TEAM ADAPTATION

A COGNITIVE PERSPECTIVE

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Chapter 1

Introduction

Introduction

On Friday afternoon, the ninth of May 2008 a 'house fire' was reported to the fire station of the fire brigade Eelde, The Netherlands[1]. While the first unit of fire fighters was on its way to the fire, it became clear that it concerned a fire in a boatshed at a shipyard in the village of De Punt. During the drive to the shipyard the fire fighters, most of whom were familiar with the premises, discussed the dangers associated with the operation. When they approached the boatshed they saw thick brown-yellow clouds of smoke coming from the backside of the building. Based on the possible dangers inferred from this, the commander scaled up the situation to an 'intermediate level fire.' However, when the unit arrived at the location and the fire fighters looked into the shed, they only saw small clouds of smoke at the back of the shed and they were told by a police officer at the location that it concerned a burning vehicle. Based on this new information, they considered the situation as a 'vehicle fire in a covered space' and adjusted their expectations and operation plans accordingly.

Unbeknownst to the fire fighters working from the front of the shed, the situation in the backside had rapidly deteriorated. The fire was affecting polyurethane insulation foam that was being sprayed to the ceiling of the building, which led to the emission of highly flammable nitrate fumes. There were several reasons that may explain why the fire fighters had not perceived this danger. Before their arrival lack of oxygen might have reduced the fire intensity, the wind might have blown the smoke to the back of the shed, and smoke that might have drifted to the ceiling was not clearly visible from their position in the front. While some fire fighters entered the building to investigate and extinguish the fire from inside, the smoke cloud increased until the flames reached the flammable fumes. This resulted in a fire outbreak that spread with heavy pressure throughout the whole building. The burning smoke resulting from this outbreak was pressed through the front entrance, rendering it unavailable as an exit route and resulting in the deaths of three fire fighters that were trapped inside the building.

The above described sequence of events indicates that the disastrous outcome of the fire was at least partly due to a lack of fit between the fire fighters' representation of the situation and the actual state of the fire. Although the fire fighting team demonstrated adaptation when they reconsidered the situation as a 'vehicle fire in a covered space' and adjusted their expectations and operation plans accordingly, the situation was still inadvertently labeled as a 'fire in a building' instead of 'a building in fire.' Whereas in the first type of situation the fire may well be controlled with classical indoor extinguishing procedures, in the second type of situation, due to specific construction parts of buildings, fires may be

1 The following account is based on the final report of the evaluation of a fire at De Punt on May 9th 2008 by: I. Helsloot, R. Weever, and E. Oomes (2009).

difficult to reach from inside and parts of the building should be deconstructed in order to suppress the fire. A report from the research committee investigating the fire fighting operation and a number of similar fires, suggests that this misfit may be attributed in part to a lack in adaptation of fire fighters knowledge and procedures to novel developments in construction techniques. Over the last years, increasing requirements for building insulation have resulted in the use of a wider variance of insulation materials. In addition, due to lighter building constructions, collapse of structures has become more likely. These developments have resulted in changes in risk profiles of fires. Because these changes were not yet fully incorporated in the education and training of the fire fighters at De Punt, they lacked the appropriate knowledge structures and procedures to timely recognize and appropriately adapt to the situation (Helsloot, Weewer, & Oomes, 2009).

Like the fire fighting unit described above, in many situations teams function as the final safeguards responsible for the health and safety of many individuals (E.g. Faraj & Xiao, 2006; Klein, Ziegert, Knight, & Xiao, 2006; Smart & Vertinski, 1977). For example, emergency management teams, health prevention teams, nuclear power plant operating crews, and pilot crews all carry high responsibilities and need to be able to rapidly adapt to a variety of often unexpected highly challenging situations. Although the body of knowledge concerning factors that impact team performance has increased over the last decades (e.g. Kozlowski & Ilgen, 2006; Mathieu, Maynard, Rapp, & Gilson, 2008), relatively few studies, specifically address how teams adapt to novel and challenging circumstances (LePine, 2005; Waller, 1999). This is all the more critical since it is particularly during novel non-routine situations that effective team performance becomes most crucial and at the same time most difficult to uphold (Waller, Roe, Gevers, & Raes, 2005).

Moreover, although researchers have in their reasoning often applied team cognition concepts to explain team adaptation, studies that explicitly investigate the role of team cognition constructs in team adaptation are relatively scarce (some notable exceptions include Marks, Zaccaro, & Mathieu, 2000; Lewis, Lange, & Gillis, 2005). With team cognition, I refer to both the cognitive structures—structured knowledge team members have regarding their task or team—and cognitive processes—cognitive actions, such as information gathering, interpretation, and decision making that are performed by the team members during their task (Salas & Fiore, 2004). Cognitive structures may facilitate or hinder adaptation and often have to be changed in order for a team to adapt (Marks et al., 2000; Weick, 1995) and cognitive processes are generally considered to lie at the heart of the team adaptation process (e.g. Burke, Stagl, Salas, Pierce, & Kendall, 2006; Letsky, Warner, Fiore, & Smith, 2008; Waller, Gupta, & Giambatista, 2004). Therefore, in order to add to our understanding of how such teams adapt to dynamic and challenging circumstances, this dissertation focuses on the role of cognition in team adaptation. More specifically, in this dissertation I aim to investigate how characteristics of team members' cognitive structures impact team adaptation, how these cognitive structures change over time, and the role of team cognitive processes in team adaptation to novel task situations

This introduction will proceed as follows: After starting with a short description of what I mean with a team, I provide a definition of team adaptation based on existing literature, and I clarify this definition by expounding on its components. I provide an introduction of the role of the cognitive constructs I use in the dissertation and develop a cognitive model of team adaptation that provides the background of the studies in the dissertation. Thereby, I show that team cognition—in terms of team cognitive structures and processes—plays an important role in the team adaptation process. I close with an overview of the structure of the remainder of the dissertation.

Teams

In this dissertation I look at adaptation of teams. Etymological accounts of the word 'team' relate it back to a set of animals yoked together to collectively pull a vehicle (Hoad, 1996). From there on, the concept developed through its application in sports games into its contemporary meaning of a 'number of persons in concerted action.' In the scientific literature, a team is formally defined as "a distinguishable set of two or more people who interact, dynamically, interdependently, and adaptively toward a common and valued goal/objective/mission, who have each been assigned specific roles or functions to perform, and who have a limited life-span of membership" (Salas et al., 1992, p.4). Teams can be distinguished from groups by the interdependence of the members and a common goal; however, in the extant literature the concepts of team and group have often been used interchangeably. Therefore, and because the notion of a group is generally seen as more encompassing than the notion of a 'team'—all teams are groups but not all groups necessarily have to be teams—I will draw from literature on both groups and teams in this dissertation, referring as much as possible to the terms used by the original authors of the articles I describe.

What is team adaptation?

Although many definitions of adaptation have been posed in the team literature (e.g. Burke et al., 2006; Kozlowski, Gully, Nason, & Smith, 1999; LePine 2003; Marks et al., 2000) authors do not seem to agree on the exact nature of the concept. In particular, disagreement exists on whether adaptation is a process, a capability, or an outcome, and on the nature of the content of that which is adapted. Therefore I will present a definition based on a common denominator of existing definitions and I will distinguish team adaptation from related concepts. I refer to team adaptation as the effective process whereby, in response to changes in its task situation, a team changes its configuration, over a specific period (e.g. Marks et al., 2000; Waller, 1999; LePine 2003, 2005). The first element of this definition, *effective process*, indicates that adaptation is explicitly considered as a process—a collection of actions—and is thereby distinguished from the capability and the outcome of adaptation. Moreover, the addition *effective* is added to indicate that team adaptation refers to processes that positively contribute to team outcomes. The second element, *changes in the task situation*, refers to that to which the team adapts itself. It indicates that adaptation occurs in response to changes that are external to the team and relevant to the team task. The third element, a *change in configuration*, refers to the actual content of that which is changed by the team—in terms of structures, behaviors, and cognitions. And the fourth element, *over a specific period,* indicates that there is a specific time period over which adaptation takes place. In the following paragraphs I will further clarify each of these elements.

Team adaptation as an effective process

The definition given in the previous section explicitly considers team adaptation as a process and thereby distinguishes it from the capability and the outcome of adaptation. Some scholars have defined adaptation as a team's capability to adapt to changing circumstances (e.g. Klein & Pierce, 2001; Kozlowski et al., 1999). For example Kozlowski and colleagues (1999) defined adaptation as the "capability of the team to maintain coordinated interdependence and performance by selecting an appropriate network from its repertoire or by inventing a new configuration." However, the capability of a team to adapt should not be equated with the actual process of adapting—less capable teams may be able to adapt under beneficiary circumstances and a capable team may choose not to adapt. Therefore, I will reserve the term adaptation for the process and use the term adaptability to denote a team's general ability to adapt.

It should be mentioned that adaptation is not a singular process; rather scholars have depicted adaptation as a more encompassing process comprising a number of phases or sub-processes that have to be successfully fulfilled in order for a team to adapt. Kiesler and Sproull (1982) posed problem sensing—noticing, interpreting, and incorporating stimuli—as a necessary part of adaptation. Marks and colleagues (2000) suggest that teams adapt by surveying their task environments, interpreting its meaning with regard to the team goal, deciding on a strategy for action, and executing the novel strategy. Burke and colleagues (2006) depict team adaptation as a recursive process consisting of a situation assessment phase, a plan formulation phase, a plan execution phase, and a team learning phase. So team adaptation is used as the general term that comprises the specific sub-process teams may execute sequentially or in parallel and that together make up the adaptation process.

Adaptation is defined as an *effective* process, indicating that whether specific team processes can be considered to be adaptive can only be judged from an outcome variable—inappropriate changes leading to performance decrements are not considered as team adaptation (Burke et al., 2006). Therefore, in empirical work team adaptation is sometimes seen as an outcome and operationalized in terms of performance during a novel or non-routine situation. The rationale behind an operationalization of team adaptation as an outcome is, that if a team attains a satisfactory level of performance in a novel task situation, it is likely that it has engaged in the appropriate adaptation processes. Success measures of adaptation behaviors have therefore been operationalized in terms of teams' scores on outcome variables relative to the scores of other teams or relative to their own scores in a pre-change period. For example, several researchers have assessed team adaptation as team performance after an environmental change or under novel task circumstances (e.g. LePine, 2003; Marks et al., 2000; Woolley, 2009). Analogously, researchers have identified adaptation behaviors by comparing the communication of teams with high performance with that of teams with low performance under novel or non-routine tasks circumstances (e.g. Kanki, Folk, & Irwin, 1991; Waller, 1999; Stachowski, Kaplan, & Waller, 2009).

Recently scholars have argued that team performance should not be conceptualized merely as an end product or retrospective summary of the result of team actions but as the dynamic trajectory of team performance indicators over time (Kozlowski, et al. 1999; Landis, 2001; Mathieu & Rapp, 2009). Applying this notion to team adaptation suggests that adaptive performance is a temporal phenomenon that is characterized by a demarcated time interval with clear and theoretical meaningful beginning and end points that manifests specific dynamics over time (Roe, 2008). Consistent with this notion, on the individual level, scholars have started studying adaptation by more explicitly incorporating its temporal nature and modeling adaptation as a function of performance over time (e.g. Chen, 2005). For example, Lang and Bliese (2009) showed that there are actually two different types of performance indicators for adaptation: transition adaptation referring to the relapse in performance immediately after the task change and reacquisition adaptation referring to the rate at which performance increases again after the task change. Findings of these studies are also relevant for a dynamic assessment of adaptive performance on the team level. However, it should be noted that in order to avoid confusion, I will use the term adaptation to refer to the process—the cognitive and behavioral actions team members execute to realign their configuration with the task situation—and I will use the term adaptive performance to refer to the outcome of adaptation.

Changes in the task situation

The second element of the definition of team adaptation indicates that a team changes its configuration, in response to a change in its task situation. As our definition of teams indicates, teams are task-oriented—team members have a common goal or mission, and team processes are oriented towards fulfilling that mission. Team goals are often defined in broad terms and the specific manner in which the task is accomplished is at the discretion of the team (Steiner, 1972)—it is up to the team itself to set specific subgoals, distribute subtasks among the members, and decide on the specific actions and coordination mechanisms they will use for goal attainment.

Although in laboratory situations, team tasks situations are often fixed and teams are treated as isolated entities, in field situations task situations are often dynamic and linked to the environment in which the team operates (McGrath, Arrow, & Berdahl, 2000). McGrath and colleagues (2000) argued that teams research has a long history of ignoring the environment and assuming that teams are static, closed systems. Instead they propose a view of teams as complex, dynamic, open systems in which team tasks are intrinsically linked with the environment in which the team operates. Because teams are embedded within and interacting with their environment, team tasks do not exist in isolation but are influenced and shaped by the team's environment. As Kozlowski and Ilgen note "a team is embedded in a broader system context and task environment that drives team task demands; that is, the task requirements necessary to resolve the problem or situation presented by the environment and the load placed on team members' resources and the team task changes with respect to changes in the environment" (2006, p. 78). Therefore, the effectiveness of a team's configuration for goal attainment depends on the specific characteristics of the task situation—the part of the team's environment that is relevant for team task execution, including aspects such as the relationship among task variables, the resources available for task performance, and the information a team can attain about the task. Given that the task situation may change over time, a team will have to adapt its configuration to fit the task situation it momentary faces in order to attain its goal. For example, the task of the fire fighting teams from the opening example is to contain fires and rescue victims but the specific actions they use to accomplish these goals may vary as the situation unfolds and differ across specific fires.

Over repeated series of task performance in stable task situations, teams gain experience with the task and developed standardized procedures for dealing with recurring task elements (Gersick & Hackman, 1990). Empirical research indicates that on recurring stable tasks, team performance reaches an asymptotic level (Argote, 1993) and that standardized interaction patters or routines constitute a major source of the speed and reliability in task performance (Cohen & Bacdayan, 1994). For example, as a team of fire fighters recurrently works together on a specific type of fire, they will develop an efficient division of roles and a sequence of behaviors that enable them to effectively contain that type of fire. However, when team members are faced with a considerable change in the task situation, they have to 'think on their feet', modify existing structures, and rapidly develop and apply new task practices (Waller, 1999). Although the broadly defined team task remains similar, important elements of the task situation change, and the activities that led to successful task fulfillment in the past will no longer be effective. For instance, the fire fighters in the opening example used practices that had worked effectively for a 'fire in building' but failed in the novel 'building in fire situation'. Therefore, a common approach to study team adaptation is by means of the task-change paradigm (e.g. Marks et al., 2000 LePine, 2003, 2005). In this paradigm, teams are trained to reach a basic level of task proficiency, after which the task situation is changed so that the team has to realign its structures and behaviors to fit the novel task situation (Lang & Bliese, 2009).

A change in configuration

Till now I have discussed adaptation in terms of a team's configuration relative to its task situation without indicating specifically what it is that a team has to adapt—in other words what is the substance of adaptation? A perusal of the literature indicates that scholars have described team adaptation mainly in terms of alterations in a team's structures or behavioral patterns. Hutchins (1991) located a navigation team's adaptation to a sudden loss of equipment in the alteration of the team's stable work configuration. Kozlowski and colleagues (1999) view team adaptation as a revision or reconfiguration of the team-level role network—the set of task relevant relations among team members occupying specific roles. LePine (2005) locates team adaptability in "the extent to which a team is able to modify its configuration of roles into a new configuration of roles" (p. 1154). Marks and colleagues (2000, p. 972) refer to team adaptation as occurring when "teams are able to derive and use new strategies and techniques for confronting novel elements in their environment." Finally, Burke and colleagues (2006, p. 1190) describe team adaptation as manifested in "the innovation of new or modifications of existing structures, capacities, and/or behavioral or cognitive goal-directed actions." The common denominator among these definitions seems to be that adaptation occurs within the structures that shape team members' interaction behaviors.

Structure refers to the recurrence in the patterns of behavior by team members. As, Ranson, Hinings, and Greenwood notice "(t)he concept of structure is usually understood to imply a configuration of activities that is characteristically enduring and persistent; the dominant feature of organizational structure is its patterned regularity" (1980, p. 1). Within the team literature, this notion of structure is closely related to the concepts of team routines and interaction patterns. Habitual routines are formally defined by Gersick and Hackman (1990) as "when a group repeatedly exhibits a functionally similar pattern of behavior in a given stimulus situation without explicitly selecting it over alternative ways of behaving." Whereas this definition emphasizes that habitual routines are triggered and executed without conscious deliberation, interaction patterns are defined simply as "regular sets of verbalizations and nonverbal actions intended for collective action and coordination" (Stachowski et al., 2009, p. 1537). Hence the term seems to be less stringent and more neutral to whether the recurring behaviors are consciously selected and executed.

A cognitive perspective recognizes that interaction is represented by a cognitive component that resides within the minds of the team members (Weick, 1979). For instance, Feldman and Pentland (2003) distinguish between ostensive and performative aspects of collective routines. Whereas the performative aspect consists of the specific actions by specific people at specific times, the ostensive aspect represents the ideal or schematic representation of the routine. This ostensive aspect is embedded within the subjective understanding the participants have of the routine—within their cognitive scripts or procedural knowledge structures that represent the sequence of events associated with a specific situation (Abelson, 1976; Cohen & Bacdayan, 1994). Past interactions in similar circumstances are stored in cognitive structures that function as drivers and constraints for future behaviors (Abelson & Black, 1986; Walsh, 1995). Because team members brings to the team their own specific knowledge structures it is from the compilation of the participating members' knowledge structures, which can be considered to be a structure as well, that typical patterns of interaction arise (Cohen & Bacdayan, 1994; Cannon-Bowers, Salas, & Converse, 1993). Therefore apart from changes in structures and behaviors, alterations in team members' knowledge structures also constitute an important part of team adaptation.

It should also be noted that team adaptation is a path dependent process in that teams always adapt relative to their previous state (Beersma et al., 2009; Moon et al., 2004). Because a team's previous configuration provides the starting point from which it changes into a new configuration, the extent to which a team is able to adapt will depend on the difference between the existing configuration and the requisite configuration. Under some conditions adaptation may therefore be asymmetric; it may be easier for a team to move from one configuration to another configuration than the other way around (Hollenbeck, Ellis, Humphrey, Garza, & Ilgen, 2010; Moon et al., 2004). So, team adaptation is a path dependent process of adjustment in which a team's future state is not only determined by efforts to synchronize with its task situation but also is also constrained and enabled by its previous configuration.

