction mental models were assessed after task completion. I conceptualized team interaction mental models as mediators of the relationship between acute stress and team performance, yet the fact that they were measured afterwards potentially compromises the implied causal sequence. Several supplemental analyses were run to address this issue, and findings supported the mediated model over other alternative models.[1] Nevertheless, future research should employ designs that are consistent with the hypothesized causal sequence.

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