Over a certain period

The final element of the proposed definition of team adaptation indicates that adaptation is a process that occurs over a specific time period (Roe, 2008). With respect to the duration of adaptation, a distinction can be made between two perspectives: singular and continuous adaptation. A singular perspective—often endorsed by empirical researchers—considers adaptation to have a clear starting and end point. The adaptation process can be considered to start at the moment a relevant change occurs in the team's environment or when this change is noticed by one of the team members and finishes at the moment when the team has adapted its configuration to the novel environment (e.g. LePine, 2003; 2005).
However, apart from a perspective of adaptation as the process of an entity adapting to a single change in its task situation, another perspective—often endorsed by field researchers and in theoretical papers—takes a broader perspective and views adaptation as an ongoing process (e.g. Burke et al., 2006). This view of adaptation considers adaptation as an inherent aspect of the team's task and implies that a team may engage in ongoing adaptation processes (e.g. Kozlowsky et al., 1999). This form of adaptation particularly applies to teams functioning in dynamic contexts characterized by high ambiguity, complexity, and inconsistent relations between actions and outcomes. In such task situations, change is an inherent element of the task and therefore, adaptation processes such as scanning the relevant task environment and modification of task strategies are likely to occur on an ongoing basis. For example, a production team may rapidly reach asymptotic performance levels as it repeatedly executes a similar or comparable task, and may only have to adapt during specific time intervals when a new product is being taken into production. An emergency management team, on the other hand, is often faced with novel and unique crises, and therefore needs to continuously engage in deliberate cognitive processing and adjustment of task practices. The duration of the adaptation process in cases such as the later cannot be restricted to a single adaptive episode and are therefore bracketed by the duration of the task or the lifetime of the team.

The role of team cognition in team adaptation: presentation of a model

Now I have provided and elaborated on the definition of team adaptation I will use in the present dissertation, I will discuss the role of team cognition in team adaptation. I make a distinction between cognitive structures—the structured knowledge team members have regarding their task or team—and cognitive processes—occurring as team members perform their tasks (Salas & Fiore, 2004). Cognitive structures may hinder or facilitate team adaptation and are often part of the content of that which teams have to alter in order to adapt. Cognitive processes constitute an important element of the adaptation process and are the drivers of change in the cognitive structures. In the following section I will present a model that depicts how these cognitive aspects relate to team adaptation. I will start with a general description of the model, then I will describe the role of cognitive structures, and finally the role of cognitive processes in the adaptation process. Then, based on this model I will formulate three research aims for this dissertation.

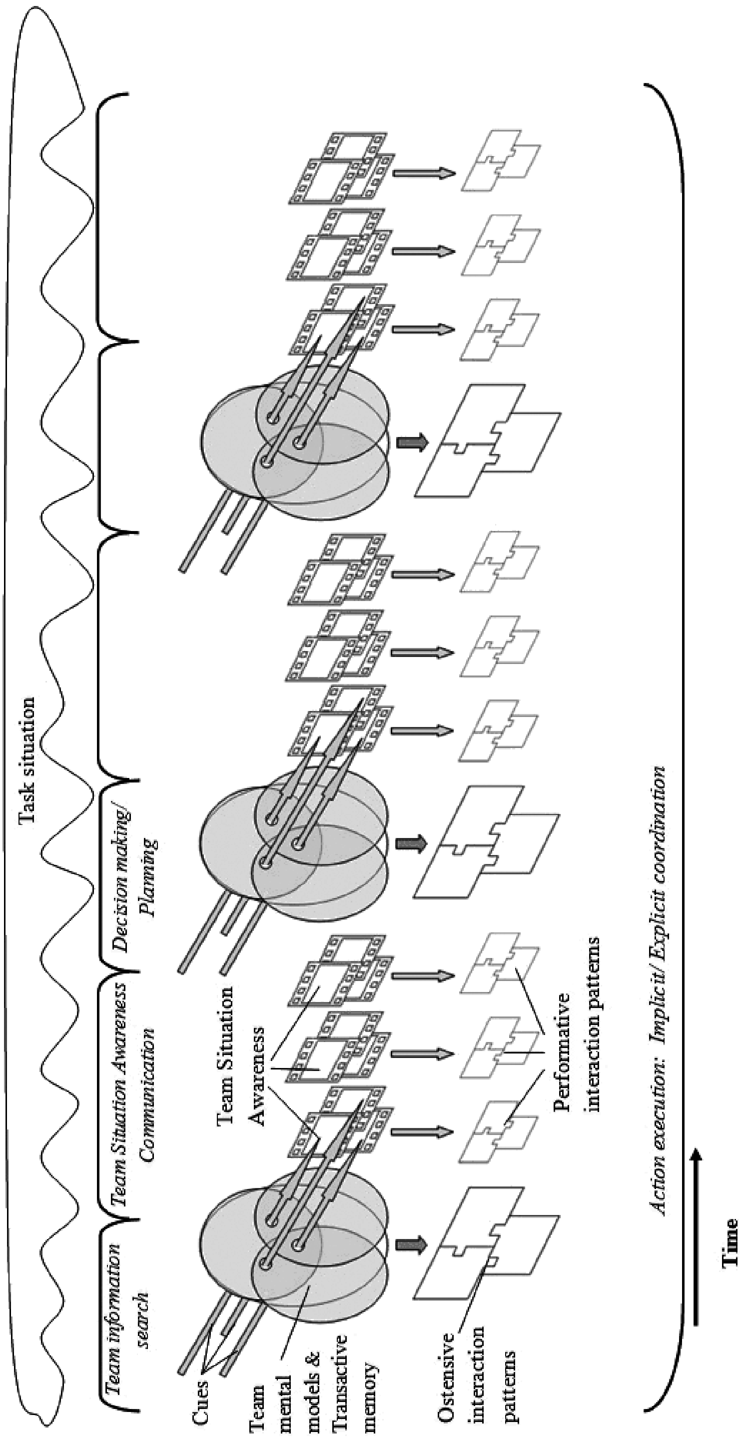

Figure 1. A cognitive perspective on team adaptation

Figure 1 depicts a cognitive perspective on team adaptation. In the model the passing of time is depicted from left to right. The top of the figure represents 'that to which the team adapts'—the team's task situation. The middle of the figure represents the teams' configurations or 'that which is adapted' – the team knowledge structures and the interlocking actions team members perform to execute their task. The teams' knowledge structures and interaction processes are enclosed by team adaptation processes in order to indicate that alterations in these team configurations represent team adaptation processes. Team adaptation processes are written in italics and are provided with an arc to indicate that they occur over time with a specific duration. In line with Marks, Mathieu, and Zaccaro's (2001) temporal framework of team processes, the patterns are repeated to indicate the ongoing and recursive nature of team adaptation. So, team cognitive processes impact team configurations, which then may impact subsequent team cognitive processes and so on. The present model deviates from models prevalent in group development theories that consider groups to linearly progress through a number of group stages (e.g. Tuckman, 1965; Tuckman & Jensen, 1977; Worchel, 1994). Instead teams are considered to adapt relative to changes in their task situation. So, the emphasis is not on development factors that are driven by factors internal to the team but on team adaptation driven by teams' contextual dynamics—factors in the team's external environment (McGrath, Arrow, & Berdahl, 2000). Moreover, the sequence in which teams' cognitive processes occur is not considered linear, as teams may for example engage in action execution and information search concurrently and decision making may follow as well as precede information search.

Changes occurring over time in the team's task situation are depicted in the top of the figure as a capricious form in order to depict the typical irregularity and unpredictability of adaptation requiring environments. The task situation is depicted as a formless mass in order to indicate that it is only through their pre-existing knowledge structures that team members make sense of their task situation (Weick, 1979). Changes in the task situation can be partitioned in momentary changes in the environment—for example, the spreading of a specific fire—and changes in the recurring structural relationship between elements of the environment—for example, alterations in the use of construction materials that change how building fires spread in general. Information about the environment becomes available as team members engage in active information search or passively absorb information *cues*, which are depicted in the figure by the long grey arrows.

Team cognitive structures and interaction processes

In the middle of the figure the cognitive structures that impact the team's adaptation to the task situation are depicted. Which cues a team picks up and the interpretation team members form based on these cues depends on team members' mental models (e.g. Starbuck & Milliken, 1988; Walsh, 1995). *Mental models* are organized knowledge structures of a specific domain or system, consisting of concepts as well as structures relating these concepts (Cannon-Bowers, Salas, & Converse, 1993). Mental models need not be technically accurate but they must be functional—they must enable humans to effectively interact with the system (Norman, 1983). When people interact with a system, they form cognitive representations of that system that enable them to "generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future system states" (Rouse & Morris, 1986, p. 351). With *team mental models* I refer to the specific compilation on the team level of the mental models of the individual team members (Klimoski & Mohammed, 1994). In the figure, team members' mental models are depicted by grey circles. The circles are partly overlapping and partly unique, to indicate the shared and distributed nature of team level knowledge (Cannon-Bowers & Salas, 2001).

From the interaction of cues and mental models, team members derive representations of the situation or *situation awareness* (Endsley, 1995; Weick, 1995). Situation awareness refers to the momentary understanding people have about a specific task situation. It consists of knowledge about facts, interpretations based on these facts, and anticipations of how the situation may develop in the near future (Endsley, 1995). For example, from the moment they first heard of the incident, the fire fighting team from the opening example, gradually received novel cues about the fire and, based on these cues they interpreted the situation subsequently as a 'house fire', 'an intermediate level fire', and a 'vehicle fire in a covered space'. *Team situation awareness* refers to the common understanding of the situation by the team members, as well as, to the representations of the situation that are unique for each team member (Endsley, 1995; Wellens, 1993). Because compared to team members' mental models, situation awareness is a much more dynamic construct—in rapidly changing situation, people also rapidly adjust their representations of those situations—, I have depicted team members' situation awareness as a sequence of snapshots (Cooke, Salas, Cannon-Bower, & Stout, 2001).

Another cognitive structure that has been related to team adaptation is a team's transactive memory (Lewis et al., 2005; , Moreland & Myaskovsky, 2000). A team's transactive memory consists of the knowledge of the individual members of the group combined with members' knowledge of the content of information held by other members of the group. Through their experience of working together, team members not only achieve individual task experience but also develop an understanding of the knowledge and fields of expertise of their group members. This knowledge of "who knows what" enables group members to arrange their tasks in such a way as to optimally benefit from the variety of experience available within the team as a whole.

The symbol depicting team mental models is repeated over time to indicate that not only mental models influence team situation awareness, but also the other way around; team members' understanding of the situation will influence which mental models or which aspects of their mental models will be activated (Uitdewilligen, Waller, & Zijlstra, 2010). Moreover, mental models may change over time as team members update them and learn new associations of relationships in the environment. Note that the rate at which change occurs is likely to differ between the different types of knowledge structures (Cooke, Salas, Cannon-Bowers, & Stout, 2000). Whereas in dynamic situations, situation awareness is likely to be in a constant flux, as the team continually updates its image of the situation, mental models and transactive memory will evolve more gradually as team members gain experience with the task and with each other.

Below the team cognitive structures the team interaction patterns are depicted. With *interaction patterns* I refer to recurring sequences of behaviors team members execute during task performance (Stachowski et al., 2009; Zellmer-Bruhn, Waller, & Ancona, 2004). For example, in a team of fire fighters, when reaching the location of a fire, one member may start surveying the premises, while two others prepare the fire engine, and a fourth gathers information from the residents. As soon as they have finished their initial activities they start extinguishing the fire and possibly enter the building. I depict team interaction patterns as interlocking puzzle pieces in order to depict the interdependent nature of team work and to indicate that individual team members' actions are often related to their specific role within the team (LePine, 2003).

I follow the distinction made by Feldman and Pentland between ostensive and performative aspects of routines (2003). The ostensive aspects of team interaction patterns are relatively fixed; whereas the performative aspects may be more easily adapted as team members adjust their actions relative to the demand of the situation. The arrow pointing downwards from the team knowledge structures indicates that the ostensive aspect of team interaction patterns are embedded within the cognitive scripts or procedural knowledge structures team members have of the sequence of events and actions that should occur in a specific situation (Abelson, 1976; Cohen & Bacdayan, 1994). The symbol for ostensive interaction patterns is repeated to indicate that over time, as they adjust their performative interaction patterns, team members develop new and adapt their existing interaction patterns.

Team cognitive processes and team adaptation

Team cognition refers to the collection of team knowledge structures, but also to the cognitive processes team members collectively engage in during team performance (Salas & Fiore, 2004). Scholars have depicted adaptation as a process consisting of a number of phases or sub-processes that have to be successfully fulfilled in order for a team to successfully adapt. This view of team adaptation is based on a conceptualization of teams as information processing systems—as entities that acquire, process, store, exchange, and use information (Hinsz, Tindale, & Vollrath, 1997). Although a wide variety of processes have been related to team adaptation, for sake of parsimony I will focus on four generic processes that consistently appear in information processing models of team adaptation (Burke et al., 2006; Kiesler & Sproull, 1982; Marks et al., 2000): team information search, team situation awareness communication, decision making and planning, and action execution. Below I will give a short description of these processes and describe how they are related to cognitive structures and team interaction patterns.

Team information search is often considered the initial subprocess of team adaptation (Burke et al., 2006). In complex and dynamic environments, the extent to which teams take into account all aspects of their task situation is crucial for task performance (Burke et al., 2006; Hollenbeck, Ilgen, Sego, Hedlund, Major, & Philips, 1995; Waller, 1999). Teams must collect information in order to recognize the need for change in their task strategies and to make informed decisions on team actions. For instance, the literature on team situation assessment indicates that particularly in highly dynamic task situations, continuous scanning of the relevant task environment is crucial for team performance and viability (Artman, 2000; Mosier & Chidester, 1991). On the individual level, scholars have argued that the type of information team members' perceive and the interpretations they form based on this interpretation depends on a person's existing knowledge structures (Endsley, 1995; Starbuck & Milliken, 1988). Extrapolating this reasoning to the team level implies that characteristics of the composition of the team members' knowledge structures impact how a team selects and processes information from the task situation (Hinsz et al., 1997). For instance, if the members of a team hold diverse mental models, they are likely to attend to a variety of information sources, whereas if team members have similar mental models, they are likely to attend to similar information sources and draw similar interpretations. Moreover, if a team has a well functioning transactive memory system, responsibilities for attending to and remembering information can be efficiently distributed among the team members (Liang, Moreland, & Argote, 1995; Moreland, Argote, & Krishnan, 1996, 1998).

Team situation awareness communication. Information gleaned from the task situation becomes part of team members' situation awareness. Although team members' initial situation awareness arises from an interaction of their mental models and cues from the environment, team members also engage in *team situation awareness communication* through which they share information about the situation, influence each others' understanding, and co-construct their situation awareness (Stout, Cannon-Bowers, & Salas, 1996; Weick, 1995). Team situation awareness communication is closely related to team sensemaking "the process by which a team manages and coordinates its efforts to explain the current situation and to anticipate future situations" (Klein, Wiggins, & Dominguez, 2010). While engaging in active task execution, team members must construct and continually update their understanding of the dynamic task situation as it unfolds over time. Moreover, in order for the team members to align their actions with one another and to function as an integrated entity, team members must share crucial aspects of their situation understanding (Endsley, 1995; Salas, Prince, Baker, & Shrestha, 1995; Rico, Sánchez-Manzanares, Gil, & Gibson, 2008).

Team decision making/ planning. When team members have developed their understanding of the task situation, the next step is to translate this novel understanding into decisions and plans for task execution. When the task situation has changed, team members need to reprioritize subtasks and redistribute responsibilities over the team members (Waller, 1999). Even though teams may have developed initial plans prior to their task performance, unexpected developments in the task situation requires teams to reflect on these previously formed plans and adjust them incorporating the new information (DeChurch & Haas, 2008; Weingart, 1992). Research on individual decision making in field situations indicates a direct link between recognition of the situation and the selection and execution of an appropriate action (Klein, Orasanu, Calderwood, & Zsambok, 1993). However, on the team level, team members need to ensure that the actions of individual members are attuned to one another, so that the team functions as an integrated entity. Therefore, collective decision making and the development of an integrated plan of action constitute an important element of team adaptation.

Although team decision making may under some circumstances be a horizontal process in which all team members have equal influence, in many situations hierarchical distinction are likely to impact how decisions are formed (Hollenbeck, Ilgen, Sego, & Hedlunc, 1995). Threat rigidity theory (Staw, Sandelands, & Dutton, 1981) suggests that: particularly during threatening crisis situations, teams are likely to experience constriction of control, whereby decision authority becomes concentrated within one or few team members. Constriction of control is likely to have an effect on how the compilation of team members' knowledge structures impacts team decisions. For example, in a study with students performing in a team decision making simulation, Walsh, Henderson, and Deighton (1988), found that the knowledge structures of the most influential members had more impact on for team decision outcomes than those of less influential members (Walsh, Henderson, and Deighton, 1988). Driskell and Salas (1991), however, found in an experimental study that under threatening conditions, high status team members accepted more influence on their decision from low status members than under non-threatening conditions.

Action execution (Implicit/ Explicit coordination). The fourth process, *action execution*, refers to the actual implementation of plans and execution of team members' synchronized actions. A wide variety of studies emphasizes the role of coordination of team members' action for successful task performance (Cannon-Bowers, Tannenbaum, Salas, & Volpe, 1995; Mathieu at al., 2008). The arrows pointing down from team situation awareness indicate the link between the sharedness and accuracy of team members' representations of the situation and team implicit and explicit coordination (Rico et al., 2008). *Implicit coordination* refers to a team's coordination of team members' actions without the need for overt communication (Kleinman & Serfaty, 1989). Implicit coordination is based on anticipations of the actions and needs of the other team members and the ongoing adjustment of team members' actions in order to maintain concerted goal directed interaction patterns (Rico et al., 2008). Implicit coordination depends on the availability of appropriate ostensive interaction patterns for the specific task situations, as well as, on the appropriateness and sharedness of team members' situation representations.

If a team's repertoire does not contain ostensive interaction patterns that fit the task situation or team members diverge in their representation of the situation, they have to engage in *explicit coordination*—overtly communicating their actions and intentions—during task performance. For example, if in a 'burning vehicle in building' situation, all members of a fire fighting team have been trained on conducting the actions belonging to their role for that specific situation, and each individual fire fighter correctly labels the situation, there will be little need for explicit coordination. However, in case the fire fighters encounter a situation for which they have not been explicitly trained or that cannot be unambiguously categorized, they will have to engage in team situation awareness communication and explicit planning processes to synchronize their actions.

Levels of cognitive processing and cognitively switching gears

The distinction between implicit and explicit coordination is related to the notion that information processing can take place at different levels. Literature on individual level cognition indicates that cognitive processes may occur at two (Schiffrin & Schneider, 1977) or three (Rasmussen, 1982) different levels. For example, Rasmussen (1982; 1986) distinguished between three levels of cognitive control in task performance. The first, skill based control, is associated with the highly automated integrated patterns of behavior of people when they are highly experienced with a task. The second, rule based control, occurs when people are familiar with but do not have extensive experience with a task and is based on a linkage between the recognition of a situation and rules for actions derived from previous experience or from instruction. Third, in novel situations where proper rules are not available individuals engage in knowledge based regulation—controlled analytical processing in which people draw on their declarative knowledge to make sense of their task situation and infer goal appropriate actions.

On a more general level, scholars have made a distinction between automatic and controlled processing (Schiffrin & Schneider, 1977). Automatic processing is a fast, rigid, and relatively effortless form of information processing based on experience in similar situations. With controlled processing, on the other hand, people actively and consciously process information. It is therefore more flexible, much slower, and it puts heavy demands on attentional capacity. Moreover, the type of knowledge structures people rely on in the different modes of processing varies. Whereas task performance in an automatic mode of control relies on procedural knowledge—relatively automatic and inarticulate memory providing the steps and action sequences required for task performance (Cohen & Bacdayan, 1994), controlled processing involves the conscious application of higher level knowledge in the form of declarative knowledge structures or mental models (Rasmussen, 1993).

On the team level, routine based interactions can be considered a form of automatic processing (Cohen & Bacdayan, 1994; Gersick & Hackman, 1990). As Cohen and Bacdayan indicate "(r)outines arise in repetitive situations where the recurring cost of careful deliberation can become a heavy burden" (1994, p.555). Routine based interaction facilitates coordination by contributing to the predictability of the behavior of other team members. Moreover, due to its cognitive efficiency routine based automatic processing may be optimal in many task situations—if tasks are automatically executed people have at their disposal spare attentional resources, which enable them to engage in additional activities, such as scanning the environment for possible alterations and the rehearsal of future responses (Thorngate, 1976). However, when teams are faced with novel task situations, teams require controlled processing in order to make sense of the task situation and critically reflect on the appropriateness of their interaction practices (Cohen & Bacdayan, 1994).

Louis and Sutton (1991) argued that it is not so much the mode of operation that is important but the extent to which individuals and teams are able to switch between modes. In other words, teams have to be able to sense when the task situation has changed to such an extent that a reliance on automatic routine processing becomes detrimental to performance (e.g. Stachowski et al., 2009). This is consistent with findings of Waller (1999) that it is not so much adaption processes per se, but the timing of these processes directly following non-routine events that enable a team to maintain high performance. Likewise, the argument of Louis and Sutton (1991) implies that as soon as the team has developed and incorporated interaction patterns that fit the novel task situation, the team should shift gears back again into automatic functioning.

A cautionary note: limits to the positive effects of team adaptation

Finally, although I have defined team adaptation explicitly as an effective process, a cautionary note should be made that this does not mean that all adjustments to the environment are equally positive. Discrepancies between short term and long term outcomes and between team goals and higher level system goals may render some forms of adaptation undesirable. I will shortly consider these boundary conditions to the beneficial effects of team adaptation.

First, an adjustment that positively contributes to team performance in the short term may have negative performance effects in the long run. Research by Rudolph and Repenning (2002) indicates that an accumulation of small interruptions can shift an organizational system from a resilient, self-regulating regime, to a fragile, self-escalating system. Comparably, too much adaptation aimed at short term outcomes may lead to instability in the team in terms of its interaction patterns and cognitive structures, which in the end may become detrimental to team performance. The more instable the team interaction patterns, the more difficult it becomes for team members to anticipate what actions they can expect from the other members, which may lead to breakdowns in coordination (e.g. Kanki et al., 1991). Moreover, instability in knowledge structures may create uncertainty in team members about their knowledge structures, which might temporarily paralyze team members. As an example, a soccer team that continuously adapts its playing style to its opponents may win some games but will ultimately fail as it fails to develop its own playing style. Besides, if teams are faced with successive adaptation requiring situations, the accumulation of attentional resources this requires may overtax team members and eventually lead to cognitive breakdowns. Therefore, under some circumstances it maybe optimal to take a short term performance loss by not adapting, in order to secure stability and long term performance. Alternative strategies teams may apply is shielding itself from external influences or engaging in adaptation only after a critical mass of changes has accumulated (Miller, 1978).

Second, adaptation that has positive outcomes for a single team may have negative outcomes for a higher entity in which that team is embedded. Given that teams often constitute part of a wider system, adaptation of a single team, may, although positive for the outcomes of that team, have detrimental effects on the performance of the overall system. In particular, adaptation of one team may have a disruptive effect on the linkage of that team with other teams. For example if a fire fighting team deviates from standard operating procedures regarding their treatment and location of victims, expectation of the medical teams about the procedures that will be followed may diverge from the actual situation and therefore between-team coordination breakdowns may occur. This implies that, if adaptation of lower level entities is not coordinated with adaptation of other entities that are interdependent with that entity, the outcomes for the higher level entity may be negative. This suggests that adaptation should not only be investigated at the team level but also on the higher levels of the entity in which teams are embedded (Mathieu et al., 2001).

Summary

To summarize, team adaptation is aimed at attaining congruence between the team's configuration (members' knowledge structures, interaction patterns) and a changing task situation. Team situation awareness and performative interaction patterns are relatively responsive to the immediate changes in the environment, while this responsiveness is less for the more fixed aspects represented by team mental models and ostensive interaction patterns. However, cumulative deviations in team situation awareness and performative interaction patterns will cause team mental models and ostensive interaction patterns also to change over time, leading to updating and learning in mental models and the development of new performance routines. Team cognitive processes can be seen as the drivers of change in team cognitive structures and interaction processes. Finally, it has to be noted that there also is an inverse relation from team actions to the environment. An embedded system model of teams suggests that teams are not merely passively reacting to their environment but may also actively shape and influence the environment in which they are embedded (Arrow et al., 2000; Kozlowski & Ilgen, 2006; Weick, 1988).

Aim and overview of the dissertation

As the model described above indicates, team cognition constitutes an essential element of team adaptation. However, although this model is based on existing theory and research, the effect of most of the cognitive structures and processes on team adaptation outcomes have not been empirically investigated. Therefore, in the present dissertation I take a cognitive perspective to team adaptation, viewing teams as collective information processing systems (Hinsz et al., 1997) and investigate the role of cognitive structures and processes in team adaptation. The aim of this dissertation is threefold. First, I aim to unravel the relationship between characteristics of the described cognitive structures and team adaptation and I aim to investigate how team cognitive structures interact with team processes in predicting team adaptive performance. Second, I aim to investigate the nature, antecedents, and consequences of change and development of cognitive structures. Third, I aim to investigate the nature of teams' cognitive adaptation processes and their effect on team adaptation to novel circumstances. In the dissertation I present five chapters in which I focus on and elaborate on aspects of the presented cognitive model and contribute to the research aims stated above.

Chapter 2 focuses on the first research aim, unraveling the relationship between cognitive structures and team adaptation. The chapter provides an extensive review of the role of three team cognition constructs in predicting team adaptation: shared mental models, a transactive memory system, and team situation awareness. We[2] provide an extensive review of existing literature on these concepts and critically investigate how each of these concepts relates to team adaptation. We find that overall much of the research in the extant literature suggests that these cognitive structures facilitate the coordination and communication necessary for teams to adapt in turbulent and dynamic task settings. However, we conclude with a critical note, questioning the basic assumption that these structures always facilitate team adaptation. Moreover, we find that research on team mental models has mainly focused on characteristics of similarity and accuracy whereas aspects such as mental model complexity and change, which are likely to also be important for team adaptation, have been underexposed.

In line with the second research aim, in *Chapter 3* we investigate the nature, antecedents, and consequences of change and development of cognitive structures. We present a study in which we investigated the effects of team situation awareness, adaptation behaviors, and changes in mental models on post-change adaptive performance. For this study we constructed a task-change simulation scenario in which the team task structure changed halfway the simulation. We measured team situation awareness before the change and mental models before and after the change. In addition, we analyzed team communication and assessed the extent to which the teams applied repetitive patterns in their behaviors in the performance period after the change. The results indicate a positive relationship between the extent to which team members updated their mental models relative to changes in the task situation and team adaptive performance. Moreover, this relationship was partially mediated by team interaction patterns.

Chapter 4 focuses on the relationship between cognitive structures and team adaptation and on the interaction between cognitive structures, processes, and performance. The chapter describes how theories that advocate cognitive similarity and theories that advocate cognitive diversity seem to lead to opposing inferences regarding team performance under dynamic circumstances. Shared mental model theory advocates similarity in cognitive knowledge structures among team members, while transactive memory theory emphasizes the benefits that can be gained from cognitive diversification. We attempt to unite these theories by introducing the notion of cognitive complexity—teams require external alignment in order to deal with complex environments and internal alignment to coordinate their information processing. We conducted a study in which teams performed in a dynamic complex management simulation. In contrast to the previous study, the team task does not contain a single adaptation event but instead the teams had to repeatedly adapt their tactics and strategies to a dynamically changing task situation. Findings of the study indicate that both internal and external cognitive alignments are crucial for team performance development over time. Team mental model complexity, transactive memory systems, and shared

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[2] Because I have worked together with a number of different co-authors on the studies reported in this dissertation, I use the term 'we' to designate myself and the co-authors with whom the various studies were executed.

mental models had an influence on team performance trajectories. In addition, we found a moderation effect of team mental model complexity on the relationship between team information search and team performance over time.

In *chapter 5* we explore the third research aim, the nature of teams' cognitive adaptation processes. We present a case study on a single team in which we investigate how this team alters its understanding of an unexpected dynamic situation over time. We analyzed a sample of the audio communication of the operations team of NEADS— the organization responsible for coordinating the air defense of the northeast quadrant of the United States during the terrorist attacks of September 11, 2001. From our analyses of the data we concluded that in ambiguous situations, teams construct temporary 'working hypotheses' of the situation that enable them to maintain sense and coordinate their actions. The formation and abandonment of these working hypotheses over time consisted of an iterative process of using and discarding working hypotheses as events unfolded and sensemaking occurred.

In *Chapter 6* we investigate how the central command teams of an emergency management system developed an understanding of an unfolding crisis management situation and make decisions on what actions to take. In this chapter, we take a communication perspective on team cognition (Keyton, Beck, & Asbury, 2010; Waller, 1999), as we investigate teams' situation awareness formation from the communication among the team members. We analyze video recordings of emergency management command teams as they perform in a crisis management simulation. Our findings indicate that the team communication process can be divided into a two phase structure. An initial phase aimed at setting the structure of the meeting and sharing individually held information and a second decision making phase in which the teams focus on making decisions on actions to take. Our results indicate that, compared to average-performing teams, high-performing teams spent more time on the initial phase and make decisions more rapidly in the decision making phase. Moreover, high-performing teams engaged in more collective interpretation processes during the decision making phase compared to average-performing teams and schematic use of the whiteboard influenced the extent to which teams engaged in collective interpretation processes.

Finally in *Chapter 7*, I provide an overview of the main findings of each study. I discuss theoretical, methodological, and practical implications and provide suggestions for future research.

CHAPTER 2*

Team cognition and adaptability in dynamic settings: A review of pertinent work

* This chapter is based on: Uitdewilligen, S., Waller, M. J. Zijlstra, F. R. H. 2010. Team Cognition and Adaptability in Dynamic Settings: A Review of Pertinent Work. pp. 293–353. *International Review of Industrial and Organizational Psychology*. Gerard P. Hodgkinson, J. Kevin Ford (Eds.) John Wiley & Sons Ltd. Chichester.

ABSTRACT

In this chapter we aim to unravel the relationship between cognitive structures and team adaptability. The chapter provides an extensive review of the role of three team cognition constructs in predicting team adaptation success: shared mental models, a transactive memory system, and team situation awareness. We provide an extensive review of existing literature on these concepts and critically investigate how each of these concepts relates to team adaptation. We find that overall much of the research in the extant literature suggests that these cognitive structures facilitate the coordination and communication necessary for teams to adapt in turbulent and dynamic task settings. However, we conclude with a critical note, questioning the basic assumption that these structures always facilitate team adaptation. Moreover, we find that research on team mental models has mainly focused on characteristics of similarity and accuracy whereas aspects such as mental model complexity and change, which are likely to also be important for team adaptation, have been underexposed.

Introduction

Given the increased unpredictability, complexity, and turbulence of organizational and economic environments, organizations are relying on teams of individuals to analyze situations, solve problems, make decisions, negotiate agreements, and generally keep things running. Teams provide an efficient means of arranging work in many organizational structures (Zaccaro & Bader, 2003), and researchers for some time have trained their focus on understanding how teams successfully and unsuccessfully manage the aforelisted tasks. One particular team characteristic has emerged as critical, given the dynamic situations within which many teams now find themselves embedded: adaptability.

It is no longer adequate, in countless organizational situations, for teams to follow the "rational" prescription of scanning the environment, collecting and analyzing data, developing alternatives, and solving problems or making decisions. Teams may be peppered with non-routine events as they struggle to follow accepted guidelines and operating procedures (Stachowski, Kaplan, & Waller, 2009). Team decision rules meant for relatively stable conditions may become obsolete as competitors run and change at Internet speed. Instead, these and similar situations that call for proactive anticipation and agile adaptation require teams with members who are connected in very particular ways.

In this chapter, we present a review of recent research published within the last 15 years about those "particular ways"—specifically, the shared mental models, transactive memory, and team situation awareness (TSA)—that are suggested to enable teams to sense and manage unexpected events in their dynamic task environments. Briefly, shared mental models are mental representations of knowledge, relationships, or systems that are similar across team members. Transactive memory has been defined as the division of cognitive labor in a team with respect to encoding, storing, and retrieving knowledge from different domains (Lewis, Belliveau, Herndon, & Keller, 2007)—or more colloquially, the system of knowing who on the team knows what. Finally, team situation awareness differs from shared mental models and transactive memory in that it is shared contextual knowledge about the current situation, team members' knowledge of each other's goals, and their current and future activities and intentions (Roth, Multer, & Raslear, 2006).

Overall, much of the research to be reviewed in this chapter suggests that each of these team cognitive structures facilitate the coordination and communication necessary in teams attempting to successfully anticipate and react to turbulent, dynamic task settings. In our conclusion to the chapter, however, we question the building assumption that these types of shared cognition always facilitate the adaptability needed by teams facing unexpected and turbulent situations, and explain how the level and type of dynamism in teams' environments may significantly influence the positive effects of shared mental models, transactive memory, and shared situation awareness in teams. Additionally, given our focus on these aspects of shared cognition, we pay particular attention in this review to work pertaining to "action" teams—that is, teams that face unpredictable, dynamic and complex task environments, and both react to and influence those environments (Chen, Thomas, & Wallace, 2005; Marks, Zaccaro, & Mathieu, 2000). Where appropriate in our review, we highlight how each of the three types of shared cognition is thought to facilitate adaptability in teams, and we include suggestions for future research.

Adaptability

Several models of team adaptation have appeared in the teams literature in recent years. Referring to their advanced conceptual model of team adaptation, Burke and colleagues define team adaptation as "a change in team performance, in response to a salient cue or cue stream, that leads to a functional outcome for the entire team" (Burke, Stagl, Salas, Pierce, & Kendall, 2006, p. 1190). These scholars suggest that teams adapt in a recursive, cyclical nature over time to their changing contexts, and specifically suggest that teams with accurate and flexible mental models and heightened levels of TSA will be better able than other teams to notice and correctly identify important changes in their task situations. LePine (2005, p. 1154) refers to team adaptation a "nonscripted" response that calls for action other than learned routines, or as a "response to an unforeseen change that creates problems for which the team has had limited experience or training", and suggests that individuals' cognition levels provide an important antecedent to team-level adaptation. Marks and colleagues (2000, p. 972) refer to team adaptation as occurring when "teams are able to derive and use new strategies and techniques for confronting novel elements in their environments." Marks and colleagues also suggest that the similarity and accuracy of teams' mental models will facilitate team adaptation efforts. Chen and co-authors (2005) suggest that the transfer of training in teams involves adaptive expertise, or "the capacity to modify knowledge, skill, and other characteristics acquired during training to meet novel, difficult, and complex situations" (p. 828).

Thus, the recent work on adaptation in teams is fairly consistent in characterizing team adaptation as change undertaken by a team in terms of (1) specific task performance behavior, (2) strategies for planned behavior, or (3) collective knowledge, in response to or anticipation of some unexpected, novel, non-routine, complex event. This work is also consistent in suggesting that elements of shared cognition in teams, most often shared mental models, facilitate teams' efforts to make these necessary and often time-pressured changes. Consequently, we turn now to review the literature on shared mental models in order to better understand the role of this form of shared cognition as a shaper of team outcomes.

Shared mental models

Probably the most widely researched concept pertaining to shared cognition is the shared mental model notion (Cannon-Bowers, Salas, & Converse, 1993; Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000; Klimoski & Mohammed, 1994) and the related concept of shared schema (Rentsch & Hall, 1994). Mental models are organized knowledge structures consisting of the content as well as the structure of the concepts in the mind of individuals that represent a specific task or knowledge domain (Johnson-Laird, 1983; Kieras, & Bovair, 1984; Orasanu & Salas, 1993). Reasoning based on mental models is a form of top-down information processing in the sense that cumulated knowledge from past experiences is used to make sense of information environments and to guide action (Abelson & Black, 1986; Hodgkinson & Healey, 2008; Johnson-Laird, 1983; Walsh, 1995). Hence, mental models are functional structures that enable people to describe, explain, and predict a system with which they interact (Gentner & Stevens, 1983; Hodgkinson & Healey, 2008: Rouse & Morris, 1986). For example, machine operators may possess a mental model that depicts the cause and effect relations of the internal functioning of a machine. To the extent that their mental models properly mirror the actual functioning of the machine, operators will be able to deduce what the parameters on the machine display signify about the system's state and be able to infer the consequences of alternative actions.

Since the introduction of the concept of mental models to teams research in a number of seminal theory papers (e.g. Cannon-Bowers et al., 1993; Klimoski & Mohammed, 1994; Kraiger & Wenzel, 1997; Rentsch & Hall, 1994), teams researchers have embraced this concept and provided an ongoing stream of articles and studies covering team-level properties of mental models, which we will refer to here as shared mental model theory. The basic tenet of shared mental model theory is that congruence in team members' mental models facilitates efficient teamwork and consequently leads to high performance (Cannon-Bowers et al., 1993). On the basis of this principle, researchers have suggested that shared mental models may facilitate team performance and decision making in a wide variety of situations (e.g. Langfield-Smith, 1992; Smith & Dowell, 2000; Stout, Cannon-Bowers, Salas, & Milanovich, 1999; Walsh & Fahey, 1986) and facilitate team adaptation in challenging and novel situations (Burke et al., 2006; Marks, et al., 2000; McIntyre & Salas, 1995; Waller, 1999; Waller, Gupta, & Giambatista, 2004).

The field has now reached a point where a substantial number of empirical studies have been published in the area, allowing us to draw more informed conclusions regarding the consequences, antecedents, mediators, and contingencies of shared mental models. Here we seek to provide an update of the state of the field, and focus in particular on the empirical evidence that has been found, identifying some outstanding issues for which empirical tests are still wanting. In the following section we will first describe some conceptual issues related to shared mental models. After this we will discuss the measurement techniques that have been used to elicit mental models from team members and report team outcomes and processes that are associated with shared mental models. Then we will review antecedents of shared mental models and contingency factors that influence the impact of shared mental models. We will end with some outstanding issues in research on shared mental models and present directions for further research.

Types of Shared Mental Models

Researchers in the area have generally agreed that different types of mental models may be active simultaneously in teams. Klimoski and Mohammed (1994) suggested that at any given point in time, multiple mental models may be shared among the members of a team. Regarding mental model types, Cooke and colleagues (2000) distinguished between three types of knowledge that individuals‘ mental models may contain: (1) declarative knowledge, containing the facts, figures, rules, relations, and concepts of a task domain; (2) procedural knowledge, consisting of the steps, procedures, sequences, and actions required for task performance; and (3) strategic knowledge, consisting of the superseding task strategies and knowledge of when they apply. It has also been suggested variously that mental models may consist of collections of these different knowledge types (Klimoski & Mohammed, 1994) and that each type of knowledge may be considered as a separate mental model (Banks & Millward, 2007).

Whereas the aforementioned division applies to the type or form of mental models, team members may also hold mental models for different aspects of their task. Cannon-Bowers and co-authors (1993) identified mental models for four aspects of a task that may be required for successful team performance: (1) a model of the equipment used in the execution of the task, (2) a model representing aspects of the task itself, such as task processes, strategies, and likely scenarios, (3) a team interaction mental model, representing team members interaction and communication patterns, roles, and responsibilities, (4) a team member model, containing knowledge about other teammates' knowledge, skills, abilities, attitudes, beliefs, and tendencies. An examination of empirical studies on shared mental models indicates that most researchers have used a somewhat simpler division, and have—on the basis of a classical distinction of Morgan, Glickman, Woodward, Blaiwes, and Salas (1986) between a taskwork track and a teamwork track of team development—collapsed the first two and the second two mental model types into task and team mental models (e.g. Cooke et al., 2003; Fleming, Wood, Gonzalo, Bader, & Zaccaro, 2003; Lim & Klein, 2006, Mathieu et al, 2000; Mathieu, Heffner, Goodwin, Cannon-Bowers, & Salas, 2005). However, many other scholars have focused on a single mental model (e.g. Ellis, 2006; Marks, Sabella, Burke, & Zaccaro, 2002; Marks, et al., 2000; Rentsch & Klimoski, 2001).

In sum, shared mental models are a configural type of team construct indicating the degree of similarity among the mental models of members of a team (Kozlowski & Klein, 2000; Mathieu et al., 2005).

Measurement of Mental Models

The measurement of mental models is a topic that has garnered increasing interest and concern among teams researchers. On the basis of a review of the various techniques available to measure mental models, Mohammed, Klimoski, and Rentsch (2000) concluded that researchers must base their choice of measurement technique on a careful consideration of the research question and research context. They also called for the inclusion of multiple measurement techniques in single studies in order to assess their relative benefits and increase their predictive validity.

In a number of methodological articles and reviews, researchers have noted a wide variety of elicitation, representation, and analysis techniques available for assessing mental models that could be applied to a team context (see, e.g., Cooke et al., 2000; Hodgkinson & Healey, 2008; Langan-Fox, Code, & Langfield-Smith, 2000; Mohammed et al., 2000). Elicitation techniques have included: cognitive interviewing, questionnaires, process tracing and verbal protocol analysis, text based content analysis, and a variety of conceptual methods including visual card sorting, repertory grid, causal mapping, ordered tree technique, and matrix based and pairwise ratings. Analysis and representation methods included: pathfinder networks, multidimensional scaling, and UCINET techniques based on proximity ratings, cause mapping based on interviews and questionnaire data, and text-based cause mapping involving the systematic coding of documents and transcripts.

Whereas Mohammed and colleagues (2000) indicated that the most common elicitation methodologies in the study of team mental models were similarity ratings and Likert-scale questionnaires, it seems that the popularity of Likert-scale questions has decreased while the use of similarity ratings and concept mapping seems to have increased in recent empirical studies. With similarity ratings, researchers typically derive, by means of a task analysis, a number of concepts that are relevant for team task execution. Respondents are asked to rate the similarity—in terms of causality, relatedness, proximity, or association—they perceive between these concepts. Outcomes of this ratings process are subsequently subjected to systems such as Pathfinder or UCINET to derive and analyze the mental models (see Edwards et al., 2006 and Mathieu et al., 2000 for examples). With concept mapping methods, team members are asked to place concepts in a pre-specified hierarchical structure (Mohammed et al., 2000). For example, Marks and colleagues (2000) asked team members to indicate on a timeline the sequence of actions they themselves would take, as well as the actions the other team members would be taking at the same time during team task performance. Similarity is typically subsequently calculated by assigning points for each instance in which team members located similar concepts or actions within the predefined structure. Using a different method, Carley (1997) employed a textual analysis technique that helped automate the approach for deriving mental models from written text. In her study, participants answered an open-ended essay question regarding their team task. Concepts were derived from the words team members used in their texts, and the relationships among those concepts were obtained from the proximity of the location of these concepts within the text.

Webber and colleagues (2000) distinguished between consistency measures of similarity and consensus measures in their work. According to this conceptualization, consistency only requires similarity in rank ordering between raters, whereas consensus requires essentially the same ratings. Weber and colleagues' results indicated that although team mental model consistency was not significantly related with team performance, team mental model consensus was. On the other hand, Smith-Jentsch, Mathieu, and Kraiger (2005) only found significant relationships between mental model similarity and team performance with a consistency-based measure of similarity and not with a consensus measure of this construct.

Some researchers have suggested that in particular situations, there may not be one single most accurate mental model; instead, multiple mental models of equally high quality may exist at the same time (Marks et al., 2000; Smith-Jentsch et al., 2001). Mathieu and colleagues (2005) noted that measures of mental model accuracy that depend on a single referent or "ideal" model cannot distinguish mental model similarity from mental model quality at the high end of the continuum—that is, if team members' mental models highly resemble the referent model, they will, as an artifact of the measurement method, also highly resemble each other. To remedy this limitation, they developed a measure of quality as an alternative to accuracy of mental models that does not depend on reference to "ideal" models; as a result, the new measure leaves open the possibility of several structurally different, high quality mental models. These researchers derived referent task mental models by identifying clusters among the mental models of a group of experienced flight simulation players and referent team mental models by clustering mental models of a sample of teams researchers.

To summarize, it appears that the techniques often used by researchers to measure various aspects of mental models provide relatively straightforward measures of accuracy and similarity. However, these techniques may be restricted in that participants' mental models are constructed with a limited amount of concepts that are often predefined by the researchers. This may render these measurement techniques less than optimal means to investigate richer and more idiosyncratic aspects of mental models, such as mental model complexity (Curseu, Schruijer, & Boros, 2007) or flexibility in the cognitive processes and structures that may facilitate adaptation (Chen et al., 2005; Eisenhardt & Tabrizi, 1995). However, a number of recent advances in the measurement of individual-level mental models reported in Organizational Research Methods seem to provide a promising avenue for more complex operationalizations of the structural aspects of shared mental models (e.g. Clarkson & Hodgkinson, 2005; Hodgkinson, Maule, & Bown, 2004; Nadkarni & Narayanan, 2005; Wright, 2008).

Outcomes of Shared Mental Models

Direct effects of shared mental models. Previous reviews of shared mental models have indicated that despite several articles and chapters describing shared mental models, the empirical record of evidence supporting the beneficial effects of shared mental models on team performance is still wanting (Klimoski & Mohammed, 1994; Kraiger & Wenzel, 1997; Mohammed et al., 2000). An investigation of studies appearing in the trail of these publications indicates that researchers have clearly taken these comments to heart and have gone beyond applying mental models merely a posteriori to explain relationships between team behavior and performance; instead, researchers have moved towards directly eliciting the mental models held by team members and relating them to a variety of team outcomes. Over the past two decades, an accumulating body of research has supplied evidence for a direct effect between the similarity of team members' mental models and team task performance in a large variety of domains, including simulation studies (e.g. Cooke, Kiekel, & Helm, 2001; Cooke et al., 2003; Ellis, 2006; Fleming et al., 2003; Gurtner, Tschan, Semmer, & Nagele, 2007; Marks et al., 2002; Marks et al., 2000; Mathieu et al., 2000; Mathieu et al., 2005) and also field studies on air traffic control teams (Smith-Jentsch, Mathieu, & Kraiger, 2005), work teams (Rentsch & Klimoski, 2001), combat teams (Lim & Klein, 2006), and basketball teams (Webber, Chen, Payne, Marsh, & Zaccaro, 2000).

Similarity and accuracy. Several scholars have indicated that it is not only similarity or overlap in team mental models but also the accuracy of those mental models that is required to benefit team effectiveness (Cooke, et al., 2000; Rentsch & Hall, 1994). Team mental model accuracy refers to the extent to which the mental models of the team members adequately represent the structure of the system it models (Stout, Salas, & Kraiger, 1997). Mental model accuracy is most often assessed by comparing participants' mental models with a referent mental model developed by one or a few task experts (e.g. Cook et al., 2001; Lim & Klein, 2006) or by having experts rate the quality of participants' mental models (e.g. Ellis, 2006; Marks et al., 2000). Team mental model accuracy is subsequently calculated as the average accuracy of the team members' mental models (Cooke et al., 2003; Lim & Klein, 2006; Webber et al., 2000).

Results of a number of studies indicate that team mental model accuracy is sometimes (Cooke et al., 2001; Cooke et al., 2003; Edwards, Day, Arthur, & Bell, 2006; Lim & Klein, 2006; Marks et al., 2000) but not always (e.g. Webber et al., 2000) directly related to team performance. Interestingly Marks and co-authors (2000) found an interaction between the effects of mental model similarity and accuracy on performance, such that teams with less accurate mental models seemed to benefit more from mental model similarity than teams with more accurate mental models. Additionally, in a study directly comparing the predictive accuracy of team mental model similarity and accuracy, Edwards and colleagues (2006) found that mental model accuracy was a stronger predictor of team performance than mental model similarity

Scholars have posited that shared mental models influence team performance through their effect on team interaction processes (Cannon-Bowers et al., 1993; Klimoski & Mohammed, 1994), and this seems to have been supported by empirical studies indicating mediating effects of coordination, communication, and collaboration processes on the relationship between shared mental models and team performance (Marks et al., 2000; Mathieu et al., 2000; Mathieu et al., 2005). Below, we review in greater detail work that has examined each of these three mediating processes.

Coordination. Congruence in team members' mental models is considered to affect team functioning through its effect on team coordination processes. Coordination processes refer to those behaviors that are aimed at attuning the resources and activities of individual team members towards the concerted goal directed behavior of the team as a unit (Cannon-Bowers et al., 1995). A crucial aspect of coordination is the harmonization of interdependent activities performed by the different members of the team. Shared mental models are expected to affect team coordination by providing mutual expectations from which accurate, timely predictions can be drawn about the behavior of other team members (Cannon-Bowers et al., 1993). In particular, shared expectations are considered to facilitate tacit coordination—coordination based on unspoken assumptions about what actions other members are likely to pursue and what information they require (Wittenbaum, Vaughan, & Stasser, 1998).

Especially in high-workload situations, implicit coordination may be the optimal way to manage intra-team interdependencies because it requires only a limited amount of communication overhead, time, and cognitive energy (Entin & Serfaty, 1999; Macmillan, Entin, & Serfaty, 2004). It is, therefore, not surprising that a number of studies have indicated that coordination mediates the relationship between mental model similarity and performance (e.g. Marks et al., 2002; Mathieu et al., 2000; 2005).

Apart from facilitating coordination through attuning actions, overlapping knowledge also comprises a source of robustness for a social cognitive system in the face of error and interruption (Hutchins, 1995). In case a team member is unable to perform his or her appointed responsibilities, cognitive redundancy makes it possible for the team as a whole to perform its team task because another team member may be able to take over execution of the task. Salas and colleagues (2005) emphasized the importance of shared mental models in two processes related to the robustness of the system: mutual performance monitoring and back-up behavior. The ability to keep track of other team members' task performance while executing one's own task and to correct errors and assist others if necessary is important to guarantee consistent team performance, in particular under non-routine, stressful circumstances (Marks & Panzer, 2004). Empirical evidence indicating back-up behavior as a significant mediator between mental model similarity and team performance seems to support this reasoning (Marks et al., 2002). Thus, a shared understanding about team tasks enables members to assess if other team members are falling short of task performance and to give assistance if required.

Communication. Research also suggests that shared mental models are positively related to the quality of communication in teams (Marks et al., 2000; Mathieu et al., 2000; 2005). Marks and co-authors (2000) found that mental model similarity was positively related to quality of team communication as well as to team performance. Additionally, mental model accuracy was positively related to team performance, but a linear relation between mental model accuracy and quality of team communication was not supported in these researchers' results. Team members with similar mental models are also more likely to communicate information that is required by others at the time it is required, and in a way that is understood by the recipient (Fussell & Krauss, 1989; Krauss & Fussell, 1991). Especially during periods with strong time constraints and high stress levels, the ability to communicate can be highly reduced (Kleinman & Serfaty, 1989); therefore, in order to function effectively as a team with minimum amounts of communication, it is essential for team performance that members share a similar understanding of the task situation. This allows team members to coordinate implicitly without the need for overt communication (Kleinman & Serfaty, 1989; Salas, Cannon-Bowers, & Johnston, 1997). Ironically, however, maintaining a shared understanding may be especially problematic under stressful circumstances (Driskell, Salas, & Johnston, 1999). Ellis (2006) found that acute stress negatively affected team interaction model similarity and accuracy, which consequently had a negative impact on performance. This suggests that, for those situations in which a shared understanding is most essential for task performance, maintaining this shared understanding may be most difficult.

Collaboration. With respect to collaboration, the existence of shared mental models can reduce a team's investment in time and resources for reaching consensus, and can decrease the occurrence of friction due to cognitive divergence and misunderstanding. Research on group[3] negotiations has indicated that a common understanding of each party's problems and possible solutions constitutes an essential ingredient for reaching the maximum joint outcome (Swaab, Postmes, van Beest, & Spears, 2007). In newly formed teams, members often require a considerable proportion of their time getting to know each other and establishing a shared understanding of the task structure and the actions that are appropriate for performance (Bettenhausen & Murnighan, 1985). Constructing a shared understanding about the nature of the task and the norms for team interaction may involve political processes and negotiation (Walsh & Fahay, 1986). Therefore, teams in which shared mental models are present before task performance may need less time for clarifying and agreeing upon strategies. Consequently, such teams may have more time and resources for task execution and performance monitoring than other teams. Mohammed and colleagues (2000) have suggested that if team members even perceive that their mental models are similar, this perception may lead to positive affective reactions and facilitate the development of trust within the team.

Antecedents of Shared Mental Models

A number of researchers have investigated the conditions under which accurate and shared mental models are most likely to arise in teams. Kraiger and Wenzel (1997) suggested four categories of antecedents of team mental models: environmental, organizational, team, and individual. Klimoski and Mohammed (1994) emphasize group formation, development, and training as important factors that may affect the course and speed of team mental model development. There is supportive evidence for each of these aspects.

Teams researchers have indicated the necessity of considering the broader system context in which a team operates for understanding the functioning of individual teams (Arrow, McGrath, & Berdahl, 2000; Hackman, 2003; Kozlowski, Gully, Nason, & Smith, 1999). One way in which the environmental context influences team functioning is by shaping the mental models the team members bring with them to their team task. Although some researchers have set out to identify aspects of mental models that are generic and transfer over different contexts (Druskat & Pescosolido, 2002; Johnson et al., 2007), most mental models are learned and developed within, and are idiosyncratic to, a specific context—for example, a department, organization, or industry. As individuals spend time within an organization, they learn and become socialized as to the 'dominant logic' prevailing within that organization (Prahalad & Bettis, 1986). Also, selection criteria used in member recruitment and self-

[3] We will use the terms "group" and "team" interchangeably in the present review, reverting as much as possible to the terms used by the original authors of the articles we describe

selection processes may contribute to ensure that organization members hold similar orientations to their work and tasks (Mohammed et al., 2000).

Two field studies provide support for this kind of contextual influence on shared mental model formation. In a study addressing the antecedents of team member mental model similarity, Rentsch and Klimoski (2001) found that similarity in education and organizational level, average team experience, and whether a team member was actively recruited to the team were positively related to mental model similarity. In a study among navy personnel, Smith-Jentsch and co-authors (2001) found that higher ranking personnel had more accurate team mental models—as measured by similarity to a referent model—than lower ranking personnel. Additionally, they found that higher ranking individuals and individuals who had spent more time in the navy held more similar mental models of teamwork than lower ranking officers and individuals who had spend less time in the navy.

Whereas such organizational assimilation effects can lead to congruence of mental models within teams from a single organization, for teams consisting of members originating from different organizations (e.g. temporary teams such as inter-agency crisis management teams), it may be particularly difficult to attain such a shared understanding (e.g. Smith & Dowell, 2000). Cronin and Weingart (2007) noticed that when members hold different functional backgrounds in which different mental models prevail, teams may suffer from 'perceptual gaps'—misunderstanding between team members about what is needed for the team to be successful. There also is some evidence of task contextual influences on team members' mental models. In an experimental simulation, Driskell and colleagues (1999) found that, relative to teams performing in a low-stress condition, team members performing the task in a high-stress environment became more individualistic and self-focused, which manifested in more individual and less collective representations of the task. Building on these findings, Ellis (2006) conducted an experimental study in which he directly investigated the effects of acute stress on team cognition. The results of his study indicated that acute stress negatively affected the similarity and the accuracy of team members' team interaction mental models as well as their transactive memory systems (TMSs).

Another oft-investigated antecedent of shared mental models is the effect of team training. Several studies have measured mental models repeatedly over time during team training or task execution; results, however, are inconclusive and inconsistent. Cooke and colleagues (2003) found that their teamwork mental model showed improvement in team knowledge accuracy over time, but their task knowledge measure showed no change between two sessions. Xinwen, Erping, Ying, Dafei, and Jing (2006) found a significant increase in task mental model similarity but not in team interaction mental model similarity when teams increased the time spent on task implementation. Mathieu and colleagues (2000; 2005), as well as Edwards and colleagues (2006), did not find a significant increase in similarity and accuracy of team members' mental models over time. Levesque, Wilson, and Wholey (2001) actually found that the mental models of software development team members became less similar over time as team member interaction decreased due to increased specialization. This seems to imply that simply having team members train and work together on a task may not be sufficient to increase the accuracy and similarity of team members' mental models, and deliberate actions may have to be taken in order to ensure team mental models remain congruent. One way to do this is by administering training programs that are specifically aimed at improving the similarity and accuracy of team members' mental models. A distinction should be made here between individual level training programs in which team members are individually trained in facilitating adequate team mental models, and team level training programs in which the team is trained as a whole to collectively execute the task. Individual level training programs can improve the accuracy of the team members' mental models; however, they can only indirectly enhance the similarity in team members' mental models by increasing the similarity of each team member's mental models with an ideal mental model (and hence with each others' mental models). Team level training programs, on the other hand, can directly increase mental model similarity; through team interactions, team members are encouraged to explore, harmonize, integrate, and conjointly construct their mental models (Van den Bossche, Gijselaers, Segers, & Kirschner, 2006).

At the individual level, Day, Arthur, and Gettman (2001) found that the improvements in accuracy of individuals' knowledge structures of a task developed together with the acquisition of skill in executing the task. Stout, Salas, and Kraiger (1997) found that after receiving training aimed to improve their knowledge structures, navy helicopter pilots' mental models became more consistent and displayed more resemblance to an expert mental model, which translated to improved performance on a subsequent team task. Smith-Jentsch and colleagues (2001) found that after exposure to a computer based training program, trainees' teamwork mental models became more similar to an expert mental model; moreover, they became more consistent and more similar to the mental models of other trainees. Finally, the work of Marks and co-authors (2000) indicated that teams with members who received video-based team interaction training developed more accurate and more similar mental models than teams in a control condition.

Some researchers have suggested that because team members often have different roles within a team, team training should not simply be aimed at increasing similarity in mental models, but instead at increasing the understanding team members have of the roles and accompanying requirements and contributions of the other members (Blickensderfer, Cannon-Bowers, & Salas, 1998; Marks et al., 2002; Volpe, Cannon-Bowers, Salas, & Spector, 1996). Cross training has been defined by Volpe and colleagues (1996) as "an instructional strategy in which each team member is trained in the duties of his or her teammates" (p. 87). Marks and colleagues (2002) conducted two studies on the effect of three types of cross training differing in depth and method: (1) positional clarification, consisting of a verbal presentation of information about the roles of the other team members; (2) positional modeling, consisting of verbal discussions and observation of other members' roles; and (3) positional rotation in which team members gain active experience in carrying out the duties of their team members. In the first experiment, they included only positional clarification and positional modeling training, and found that both were positively related to team-interaction mental model similarity. In the second experiment, they also included positional rotation, and they found that all training conditions positively influenced mental model similarity, and that positional modeling was more effective than positional clarification. Cooke and colleagues (2003) designed a cross-training program in which team members were trained either actively in executing the role of all the other members or passively in only learning the role knowledge of the other team members. The results of their study indicated that only the active cross training condition was effective in facilitating the development of shared mental models and accurate knowledge structures regarding the other team members' roles. In sum, cross-training seems to provide an effective method for facilitating the development of shared mental models; however, results are inconsistent regarding the type and depth of cross training that is required to gain these positive effects.

The effectiveness of team training on mental model accuracy and similarity may also be moderated by individual difference variables. Day and colleagues (2001) found that general cognitive ability was positively related to mental model accuracy at the end of a training period, and Edwards and colleagues (2006) found that general cognitive ability was a significant predictor for the development of accurate and similar mental models.

Marks, Mathieu, and Zaccaros (2001) suggested that teams alternate between *action periods* in which they engage in acts that contribute directly to the goals of the team and *transition periods* in which teams focus on evaluation and planning activities that play a more supportive role towards team goal accomplishment. Given an ongoing sequence of team performance episodes, these transition episodes may have both a forward looking function during which team members actively prepare for the task ahead and a backward-looking evaluative function, during which team members collectively make sense of their functioning in preceding task episodes. These transition periods may provide a particularly good time for team leaders to play a role shaping and developing shared mental models (Hackman & Wageman, 2005; Kozlowski, Gully, Salas, & Cannon-Bowers, 1996).

Previous research indicates that both forward- and backward-oriented transition processes may function to facilitate the construction of shared mental models for ensuing task periods. Stout and colleagues (1999) found that the quality of the planning process prior to a team mission was positively related to the similarity in team members' mental models. Similarly, Marks and co-authors (2000) found that teams receiving leader briefings before the actual performance episode developed more accurate and more similar mental models than teams in a control condition. Other studies indicate that team feedback and debriefs, taking place after task performance episodes, can positively affect the development of rich and accurate mental models (Ellis & Davidi, 2005; Xinwen et al., 2006). In particular, guided team self-corrections during which the team is guided in critically reflecting upon and discussing its own functioning, fosters the construction of more accurate (Smith-Jentsch, Cannon-Bowers, Tannenbaum, & Salas, 2008) and more similar (Blickensderfer et al., 1997) mental models. A study by Rasker, Post, and Schraagen (2000) suggested that the extent to which a team has the ability to engage in performance monitoring and self-corrections, positively relates to the ability of the team to construct high quality mental models. More generally, it can be stated that the extent to which a team explicates and overtly reflects on its objectives, processes, and strategies positively relates to the quality and similarity of team members' mental models (Gurtner et al., 2007; Massey & Wallace, 1996; Müller, Herbig, & Petrovic, 2009).

Contingency Factors Influencing the Impact of Shared Mental Models

Cannon-Bowers and Salas (2001) have called for research specifying the conditions under which shared mental models may affect various team level outcomes. Various authors have suggested contingency variables that could influence when shared mental models are more or less important for team functioning. Stout, Cannon-Bowers, and Salas (1996) theorized that the importance of mental model similarity is contingent on the demands a task poses on the team. If task demands are low and team members have ample time, shared mental models may be less important than when task demands are high and the team has inadequate time to communicate and strategize. Supporting this line of reasoning, Minionis, Zaccaro, and Perez (1995) found that shared mental models enhanced performance on tasks requiring interdependence among team members, but had no significant impact on tasks that could be completed without coordinated team actions.

Espinosa, Lerch, and Kraut (2004) noted that teams may make use of two types of mechanisms to manage interdependencies: implicit team cognition based mechanisms, and explicit mechanisms, based on schedules, plans, and procedures. They argue that there may be complementarities, tradeoffs, and interactions between these mechanisms, and that various team and contextual variables may influence which mechanism may be most suitable for teams to complete a specific task. For example, if team coordination can be efficiently managed by configuration management systems such as project schedules or electronic planning systems, shared mental models may be less important for team performance.

Finally, the work of Kellermanns, Floyd, Pearson, and Spencer (2008) demonstrated that mental model similarity improves decision making quality. However, when a team has strong norms for constructive confrontation—that is, when team members value open expression, disagreement, and the avoidance of negative affect—less, instead of more, mental model similarity improves decision making quality. The authors reasoned that mental model dissimilarity indicates a diversity of perspectives from which teams can reap benefits as long as they have norms that help them avoid the negative consequences of conflict.

Additive and Compatible Mental Models

Klimoski and Mohammed (1994) noted the ambiguous nature of the term "shared" in that it may refer to overlapping or similar knowledge as well as to divided or different knowledge; similarly, Cannon-Bowers and Salas (2001) added that "shared" may also refer to similar or identical knowledge and to compatible and complimentary knowledge. Although the majority of studies on shared mental model theory seem to concern the beneficial effects of congruence in team member's mental models, there seems to be general recognition that not all knowledge should be held by all team members (Cannon-Bowers & Salas, 2001; Klimoski & Mohammed, 1994; Rentsch & Hall, 1994). Cannon-Bowers, Salas, and Converse (1993) suggest the possibility that different mental models may be accurate. They argue that it is not so much the overlap in team members' mental models that is related to team performance, but the common expectations that team members derive from these models. Accordingly, they suggested that teams may not need similar so much as compatible and supplementary knowledge structures, for example differences in expertise.

When team members have distinct team roles, they are likely to develop knowledge structures considering their own specific subtasks, which do not necessarily have to be shared among the team members. In effect, it would often be cognitively impossible or at least inefficient if all knowledge were held by all team members (Banks & Millward, 2000; Mohammed & Dumville, 2001). The theory of distributed cognition (Banks & Millward, 2000; Hutchins, 1995) indicates that it is not merely overlap in knowledge that is required, but instead that the team as a whole needs to be able to understand the complexity of the system. Some empirical evidence suggests that similarity in team mental models may not always be beneficial for team performance. Cooke and colleagues (2003) found that teams with members who had a thorough understanding of their own roles but lower similarity in taskwork knowledge tended to be the best performing teams. Similarly, Banks and Millward (2007) found in a simulation study that even though similarity in members' declarative knowledge was positively related to team performance, similarity in members' procedural knowledge was negatively related to performance.

The shared mental model perspective emphasizes the effects of mental models on team interaction behavior (Cannon-Bowers et al., 1993; Mathieu et al., 2000; 2005), while the distributed cognition perspective of team mental models focuses on the extent to which the team members' mental models cover the relevant task environment—that is, provide the requisite expertise to perform a variety of actions and perceive and interpret a variety of stimuli (Conant & Ashby, 1970; Weick, 1979). This implies that two opposing mechanisms may intervene between mental model similarity and team performance. On one hand, mental model similarity facilitates team interaction processes. On the other hand, mental model diversity may be required to ensure the requisite variety of expertise and skills in complex task environments. The effect of similarity in mental models on team performance may thus depend on the relative importance of each of these mechanisms in accomplishing the particular team task at hand.

Other researchers have associated diversity in underlying knowledge structures with the ability to generate a wide range of perspectives and alternative solutions (Milliken & Martins, 1996; Simons, Pelled, & Smith, 1999). The integration of these various viewpoints is considered to lead to deep information processing, the emergence of new insights (Jehn, Northcraft, & Neale, 1999; Levine & Resnick, 1993), and team ability to reconsider assumptions and come to more creative and high quality solutions (De Dreu & West, 2001; Nemeth, 1986; van Knippenberg, De Dreu, & Homan, 2004). However, because mental models are essentially interpretations and simplifications of an external system (Fiske & Taylor, 1991), they may compromise the ability to make decisions in complex environments (Walsh, 1995; Weick, 1979). Moreover, Starbuck and Milliken (1988) posited that knowledge structures function as lenses which filter the information that is received from the environment and determine how this information is interpreted. Thus, it may be that diversity in team members' mental models facilitate the probability that important information is noticed by at least one team member.

Beyond Input-Process-Output Conceptions

Most teams researchers have explicitly or implicitly embedded the construct of shared mental model in an input-process-output (I-P-O) framework of team performance, in which team inputs are considered to impact team processes that in turn shape team outcomes (Hackman, 1987; McGrath, 1964). Recently, however, authors have warned against adopting overly simplistic interpretations of the I-P-O framework by pointing to interaction effects that may occur between inputs and processes, and by emphasizing the temporal and ongoing nature of team functioning (Ilgen, Hollenbeck, Johnson, & Jundt, 2005; Marks et al., 2001). In consonance with this dynamic view, Marks and colleagues (2001) categorized team cognition constructs as emergent states, which they define as "constructs that are typically dynamic in nature and vary as a function of team context, inputs, processes, and outcomes" (p. 357). They argued that team emergent states describe dynamic properties of the team and should be distinguished from team processes, which describe the nature of team member interaction. Since team cognitive structures can both serve as inputs and outputs of team processes, a cyclical framework—one that takes into account the observation that outcomes and emergent states from previous cycles may be inputs in subsequent performance cycles—may be more appropriate than a purely linear view of the relationship between team inputs, processes, and outputs. Despite the increasing recognition among researchers for this more dynamic temporal perspective on team cognition, longitudinal studies that address antecedents and consequences of changes in shared mental models over time are still scarce. An alternative way by which researchers can provide for a more dynamic view of team cognition is by distinguishing between the relatively stable notion of the mental models and the more dynamic concept of situation awareness (SA) described later in this chapter.

Future Directions

A recent review on diversity literature (Harrison & Klein, 2007) warned against the problems of adopting overtly simplified conceptualizations of diversity and suggested that researchers go beyond simply looking at similarity and diversity. Similarly, teams researchers may look at more complex compositions of knowledge within teams. Research by Walsh and colleagues seems to indicate that for some tasks only the mental models of the most influential member may be important for team functioning (Walsh & Fahey, 1986; Walsh, Henderson, & Deighton, 1988). But what happens if a team is divided into two equally powerful subteams that possess equally appropriate but different mental models of the team task (cf. Cronin & Weingart, 2007)? And what are the effects on team functioning if one member holds a more accurate mental model than the other members? Under what circumstances are such minority members able to influence the other members to accept their understanding of the task?

Future research may also go beyond similarity and accuracy to take into account characteristics such as the flexibility or complexity of the mental models, or the extent to which the team's mental model covers the relevant task environment. Previous research on individual level mental models indicates that experts hold more detailed mental models than novice task performers (Murphy & Wright, 1984; Tanaka & Taylor, 1991). Complexity of mental models is considered to increase the amount of information that can be garnered from the environment (Bartunek, Gordon, & Weathersby, 1983; Starbuck & Milliken, 1988).

Another promising future direction, proposed by Huber and Lewis (2010), is cross understanding, or each member's understanding of the mental models of the other team members. The cross-understanding notion bears similarity to the transactive memory concept in that it comprises team members' understanding of the knowledge of other members. However, unlike a TMS, cross understanding does not necessarily imply a distribution of expertise. Huber and Lewis (2010) indicate that team members may also benefit from an understanding of other members' mental models when knowledge within the team is not differentiated. For instance, Rentsch and Woehr (2004) indicated that team effectiveness may be a function not only of the similarity in team members' cognitions, but also of the extent to which "a team member's schema of a target matches the target's actual schema" (2004: 22).

Of the three types of shared cognition reviewed in this chapter, the literature on shared mental models is the most mature and wide-ranging. However, many teams scholars have focused their attention away from the "sharedness" of mental representations and instead on the understanding of the distribution of different knowledge and expertise across team members. The literature on and understanding of these transactive memory systems in teams has grown in recent years, and we turn now to a review of this work.

Transactive memory systems

The theory of transactive memory was developed by Wegner and colleagues (1985, 1987) to explain how individuals can expand their own limited memory capacity with external aids, including other people. Wegner uses the analog of a computer to describe how transactive memory functions. Computers with separate hard disks can share each other's memory if they have a directory containing an abbreviated record of the contents and location of the other memory systems (Wegner, 1995). Correspondingly, a group's transactive memory consists of the knowledge of the individual members of the group combined with members' knowledge of the content of information held by other members of the group.

Initially, Wegner (1985) developed the notion of transactive memory as a theory describing the interpersonal division of memory tasks in intimate couples. For instance, in an experiment testing this theory, Wegner, Erber, and Raymond (1991) compared performance on a memory task between natural pairs—couples that had been in close dating relationships for at least three months—with impromptu pairs of strangers they had put together specifically for the experiment. They found that if pairs could decide how they would divide the memory tasks between them, the natural pairs were clearly superior, whereas when the researchers assigned a structure for how the memory task should be divided between the members, the impromptu pairs outperformed their natural counterparts. These results indicate that the memory advantage that natural pairs develop through prolonged interaction is based on an efficient, implicit structure for dividing memory tasks. When pairs are forced to adopt an alternative structure, however, this benefit breaks down, and the persistence of their previously established structure may even negatively influence the adoption of a new structure.

Although transactive memory theory was originally developed to explain how intimate couples formed a division of labor for remembering and accessing information, soon researchers noticed the merit of the concept for explaining group and team level phenomena. Moreland and colleagues applied the notion of transactive memory to the group level in order to explain the performance advantage of groups that had been trained together relative to groups whose members had been trained apart (Liang, Moreland, & Argote, 1995; Moreland, Argote, & Krishnan, 1996; Moreland, Argote, & Krishnan, 1998). Their reasoning was that during the collective training process, group members not only achieve individual task experience but also develop an understanding of the knowledge and fields of expertise of their group members. This knowledge of 'who knows what' enables group members to arrange their tasks in such a way as to optimally benefit from the variety of experience available within the group as a whole. In this way, the group can make optimal use of their cognitive resources; specifically, remembering and accessing a specific information element will cost the group member with the most experience with that type of information fewer cognitive resources than it would cost the other, less experienced and less knowledgeable group members. In sum, a transactive memory system (TMS) functions in groups as a cognitive structure that bridges the gap between individual and group level information processing by efficiently tying together contributions of individual members into collective group performance (Hinsz, Tindale, & Vollrath, 1997; Larson & Christensen, 1993).

Early in the development of the concept, scholars referred to the content of transactive memory as pertaining mainly to facts and information; later, scholars broadened the concept to also include knowledge of team members' skills or expertise (Moreland & Myaskovsky, 2000) and external relationships (Austin, 2003). Scholars have emphasized the importance of a TMS for groups functioning in a wide variety of domains, including work teams (Austin, 2003; Lewis, 2004; Littlepage, Hollingshead, Drake, & Littlepage, 2008; Zhang, Hempel, Han, & Tjosvold, 2007), action teams (Ellis, 2006; Pearsall & Ellis, 2006), disaster response groups (Majchrzak, Jarvenpaa, & Hollingshead, 2007), management teams (Rau, 2005; Rulke, Zaheer, & Anderson, 2000), and virtual teams (Cramton, 2001; Griffith & Neale, 2001; Kanawattanachai & Yoo, 2007).

Conceptual Aspects of TMSs

With the notion of a TMS, scholars refer to two separate but interrelated components of cognitive structures and group interaction processes that enable groups to efficiently divide their cognitive labor with respect to the encoding, storage, retrieval, and communication of information among their members (Hollingshead, 2001; Lewis et al., 2007; Moreland, 1999). The knowledge component, often referred to simply as transactive memory, refers to the memory content, skill base, or external relationships of the individual members in combination with the meta-knowledge of who knows what within the team. Whereas this transactive memory component emerges as a team level compositional construct from the knowledge components of the individual group members, the process component consists of the dynamic interaction processes involved in the acquisition, storage and retrieval of information among the group members, and therefore comprises a pure group level construct (Hollingshead, 2001; Kozlowski & Klein, 2000; Lewis, 2003).

This dual component structure manifests itself in the various frameworks and dimensions of TMSs that have been proposed by scholars. Some scholars have focused specifically on the structural aspects of TMSs. For instance, Moreland (1999) distinguishes between three structural aspects of TMSs: (1) the accuracy in team members' understanding of each other's knowledge, (2) the extent to which group members agree about who holds what knowledge, and (3) the complexity in terms of the extent of specialization of expertise within the group and the level of detail of this understanding. Austin (2003) identifies four structural aspects of TMSs: knowledge stock, consensus, specialization, and accuracy. Knowledge stock refers to the total knowledge of the group that is composed of the knowledge of the individual members. Specialization refers to degree of differentiation in knowledge and expertise of the different team members. Accuracy considers the extent to which team members are correct in identifying knowledge of other group members.

Regarding the process component of TMSs, scholars have relied heavily on Wegner's (1995) model, which includes directory updating, information allocation, and information retrieval. *Directory updating* refers to the establishment or refinement of team members' representations of each others' knowledge base. *Information allocation* refers to the process of forwarding information to the group member who is considered to hold expertise within the area relevant for that information. *Retrieval coordination* refers to the process of accessing information from team members based on an understanding of their relative expertise.

Others have proposed alternative TMS frameworks that include both structure and process components. For instance, Liang and colleagues (1995) identified three components reflecting the operation of a TMS among group members: memory differentiation (i.e. the tendency of group members to remember different aspects of the task processes; task coordination (i.e. the ability of the group members to work together efficiently) and task credibility, (i.e. the level of trust in the knowledge of the other group members). This tripartite framework also served as input for a collection of studies by Lewis (2003), who developed and validated a measure for assessing TMSs in the field, thereby providing additional support for the dimensionality and validity of Liang and colleagues' framework. Similarly, Brandon and Hollingshead (2004) identified three dimensions of a TMS: accuracy, the extent to which group members perceptions about other group members' knowledge are accurate; sharedness, the degree to which team members have a shared understanding of the division of expertise within the group; and validation, the extent to which the team members contribute their expertise knowledge during actual task performance. In addition, they introduced the concept of TMS convergence, reflecting the extent to which groups are characterized by high levels on each of these dimensions. In a somewhat similar vein, Faraj and Sproull (2000) identified (1) knowing where knowledge is distributed among the team members, (2) recognizing when knowledge is needed, and (3) bringing to bear expertise in a timely manner. Unlike the other dimensions reviewed earlier, which are explicitly identified by their originators as TMS dimensions, Faraj and Sproul locate their constructs under the umbrella of "expertise coordination."

Overall, it appears that a variety of comparable but slightly deviating frameworks of the dimensions of TMSs have been developed by scholars in this area. Some frameworks cover only structural aspects of the TMS notion, others only process aspects, while still others cover both aspects of TMSs.

Measurement of TMSs

In studies of dyads, pertinent TMS constructs are often operationalized indirectly, inferred from the collective output of the dyad on memory tasks (Hollingshead, 1998a; 1998b; Hollingshead, 2001; Wegner, 1987). The reasoning behind this approach is that the more information a pair of individuals is able to accurately recall, the higher the quality of their TMS. A comparison of recall performance of individual members with the collective recall performance of dyads allows researchers to disentangle the individual members' memory contributions from the collective memory component.

A wider variety of measurement techniques have been used to study TMSs in group settings than have been used in the study of dyadic TMSs. Lewis (2003) has distinguished among three methods for measuring group level TMSs: recall measures, measures that capture observed behaviors, and self-report measures of group members' expertise.

Observation measures are based on the scoring by raters of behavior indicative of TMS functioning. Following the work of Moreland and colleagues (Liang et al., 1995; Moreland, 1999; Moreland & Myaskovsky, 2000) one method commonly applied entails the use of independent judges to provide overall ratings of the quality of each team's TMS, based on their observations of the quality and/or extent of memory differentiation, task coordination, and task credibility within the teams (e.g. Prichard & Ashleigh, 2007; Rulke & Rau, 2000). Other researchers have coded the actual behaviors involved in the transactive memory processes. For instance, Ellis (2006) used additive indexes of the occurrence of directory updating, information allocation, and retrieval coordination behavior among the team members, while Rulke and Rau (2000) conducted a more fine-grained analysis of the encoding process of the TMS.

Researchers have also used self-report measures of TMSs. These measures have been in the form of Likert-scale questionnaire measures that reflect the various dimensions of TMSs enumerated. Faraj and Sproull (2000), for example, developed a Likert scale item-based questionnaire measure for expertise coordination in which they asked participants to indicate if they knew how knowledge was distributed among the team members, how team members recognized when their expertise was needed, and the extent to which they brought their expertise to bear in a timely manner. Lewis (2003) developed and validated a questionnaire measure of TMS for use in field settings, consisting of 15 items covering her "knowledge specialization", "credibility", and "coordination" dimensions. Given its ease of administration, this instrument has been adopted in a growing number of field (e.g. Michinov et al., 2008; Peltokorpi & Manka, 2008; Zhang et al., 2007) and experimental (Pearsall & Ellis, 2006; Pearsall, Ellis, & Stein, 2009) studies.

Another form of self-report measures, known as expertise identification measures, have been used mainly in field studies of teams. Adopting this method, researchers start with an analysis of the field and interviews with field experts to formulate a list of possible areas of expertise, knowledge or skills. Then team members are asked to indicate from this list their own and their team members' areas of expertise. Measures of the group's knowledge stock are calculated by aggregating the fields of expertise of all individual team members, and team TMS consensus is calculated by assessing the level of agreement concerning the location of expertise within the team (e.g. Austin, 2003; Rau, 2005; Rulke et al., 2000; Yuan, Fulk, & Monge, 2007).

TMS Outcomes

Outcomes of TMSs have been studied extensively both at the dyadic level and in larger groups and teams (Peltokorpi, 2008). Our focus here is on the group- and team-level studies; however, given the theoretical foundation provided by the dyad-level research, in our discussion of the development of the TMS construct, we will mention and elaborate upon findings from this research stream whenever relevant and appropriate. Regarding the outcomes of TMSs, we rely on the general finding that people in intimate relationships develop efficient implicit systems for remembering and retrieving information, providing them with an advantage over impromptu couples on collective memory tasks (Hollingshead, 1998a; 1998b; Johansson, Andersson, & Rönnberg, 2000; Wegner et al., 1991).

A number of studies compared the performance of work groups in which the individual members were trained apart, with groups in which the members were trained together (e.g. Liang, Moreland & Argote, 1995; Moreland et al., 1996; 1998). The latter groups outperformed groups consisting of individually trained members, suggesting that in addition to task related skills, groups that are trained together also develop a TMS with beneficial effects for group performance. Liang and colleagues (1995) scored videotapes of group tasks on typical TMS behaviors and found that the difference in performance between the two conditions could be attributed to the higher amount of transactive memory behaviors displayed by the collectively trained groups. Additional experiments confirmed that this effect was due to the development of a TMS, as opposed to general group building benefits (Moreland et al., 1999), or improved communication (Moreland & Myaskovsky, 2000).

In addition to studies demonstrating the beneficial effects of TMSs in experimental group settings, a number of studies have demonstrated positive performance outcomes in field settings. In a study of continuing work teams in a sporting goods company, Austin (2004) found positive relationships between the task and external relationship aspects of TMSs and internal and external team performance measures. Lewis (2004) similarly found positive relationships among MBA consultancy teams between TMS development—measured by means of her field scale covering the components of specialization, coordination, and credibility—and team-rated performance, client-rated performance, and the ability of the team to continue working well in the future. Using the same scale in a cross-sectional study among 193 nurse and physician anesthetists, Michinov, Olivier-Chiron, Rusch, and Chiron (2008) found that TMSs predicted members' perceptions of team effectiveness, job satisfaction, and team identification. Also using Lewis' TMS questionnaire, in a multi-organizational study Zhang and colleagues (2007) found that TMSs resulted in effective performance across diverse organizational settings. Similarly, Rau (2005) found a positive relationship between awareness of the location of expertise within management teams and an objective measure of performance. Finally, in a study of software development teams, Faraj and Sproull (2000) found a strong relation between expertise coordination and team performance.

TMS Development

Scholars have asserted that TMSs develop naturally as group members form awareness about each others' knowledge and expertise base and develop processes and routines for dividing and accessing information among them (Hollingshead, 1998a; Wegner, 1987). Brandon and Hollingshead (2004) identified three interdependent processes of TMS development: (1) team members must perceive that they are cognitively dependent upon each other to perform their task; (2) they must develop knowledge structures linking specific tasks to expertise to group members—so called task-expertise-person units; and (3) they must reconcile these perceptions among the group members. When group members perceive dependence upon each other for reaching goals, the development of a TMS begins with directory updating; group members start acquiring information about the knowledge and skills of the other members through self-disclosure or shared experiences and form knowledge structures representing the associations among tasks, expertise, and people (Brandon & Hollingshead, 2004; Wegner, 1995). The concept of directory updating can also be found in research on expertise recognition; studies in this area suggest that group members are able to indicate the individual with most expertise after a brief discussion period (Henry, 1995), and that this recognition and utilization of expertise is positively related to performance on a wide variety of tasks (Austin, 2003; Henry, 1995; Littlepage, Robinson, & Reddington, 1993; Stasser, Stewart, & Wittenbaum, 1995).

Studies indicate that active sharing of information about expertise early on in group development processes, facilitates the development of an effective TMS. In a study examining the encoding process of a TMS, Rulke and Rau (2000) found that in groups that had developed high quality TMSs, members declared expertise early during group interaction and increased the frequency of expertise evaluations over time. Similarly, in a study on the development of TMS in virtual teams, Kanawattanachai and Yoo (2007) found that the frequency and volume of task-oriented communications, particularly in the early stages of team development, were important for the development of expertise location and cognition-based trust.

It is not only actual expertise but also team members' perceptions about each other's expertise that influences the amount of specialization and diversification that occurs. If people perceive others to have expertise that is different from their own, they are more likely to focus on processing information from their own areas of expertise while trusting the others to take care of information from their areas of expertise (Hollingshead, 2000; 2001). Borgatti and Cross (2003) proposed and tested a model specifying four factors that influence the likelihood that an individual will seek information from another person: (1) awareness that the other has the knowledge; (2) the extent to which the knowledge is perceived as valuable; (3) the ability to timely access the knowledge from that person; and (4) the perceived costs involved in accessing the knowledge. These researchers found that the perceived knowledge and accessibility factors mediated the relationship between physical proximity and information seeking, while the cost factor did not.

Scholars have identified a variety of ways in which group members form an understanding of each others' expertise. Group members can self-disclose their expertise by communicating their qualifications and relevant experiences or by indicating their ignorance regarding a topic. Alternatively, team members can infer the expertise of their coworkers by monitoring their actions and judging their contributions. Finally, they can actively question and evaluate each others' expertise (Hollingshead, 1998a; Rulke & Rau, 2000). However, initial group interaction is not a necessary prerequisite for the development of a TMS. Moreland and Myaskovsky (2000) found that groups with members who were trained apart but who received information about one another's skills performed nearly as well as groups that had been trained together. Even in the case of no direct information regarding expertise, team members may use available stereotypes, such as gender roles, to infer expertise of others (Hollingshead & Fraidin, 2003). However, although stereotypes may in some instances provide basic information about a person's expertise, the benefits of using such highly inferential information may easily become overshadowed by its drawbacks. In particular, research from the social identity tradition indicates that relying merely on stereotypes may result in the development of subgroup biases and suboptimal team performance arising from inaccurate perceptions (van Knippenberg, De Dreu, & Homan, 2004).

The existence of an initially-varied distribution of expertise in teams facilitates the development of a TMS (Lewis, 2004). Hollingshead (2001) argued that when team members perceive their own expertise to differ from those of others, they are encouraged to specialize even more by gathering additional knowledge and skills in their own field of expertise while leaving information outside of their specialization area to be processed by other team members. The reasoning behind this is that information can be most efficiently processed and stored by the team member who is most knowledgeable regarding that specific type of information. Therefore, responsibility for information elements is implicitly or explicitly allocated to the member who is perceived to have most expertise with regard to that specific information (Hollingshead, 2001; Wittenbaum, Stasser, & Merry, 1996). In this way, over time the initial transactive memory structure deepens as team members increasingly differentiate their knowledge and each member specializes in his or her area of expertise (Hollingshead, 2001; Wegner, 1995). In a longitudinal study of knowledge-worker teams, Lewis (2004) examined how TMSs emerge and develop over time. She found that initially distributed expertise, member familiarity, and frequent face-to-face communication supported the development of TMSs. In another study, Lewis, Lane, and Gillis (2005) investigated if groups may also develop TMSs that facilitates group learning beyond the basic transfer of concrete knowledge from one task to a similar other task (i.e. single loop learning). She found that after experience with several tasks, groups TMSs include abstract principles that facilitate the generalization of team knowledge from one task domain to another across distinct but related tasks (i.e. double loop learning).

Parallel to the development of knowledge directories specifying where knowledge is located within the group, the TMS is further extended by the formation of effective transactive processes (Lewis et al., 2007, Lewis et al., 2005). In enacting a TMS, group members develop standardized interaction routines in an attempt to facilitate the efficient allocation and accessing of knowledge from each other during on-going task performance (Gersick & Hackman, 1990; Kanki, Folk, & Irwin, 1991). Research on the retrieval processes of TMSs suggests that apart from verbal communications, nonverbal and paralinguistic communications—referring to the manner in which something is communicated rather than the actual meaning of the words—also play an important role in the effectiveness of transactive retrieval processes (Hollingshead, 1998b).

Antecedents of TMSs

Variables that can affect TMS development include communication, group size, social network, time, group members' tenure, group training, and turnover within the group (Moreland, 1999). Antecedents of TMSs were tested in a number of studies, all using Lewis' field scale. Akgün, Byrne, Keskin, Lynn and Imamoglu (2005) found that team stability, team member familiarity, and interpersonal trust were positively related to the development of TMSs in product development teams. Lewis (2004) also found that initially distributed expertise was positively related to the emergence of a TMS and that this effect was even stronger if members were familiar with each other. In a study of daycare workgroups, Peltokorpi and Manka (2008) found that interpersonal communication, group potency, supportive supervision, and self-reported group performance were positively related to the group's TMS, and that variability in TMS development mediated the relationships between those antecedent factors and group performance.

The personality composition of teams may also affect TMS development, especially regarding the extent to which team members actively share expertise-specific information, critically evaluate other members' expertise, and share and request information varies as a function of the personality composition of the team (Pearsall & Ellis, 2006; Rulke & Rau, 2000). For example, Pearsall and Ellis (2006) found that team members' dispositional assertiveness was positively related to the formation of TMSs. Using a team level operationalization of personality constructs, De Vries, Van den Hooff, and De Ridder (2006) found that agreeableness in teams' communication styles was positively related to team members' willingness to share information, and teams' extraversion in communication style was positively related to individuals' eagerness and willingness to share information. As can be seen from the studies reported earlier, researchers have operationalized these predictor variables at different levels, leaving open the question of how individual level traits translate to team level factors that impact team level TMS outcomes.

Another antecedent to the development of a TMS is the extent to which team members depend on each other for reaching their goals (Brandon & Hollingshead, 2004). Zhang and colleagues (2007) found that task interdependence, cooperative goal interdependence, and support for innovation were positively related to the quality of teams' TMSs in terms of differentiation, coordination, and credibility. In a study of dyads, Hollingshead (2001) employed an experimental design that enabled the comparison of four incentive systems that represented a continuum of outcome interdependence, ranging from a condition in which the members only received points if both members recalled the information correctly (integration condition) to a condition in which the members received points only if one member recalled the information correctly (differentiation condition). Under the integration condition, participants were more likely to specialize in remembering different information than their partners, whereas under the integration condition participants were more likely to remember the same information.

Some scholars have applied computational modeling to logically validate propositions regarding the antecedents of TMSs. For instance, Choi and Robertson (2008) found that communication quantity and the existence of a social network in the form of a referral network were positively related to TMS consensus, while group size was negatively related to this particular outcome. Palazzolo and colleagues (2006) tested a model in which communication density mediated the relationship between initial and final transactive memory states. These researchers found that the starting knowledge level of individual members was negatively related to TMS development because of decreased communication density, whereas accuracy of expertise recognition was positively related to TMS development because of its facilitating effect on future communicative interactions. Overall team size was negatively related to TMS development. Palazzolo and colleagues (2006) argued that this may be due to people's cognitive limitations—that is, it may be more difficult to become familiar and cognitively acquainted with all members of a large group versus a smaller group. Relatedly, Ren, Carley, and Argote (2006) found that larger groups and groups functioning in more dynamic task and knowledge environments benefited more from 'knowing what others know' than smaller groups and groups functioning in more stable environments.

Apart from the benefits of training team members collectively rather than apart, which are evident in many TMS studies (Lewis et al., 2005; Liang et al., 1995; Moreland et al., 1996; Moreland & Myaskovsky, 2000), specific team skills training may also facilitate the formation of a TMS. An experimental study by Prichard and Ashleigh (2007) indicated that teams receiving team training aimed at the development of a range of skills including problem-solving, interpersonal relationships, goal setting, and role allocation developed higher quality TMSs than teams that did not receive the skills training.

Finally, given that TMSs develop idiosyncratically in groups and TMS development is contingent on the expertise of group members, changes in group composition are generally found to be devastating to group performance (Lewis, 2003; Moreland et al., 1996, 1998). Moreover, when the composition of a team is changed, the old TMS structure may interfere with the development of a new TMS structure. Lewis and colleagues (2007, Study 1) found that groups that experienced partial membership changes retained the TMS communication structure observed at the outset, which resulted in ineffective TMS processes. In a follow up study they found that these detrimental effects could be overcome by actively encouraging the retained group members to reflect on their knowledge structures (Lewis et al., 2007, Study 2).

Contingency Variables

Finally, some researchers have started to analyze the factors that influence under what circumstances a TMS is more or less important for team performance. Akgün and colleagues (2005) found that task complexity moderated the relationship between TMS and product success, such that when tasks were more complex, the positive effect of a TMS on product success was higher than when tasks were less complex. Rau (2005) found that the level of relationship conflict in teams moderated the effect of awareness of the location of expertise within a team on team performance. Awareness of expertise location had a positive effect on performance under low levels of relationship conflict, but had an insignificant effect under high levels of relationship conflict.

In an experimental study, Ellis (2006) found that acute stress negatively affected the functioning of teams' TMSs. However, a subsequent experimental study by Pearsall, Ellis, and Stein (2009) indicated that not all types of stress are detrimental to team performance. Hindrance stressors—demands or circumstances that interfere with work achievement and are associated by team members with negative outcomes — negatively affect a team's TMS, whereas challenge stressors—demands or circumstances that are associated by team members with potential gains—exert a positive effect on the team's TMS.

Future Directions

As becomes clear from the above review, several authors have indicated that a TMS consists of transactive memory knowledge structures as well as transactive processes (Hollingshead, 2001; Lewis, 2003; Wegner et al., 1985). However, much remains unclear regarding the relationship between these two components. In empirical studies, researchers generally have not made a distinction between process and knowledge components, but instead have included both together under the rubric of TMS. However, although interrelated, they clearly constitute separate factors; as Lewis and co-authors indicated, "TMS structure and processes operate synergistically within a group's TMS, but in distinctly different ways, with TMS structure providing the initial guidance for transactive processing" (p. 162). Future studies could usefully further assess the relative importance of these components and their interactive effects in the effective functioning of TMSs. Furthermore, apart from the developmental aspects, most scholars have considered the TMS notion as a relatively stable construct. Contextual variables that may vary over time are generally not explicitly taken into account, although studies by Ellis (2006) and Pearsall and colleagues (2009) indicate that TMSs may be affected in the short term by contextual factors such as team stress. This implies a need for further work to explore the interplay between the enduring properties of TMSs and situational variables that might moderate their effects on team processes and outcomes.

Finally, several scholars have alluded to the distinctions and overlap between the shared mental models concept and the TMS concept. In their review of research and theory on teams in organizations, Ilgen, Hollenbeck, Johnson, and Jundt (2005) observed that these two constructs, which dominate the recent literature on team cognition, ironically point to opposing conclusions regarding integration and differentiation of knowledge within the team. Whereas work on shared mental models emphasizes the benefits that can be gained from having overlapping knowledge among team members, the literature on TMSs emphasizes the advantages of diversification of the team's knowledge base. Other scholars, however, have pointed to the similarities between the two concepts. Mohammed and Dumville (2001) argued that the notion of shared mental model is the broader concept that encompasses aspects of the transactive memory construct. Moreover, several scholars have noted the similarity between what Cannon-Bowers and colleagues (2003) referred to as team member mental models and the 'knowing who knows what' component of a TMS (Austin, 2003; Kerr & Tindale, 2004). We agree that shared mental models and TMSs are partly overlapping; however, the relationship between the two constructs may be more complex in the sense that they could also have interactive effects on performance and that they could be causally related concepts (Brandon & Hollingshead, 2004; Ellis, 2006; Lewis, 2003). A TMS and shared mental models could reinforce each other such that a TMS will be more effective when team members also hold similar mental models. On the other hand, under some circumstances they could be supplementary in that it may suffice for a team to have either a TMS or shared mental models to facilitate team information processing. Finally, longitudinal studies may clarify if the existence of shared mental models may facilitate the development of a TMS in a team and vice versa. Empirical studies on the relationship between these two central team cognition constructs could further the formation of a more complete understanding of the cognitive structures and processes that are important for effective team functioning.

While teams researchers have focused intently on understanding more about the shared cognitive constructs of mental models and transactive memory, a third, less-prevalent team-level construct has been defined and described in extant literature: TSA. We next turn to a review of the work on TSA for three central reasons. First, existing work suggests that the concept of TSA is similar to and yet distinctive from shared mental models and transactive memory systems, particularly concerning its role in team adaptability in dynamic environments. Second, most theorizing about TSA has been published in extant literatures not routinely accessed by many teams researchers; by including a review of the concept here, we hope to increase the accessibility of this literature to those researchers. Finally, and of related concern, knowledge about situation awareness has been pioneered by researchers focusing outside the team context; our understanding of TSA could be greatly broadened with more team-level empirical research and specification. We hope here to foster more interest in the concept among researchers of groups and teams.

Team situation awareness

Even though various scholars have alluded to the crucial role of TSA in adaptive team performance (Burke et al., 2006; Cooke et al., 2000; Orasanu, 1990), unlike shared mental models and TMSs, there is only a scant empirical record of this concept.

Whereas mental models are cognitive representations of the general functioning of a system, SA refers to the knowledge and understanding of a dynamic system at a specific point in time (Durso & Gronlund, 1999; Endsley, 1995). As such, it refers to a more ephemeral and transitive type of knowledge that is developed while engaging in task performance—and one that is constantly being updated and recreated subject to changes in the task situation and performance requirements (Adams, Tenney, & Pew, 1995; Fracker & Vidulich, 1991). Correspondingly, scholars have referred to TSA as a team's awareness and understanding of a complex and dynamic situation at any point in time (e.g. Endsley, 1995; Salas, Prince, Baker, & Shresta, 1995). The concept of TSA is closely related to the notion of team situation models, which are defined by Rico and colleagues as "dynamic, context-driven mental models concerning key areas of the team's work" (2008: 164), and that have been characterized by Cooke and colleagues (2000, p.157) as team knowledge that is "in a constant state of flux."

Because a team's ability to form an appropriate understanding of the task environment plays an important role in its adjustment to unanticipated events, the concept of TSA is crucial for understanding the sustained performance and viability of teams (Ancona, 1990; Ancona & Caldwell, 1992; Burke et al., 2006) and the organizations in which they function (Bourgeois, 1985; Daft & Weick, 1984; Eisenhardt, 1989). Particularly for teams functioning in high-reliability organizations, the timely recognition of cues signaling non-routine situations, and the incorporation of those cues in the collective team-level representations, is pivotal to safe and efficient operations (Waller, 1999; Weick, Suttcliffe, & Obstfeld, 2005). Accordingly, scholars have emphasized the importance of achieving and maintaining an adequate understanding of the situation in a variety of fields including medicine (Gaba, Howard, & Small, 1995; Helmreich & Schaefer, 1994), aviation (Endsley, 1995; Mosier & Chidester, 1991; Orasanu, 1990), nuclear power plant operations (Hogg et al., 1995; Sebok, 2000; Waller et al., 2004), military command-and-control (Kaempf, Klein, & Thordsen, Wolf, 1996), and railroad operations (Roth et al., 2006). In order to clarify the concept of TSA, we will first briefly introduce the general concept of situation awareness (SA) as it has been developed at the individual level. Then we will explain the different ways scholars have conceptualized TSA at the team level. We will describe its relation to shared mental models and briefly describe measurement methods scholars have applied to this more ephemeral form of team cognition. Finally, we will provide a short overview of the few empirical studies that have been conducted on TSA.

Conceptualization

The concept of SA developed in the field of aviation, where it was used to explain the superior performance of some fighter pilots during World War I (Endsley, 1995). Because several studies indicate that a breakdown in SA constituted an important factor in many aviation accidents (Endsley, 1988; Jentsch, Barnett, Bower, & Salas, 1999; Salas et al., 1995), it is not surprising that SA has continued to receive much attention among aviation psychologists and in the related field of Human Factors.

The most widely cited definition of SA is given by Endsley as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1988, p. 97). Endsley thus considered SA to be composed of three hierarchical levels. The first level pertains to the perception of the individual elements in the environment, the second level to the integration of the elements into a comprehension of the current situation, and the third level to the projection and anticipation of future states. She posed SA as a central aspect of individual information processing, linking attention and perception of incoming information to decision making and action execution (Endsley, 1995).

Scholars have made a distinction between situation assessment, referring to the processes involved in acquiring and maintaining an understanding of the situation (i.e., perception, comprehension, and projection), and the SA that encompasses the resulting knowledge or awareness of the situation (Sarter & Woods, 1991). Situation assessment is considered a goal-directed process (e.g. Durso & Gronlund, 1999; Endsley, 1995; Sarter & Woods, 1991). It involves more than merely being conscious of, and attending to, the environment; instead, it implies an active assessment of the environment with respect to specific goals (Smith & Hancock, 1995). Accordingly, SA, which constitutes the outcome of the situation assessment processes, has been referred to as a meta-goal—an overriding goal that must be achieved before task goal completion is possible (Selcon & Taylor, 1991).

Situation assessment as a process bears close resemblance to the activities of scanning, interpretation, understanding, and action involved in sensemaking (Weick 1995). Moreover, the result of situation assessment—SA—comes close to what Weick described as the substance of sensemaking, or the linkages between cues, frames, and connections. However, the situation assessment approach stands in contrast with Weick's sensemaking perspective, in that Weick emphasizes the idiosyncratic and subjective nature of the processes of giving meaning to and constructing an understanding of the situation, while scholars studying SA have often implicitly assumed the existence of an optimal or 'true' referent to which a person's or team's situational understanding can be compared (see, e.g., Endsley, 1995; Mosier & Chidester, 1991).

Emergent Aspects of TSA

Although TSA is generally considered as an emergent phenomenon originating from the SA of the individual members, different specifications exist concerning how this higher level phenomena is shaped and constrained by its lower level constituents (Chan, 1998; Kozlowski & Klein, 2000). Wellens (1993) and Endsley (1995) conceptualized TSA as the distribution and overlap of the SA of the individual team members. They argued that optimal TSA could be obtained by the separation of the responsibilities for SA of the team members in such a way that it maximizes the coverage of the relevant environment while at the same time leverages sufficient overlap to ensure efficient group coordination. Hence, according to this view, optimal TSA strikes a balance between the differentiation and integration of team members' personal awareness of the situation.

Others, however, have argued that TSA can not be fully captured by the aggregation or overlap of the individual team members' knowledge, but instead must also involve team interaction processes such as communication, coordination, task allocation, and planning (; Salas et al., 1995; Schwartz, 1990). Cooke and co-authors (2000, 2001) proposed the concept of holistic TSA, which arises when team processes transform the knowledge of the individual team members into effective collective knowledge. They asserted that this holistic team level understanding does not reside with the individual team members; nor can it be conceptualized as a collection of individual knowledge; rather, they maintained, it constitutes the knowledge upon which the team's actions are based.

Some authors have adopted a more top down, systems approach that considers how collectives form and maintain overall SA of dynamic systems (Artman & Garbis, 2004; Artman & Waern, 1999; Heath & Luff, 1992). These scholars build on Hutchins' (1991; 1995) notion of distributed cognition which takes the joint cognitive system as the focal point of analysis. In line with the socio technical system approach (Trist & Bamforth, 1951), cognition is considered to be an embedded property of the cognitive system—the collection of individuals plus the available technology—and not merely a compilation of the cognition of individual team members. Therefore, studies from a distributed cognition perspective often consist of case studies that describe how TSA is maintained in specific naturalistic settings, such as cockpits, control rooms, or medical dispatch centres (Artman & Waern, 1999; Blandford & Wong, 2004; Heath & Luff, 1992; Hutchins, 1995). Particular emphasis is placed on the role of structural aspects, supportive technology, and artifacts in understanding how SA is represented and propagated through the system (Artman & Garbis, 1998). For example, Roth and co-authors (2006) described how in railroad operations, employees developed a variety of informal cooperative strategies that enhanced overall system safety by improving shared SA. The strategies used included alerting others of unusual or unexpected conditions and overhearing or overseeing activities of others. The use of open communication channels that could be sampled by all members of the system played an important role in enabling informational redundancy.

Distributed TSA

Other scholars have emphasized the distributed aspects of TSA, acknowledging that by distributing SA responsibilities among their members, teams can reach broader coverage of the task environment and potentially locate and process more task relevant information (Endsley, 1995; Stanton et al., 2006; Wellens, 1993). In order to maximize the extent to which they are able to gain awareness coverage of their relevant task environment, teams may distribute their situation assessment function among the different members by spatially or functionally splitting up their task environment and assigning responsibility for each subsection to a different member (Artman, 1999; 2000). For example, teams may spatially split up their task environment, as is the case in air traffic control (i.e., individuals monitor different geographic sectors), or team members may be assigned responsibility for different functional aspects, as may be the case in fire fighting teams (i.e., some members may attend to the fire while others keep track of victims involved in the incident). On the other hand, by maintaining overlapping areas of responsibility, teams can attain redundancy, which may increase the probability that important information will become noticed by at least one member (Hollenbeck et al., 1995). Particularly in environments requiring high levels of vigilance, the cost of missing pieces of information may be higher than the costs of functional redundancy.

Apart from a horizontal, geographical or functional distribution, teams may also decide to adopt a vertical distribution of TSA tasks. Stanton and colleagues (2006) theorized that distributed SA may entail different individuals being involved in different levels of SA; some individuals may be engaged in task perception, some in comprehension and others in projection. For example in military organizations, although a large number of people may span the boundary with the external environment, only a small group of people at the top of the organizational hierarchy may be involved in the actual interpretation of the organizational environment (see Kaempf et al., 1996 for an example). This, however, summons the classical dilemma between central command and distributed responsibility; is it better for teams to hold one central person responsible or to make all team members responsible for maintaining overall awareness of the situation? On the one hand, in complex situations, individual members may quickly become overloaded with information, making it difficult to maintain SA. On the other hand, assigning overall SA tasks to some members, may free up cognitive resources from other members thereby allowing them to fully concentrate on executing other tasks.

Particularly in high workload situations, it may be beneficial for teams if one individual with a cognitively-central position within the group is responsible for compiling and keeping active the higher-order situational knowledge. Studies on the role of working memory in the formation of SA suggest that the availability of sufficient attentional resources is crucial for forming and maintaining SA (Carretta, Perry, & Ree, 1996; Endsley, 1995; Gugerty & Tirre, 2000). For instance, in a study investigating 311 civilian aircraft accidents, Jentsch and coauthors (1999), found that captains were significantly more likely to lose SA when flying themselves then when the first officer was flying. This indicates that the additional workload involved in flying the aircraft negatively affected the ability to maintain SA. So, captains may play a pivotal role in forming TSA as they must receive and integrate information communicated by the other team members (Schwartz, 1990). Similarly, Bigley and Roberts (2001) observed that for members of temporary response organizations, “the cognitive or perceptual requirements of particular tasks can be so demanding that individuals performing them are not able to maintain an awareness of the surrounding system” (p. 1291). These authors found that in such cases, responsibilities for SA were shifted to someone in a better position and with sufficient cognitive resources to build and maintain an overall understanding.

Awareness of Other Members

TSA does not exclusively relate to the external task environment; it may also include awareness of the team’s internal situation, or, in other words, understanding of the current status and needs of the other team members (Endsley, 1995; Marks & Panzer, 2004). Scholars have addressed this internal aspect of TSA using labels such as shared workspace awareness (Gutwin & Greenberg, 2004), mutual awareness (Artman & Waern, 1999), and mutual organizational awareness (Macmillan, Entin, & Serfaty, 2004). However, because a proliferation of different terms for similar constructs may lead to confusion, we propose the basic distinction between *external TSA*—the awareness and understanding of the task environment and *internal TSA*—the awareness of the current status and needs of the team and the team members itself. Note that this division runs parallel to distinction between *teamwork mental models*—knowledge about the team's structure and about characteristics of the other team members—and *taskwork mental models*—knowledge about task processes, strategies, and likely scenarios of the task system the team faces.

Whereas, most studies and theories have focused on external TSA, some processes have been related to internal TSA. For example, Heath and colleagues noted the importance of rendering activities visible in order to facilitate the development of internal TSA (Heath & Luff, 1992; Heath, Svensson, Hindmarsh, Luff, & vom Lehn, 2002). By rendering visible selective aspects of their activities, team members encourage others to pay attention to features of their task that become potentially relevant to others. Although this ascribes a relatively passive role to the observer, others have pointed to the more active process of team monitoring , or "observing the activities and performance of other team members" (Dickinson & McIntyre, 1997, p.25) in maintaining internal TSA. In a study with teams performing in a simulated flight simulation Marks and Panzer (2004) found that team monitoring was positively correlated with both coordination and feedback processes, which in turn improved team performance. There is thus some indirect evidence for the relationship between internal TSA and team performance; however, apart from a few scant studies, a coherent framework of the activities, processes, and technological devices team members may apply to maintain and understand the internal status of the team is still lacking.

The relationship between shared mental models and team situation awareness

Although, no study has yet been undertaken to directly address the relationship between shared mental models and TSA, research at the individual level indicates that team members' mental models play an important role in the development of TSA for two main reasons (Stout, Cannon Bowers, & Salas, 1994). First, mental models influence the content of TSA. Because mental models focus attention onto specific aspects of the situation and determine how this information becomes interpreted (Endsley, 1995; Mogford, 1997; Sarter & Woods, 1991), team members' mental models will determine to a considerable extent how team members will understand task situation at any point in time. Second, mental models facilitate the development of TSA. Because the maintenance, integration, and projection of information take place in working memory, the ability to concurrently store and operate using different pieces of information is considered to be the main bottleneck for acquiring and maintaining SA (Fracker & Vidulich, 1991; Wickens, 1984). Therefore, scholars have argued that mental models facilitate the attainment of SA by diminishing the load on working memory capacity (for a review see Durso & Gronlund 1999). For example, Sohn and Doane (2004) conducted an experiment investigating the relative effects of working memory and memory retrieval structures—essentially a basic type of mental model—on flight SA. They demonstrated that individuals who had acquired retrieval structures through experience in a particular domain could use these structures to take the load necessary for acquiring SA off working memory capacity. The quality of the retrieval structures of experienced pilots emerged as a better predictor for SA than their working memory capacity.

The relationship between mental models and SA however is not unidirectional: rather, as argued by Waller and Uitdewilligen (2009) team members' momentary understandings of the situation can evoke and shape particular cognitive structures. For example, when a situation is perceived as a crisis, team members access different mental models from those accessed when they perceive a situation as serious but routine. Adams and colleagues (1995) nicely depicted this iterative process using Neisser's (1976) model of the perceptual cycle. This model shows how cognitive structures—mental models—influence what aspects of the environment people explore, which determines the type of information that becomes available from the environment—SA—which in turn, modifies the original cognitive structures, and so on.

The aforementioned close relationship between individual level mental models and SA leads us to speculate how shared mental models and TSA relate to each other at the team level. First, it is likely that if team members share an understanding regarding how aspects of the environment, task, and team function in general, they are also more likely to construe a common understanding of the task and team situation at a specific point in time. Second, as argued above, to the extent that mental models direct team members' focus of attention and interpretation processes, similarity in mental models may lead members to focus on similar information sources and draw similar interpretations from them. This in turn may aid rapidity of response, but also increase the danger of collective myopia. Conversely, highly divergent mental models may lead to a wider sampling of environmental information and a wide variety of interpretations, which may lead to more complete and more elaborate TSA. On the other hand this may pose a greater burden of information processing on the team as a whole, leading to conflicting and ambiguous understanding. However, as research integrating these team cognitive structure concepts is still lacking, statements about how they relate to each other remain speculative. For example, does similarity in mental models always lead to similarity in TSA? And, can similar TSA also trigger different mental models in different team members? More research is needed on how characteristics of a teams' shared mental model—accuracy, similarity, complexity—relate to characteristics of their TSA.

Measures of (T)SA

One reason for the scarcity of studies on TSA is probably the difficulty involved in developing assessment methods that take into account the dynamic nature of the concept (Cooke et al., 2000). Another explanation can be found in the challenge of deriving meaningful team level variables from individual level SA indicators. At the individual level, a variety of methods has been developed for assessing SA, including questionnaires, query measures, implicit performance measures, and behavioral checklists (Cooke et al., 2001; Durso & Gronlund, 1999; Endsley, 1995b). Dynamic aspects of SA can be assessed by repeatedly administering measures over time. Team level SA measures may be constructed from these individual measures by creating collective indexes—for instance, on the basis of aggregated accuracy, similarity, or distribution. Alternatively, some authors have argued that TSA should be directly assessed as a holistic team level situation understanding; by targeting measures to the team as a whole instead of to each member separately (Cooke et al., 2000; Hogg et al., 1995). However, when team tasks have conjunctive or disjunctive properties (Steiner, 1972), it may very well be the SA of the best or worst performing team member that drives team performance (Endsley, 1995b; Sebok, 2000).

Questionnaires measures often consist of Likert-scale questions with which participants or observers are directly questioned about situation assessment quality (e.g. Taylor, 1990). They can be administered during and/or after task performance. A disadvantage of administering SA questionnaires after a task has been completed is that respondents may confuse SA with task performance outcomes. Moreover, SA questionnaires have often been developed for specific domains—mainly pilot performance and air traffic control—and hence may not directly be generalizable to other settings.

Query measures assess the extent to which participants are aware of task relevant information at a specific point in time. Questions about the present or anticipated future state of the situation are administered, while the simulation is frozen at random moments. For instance, in the case of the Situation Awareness Global Assessment Technique (SAGAT) technique developed by Endsley (1995) a simulator task is stopped at random points and information about the task is collected from operators while they answer the SA questions. SA accuracy is subsequently measured by comparing the answers of the operators with objective data registered by the simulator (computer), and SA similarity can be assessed by comparing the answers of the different team members (Bolstad, Cuevas, Gonsalez, & Schneider, 2005; Cooke et al., 2001). An advantage of this method is that by repeatedly administering queries, researchers can develop a dynamic picture of TSA as it develops over time. The main disadvantage; however, is the intrusiveness of the method. Because the task has to be stopped every time queries are administered, the measurement often interferes with the natural execution of the task. This makes administration of the method problematic particularly in field settings as it rarely possible to interrupt a task in order to administer a measurement. Moreover, after the first round of queries participants may anticipate the queries that follow, and the questions may focus participants on aspects of the task to which they would otherwise not attend. Finally, assessment of the accuracy of team members' SA, is only possible if objectively correct answers to the queries can be determined. For lower levels of SA that refer to simple facts about the situation this will not be problematic; however, for higher levels of SA that refer to interpretations about the situation. it may not always be possible to determine the "true situation."

Implicit measures assess SA indirectly by scoring behavior or performance on tasks or subtasks which are selected or constructed specifically to require SA in order to be successfully accomplished (Cooke & Gorman, 2006; Dwyer, Fowlkes, Oser, Salas, & Lane, 1997; Patrick, James, Ahmed, & Halliday, 2006). However, although this method allows researchers to induce the quality of TSA, it does not provide any information about the content of team member's SA nor does it provide a dynamic picture of TSA over time.

Another method that may be particularly suited to assess TSA is content analysis applied to the content of team communications obtained by video, audio, and/or written text recordings (Langan-Fox, Anglim, & Wilson, 2004; Waller et al., 2004; Waller & Uitdewilligen, 2009). This approach provides the type of data amenable to continuous measurement, and can capture the dynamic and continuous nature of the TSA construct. Although communication is only an indirect measure of team members' knowledge and is therefore not likely to cover the complete content of awareness of the individual team members, it does nevertheless, include those aspects deemed appropriate to share in an open forum. Hence, coding and analyzing the content of team communications should enable researchers to gain insights into the process of collective sensemaking.

Empirical Studies

As we mentioned before, the number of studies directly assessing TSA is low. Studies that do assess TSA generally are exploratory in nature and have small sample sizes. Here, we simply give a summation of the results that have been found in these studies. In a study investigating two person pilot crews, Prince, Ellis, Brannick, and Salas (2007) found that an observer based measure of TSA accuracy administered during a high-fidelity simulation, as well as a TSA measure collected in a preceding low-fidelity scenario, were significantly correlated with performance scores of the teams on the high-fidelity simulation. In a study using a synthetic team training task in which three person teams learned to operate an uninhabited air vehicle, Cooke and co-authors (2001) found that TSA accuracy and similarity, measured by queries regarding mission progress that were randomly administered during the mission, were positively correlated with team performance. In a simulation study using a query measure of TSA, Bolstad Cuevas, Gonzalez and Schneider (2005) found that frequency of communication among team members and a social network measure of physical distance predicted TSA similarity. Hogg and colleagues (1995) developed a query measure of TSA specifically for nuclear power plant control rooms, which they administered holistically—to the team as a whole instead of separately to each member. They found that scores on this TSA measure accurately reflected the difficulty of different types of disturbances that were introduced into the simulation scenario; the more difficult the disturbances, the stronger the teams experienced a decrease in the accuracy of their TSA. In an experimental study, using this same measure, Sebok (2000) compared TSA—operationalized as the average accuracy of the SA of the team members—in normal and small teams before and during system disturbances, under two interface conditions. The first condition was a "conventional nuclear power plant interface condition", characterized by non-computerized displays where operators' stations were located several meters apart. The second condition was an "advanced interface condition", characterized by computerized displays, large-screen overview display, and co-located seating arrangement. Although she did not find main effects for plant interface and team size, Sebok found an interaction effect indicating that normal sized teams had better TSA in the conventional plant interface condition while smaller teams had better TSA in the advanced interface condition.

Other studies have not directly assessed TSA but have focused on the processes in which teams engaged while forming an understanding of the situation. For instance, in a study of air traffic controllers Hauland (2008) assessed team situation assessment behaviours using eye-movement data, and found that during the handling of non-routine events team performance improved when the two operators simultaneously accessed information regarding future traffic. In a study of nuclear power plant control teams, Waller and colleagues (2004) found that the time team members spent engaging in team situation assessment behaviors was positively related to their ability to adapt to non-routine events.

Future Directions

Although it is neither as mature nor as coherent as the literatures concerning shared mental models or TMSs, the existing work on team situational awareness may be more applicable to the dynamic, transitive nature of the turbulent environments facing many action teams. More work in the area needs to be done, both theoretically and empirically, to further understanding of how individuals' situational awareness translates to the team-level version of the construct. Through the integration of the various conceptualizations of TSA and the critique of extant methods of assessment for operationalizing this potentially important concept, we hope our review will help motivate such work.

Adaptation and shared cognition

In our review of the recent literature on shared mental models, TMSs, and TSA, we have emphasized issues of adaptability in action teams facing dynamic environments. In this, the final section of our chapter, we suggest why these shared cognitive structures may not always facilitate adaptability in such teams, and we suggest two important moderators of the relationship between shared cognition and team adaptability. Specifically, we seek to address the question as to whether the shared cognitive structures so efficient under relatively stable or even moderately dynamic circumstances actually hinder teams' abilities to adapt to radically changing environments.

Shared mental models and team adaptation

In their cyclical model of team adaptation, Burke and co-authors (2006) emphasized the importance of shared mental models for the formulation and execution of new plans and strategies in novel environments. They stated that "[in] the absence of shared mental models adaptive team performance is not possible, because members do not have compatible views of equipment, tasks, and team member roles and responsibilities, which allow members to adapt proactively" (p. 1194). Similarly, Marks and colleagues (2001) posed that under high environmental dynamism, the positive relationship between mental model similarity and accuracy and team performance will be even more pronounced than under low degrees of environmental dynamism. In particular, they argued that when faced with novel non-routine situations, similar and accurate mental models enable teams to engage in real-time interpretations of information and effective coordination. The results of their study support the reasoning that mental model similarity becomes more important for performance when teams operate in novel environments. Moreover, they found that a priori accuracy of team members' mental models was not very important in novel environments, leading them to suggest that teams with similar mental models would eventually form accurate ones as well.

However, scholars from other fields have pointed out that cognitive structures may function as barriers to radical change and lead to rigidity (Hodgkinson, 1997;2005; Porac & Thomas, 1990; Reger & Palmer, 1996; Tushman, Newman, & Romanelli, 1986; Tushman & Romanelli, 1985). Studies of mental model accuracy indicate that it is important for team functioning that the team's mental models appropriately represent the underlying structure of the environment (Cooke et al., 2001; Edwards et al., 2006; Lim & Klein, 2006). This implies that in a changing environment, alterations in the underlying structure of the environment should be matched with corresponding modifications in team members' mental models. Under low or moderate environmental dynamism, teams may adapt by making incremental changes to their mental models. Under extreme environmental dynamism, however, teams may need to completely redevelop their knowledge structures (Gersick, 1991). Because structures that may have been effective under previous circumstances may become dysfunctional in the new situation, failure to update team knowledge structures in a timely matter may lead to severe performance decrements (e.g. Weick, 1990; Weick, 1993). As March noted, "mutual learning has a dramatic long-run degenerate property under conditions of exogenous turbulence" (1991, p. 80).

More specifically, and as Cannon-Bowers and colleagues (1993) noted, if a threshold of similarity in mental models is surpassed, team's cognitive functioning may become overtly rigid; similarly, Klimoski and Mohammed noted that although often seen as functional, shared mental models may have a "dark side" as well (1994, p. 419). Mental models tend to be obstinate and enduring, and changes in mental models often lag behind changes in the environment (Fiske & Taylor, 1991; Hodgkinson, 1997;2005; Reger & Palmer, 1996). Particularly when teams have successfully functioned in environments that have been stable for a relatively long period of time, their knowledge structures may become engrained and taken for granted, making them less amenable to change in the short term (Audia, Locke, & Smith, 2000; Lant, Milliken, & Batra, 1992; March, 1991).

The first phase of team adaptation is the recognition and interpretation of cues signalling a need for change, while the second phase is the formulation of plans and strategies to deal with the challenges of the changing environment (Burke et al., 2006; Waller, 1999). The effect of shared mental models on both phases of the adaptation processes is dubious. Concerning the first phase, because mental models guide perception and interpretation processes (Neisser, 1976; Starbuck & Milliken, 1988), similarity in mental models may cause team members to attend to similar situational cues and diagnose these cues in similar ways. As Walsh (1995: 281) noted in his review of work on strategic decision making, "[while] these knowledge structures may transform complex information environments into tractable ones, they may also blind strategy makers, for example, to important changes in their business environments, compromising their ability to make sound strategic decisions" (see also Zajac & Bazerman, 1991). Therefore, Cohen and Levinthal (1990) suggested that in order to evaluate and utilize outside knowledge under conditions of rapid and uncertain change, it is best to expose a fairly broad range of prospective "receptors" to the environment. Hence, teams with very similar mental models may fail to—or lack the absorptive capacity to—timely perceive and diagnose cues that fall out of the scope of their knowledge structures, and thereby miss early indications of upcoming environmental upheaval.

Concerning the second phase of team adaptation, the formulation of new and groundbreaking plans and strategy requires the kind of improvisation and creativity processes that are often associated more with cognitive diversity than with cognitive similarity (Bantel, 1994; Bantel & Jackson, 1989; Hoffman & Maier, 1961; Jehn et al., 1999). Diversity in underlying knowledge structures has been associated, if adequately managed, with the ability to generate a wide range of perspectives and alternative solutions and the tendency to engage in deep information processing to integrate these various viewpoints (Milliken & Martins, 1996; van Knippenberg et al., 2004). A thorough elaboration of perspectives and information is related to successful problem solving, the emergence of new insights (Jehn et al., 1999; Levine & Resnick, 1993), and a team's ability to reconsider assumptions and produce more creative and high quality solutions (de Dreu & West, 2001; Nemeth, 1986). So, although similarity in mental models may lead to highly efficient team coordination processes, it may not be the optimal configuration for the adaptive planning processes teams require under extreme environmental change.

Transactive memory systems and team adaptation

Lewis states that "knowing whether the effects of a TMS persist in dynamic task environments is critical to understanding the real impact of TMSs in organizations" (2005, p. 581). Ren and colleagues (2006) found in a study using computational modeling that knowing "who knows what" is particularly important for groups functioning in volatile task and knowledge environments. However, the functionality of a TMS seems to depend on the stability of the membership and expertise specialization within the team (Lewis et al., 2005).

Particularly under circumstances requiring team adaptation, team composition may be far from stable. For example, research on top management teams indicates increases in turnover under turbulent circumstances (Keck & Tushman, 1993; Wiersema & Bantel 1994) and teams in fast-response organizations may often have to engage in plug-and-play teaming, composing teams with those members who happen to be available at the time (Bigley & Roberts, 2001; Faraj & Xiao, 2006). Moreover, modest levels of turnover can be an optimal strategy for increasing exploration in the face of environmental turbulence (March, 1991). Finally, teams may bring in outsiders to challenge the status quo and increase the variety of perspectives the team can draw on when facing novel situations (Bogner & Barr, 2000; Choi & Levine, 2004).

Various studies of TMS show the detrimental effects of breaking up and rearranging group membership (Lewis, 2003; Moreland, Argote, & Krishnan, 1996; 1998; Wegner et al., 1991). More specifically, Lewis and co-authors (2007) found that when teams had partial membership loss, remaining members rigidly adhered to their previous TMS structures, which resulted in decreased performance.

Team situation awareness and team adaptation

Numerous scholars have pointed to the pivotal role of an integrated representation and awareness of the important elements of the task environments for adaptive team performance (Bourgeois, 1985; Hogg, Knut, Strand-Volden, & Torralba, 1995; Waller et al., 2004). Scholars have represented situation representations as knowledge structures that are subject to continuous transformations (Cooke et al., 2000; Rico et al., 2008; Salas et al., 1995), as they are considered to "change with changes in the situation" (Cooke et al., 2000: 154). However, studies about if and when teams actually update their situation representations given changes in the external environment are scarce (for an exception, see Waller & Uitdewilligen, 2009). Because of the important role the accuracy of team situation representations play in team functioning, it is of pivotal importance for teams to readjust their situation representations after significant changes in the environment (Burke, et al. 2006; Rico et al., 2008). Studies on cognitive fixation suggest that people tend to stick to their original interpretations of situations even when faced with evidence disconfirming these interpretations (Einhorn & Hogarth, 1978; Lord, Ross, & Lepper, 1979). When a situation is defined in a particular way, people have a natural tendency to favour confirmatory information and discount or ignore discordant evidence (Einhorn & Hogarth, 1978).

Studies on attentional narrowing and cognitive tunnelling indicate that team members may become so preoccupied with a single aspect of the environment that they may fail to attend to other aspects and fail to update their SA (Huey & Wickens, 1993). For instance, in an incident described by Wiener and colleagues (1993), during a routine flight on the night of December 29, 1972, the pilot, first, and second officer of a Lockheed 1011 noted that the nose landing gear light did not indicate "down and locked." In the ensuing moments, while the crew became so involved discussing the underlying causes and attempting to solve this problem, their attention was distracted away from their instruments and they failed to notice a warning signal indicating a sudden drop in altitude. It was this failure to notice an unexpected change in a timely manner that eventually led to the crash of the aircraft. This is a telling example of how a team that formed an initially correct understanding of the situation became so preoccupied with their original understanding that they failed to notice significant changes that had taken place, necessitating an update of their SA. The example illustrates again the importance of taking into account the temporal aspects of team cognition; it is not correct TSA at a single point in time but the frequent updating of TSA that is the key to adaptive team performance.

Flexibility

From our previous analysis, it appears that shared cognitive structures may facilitate as well as impede team adjustment to novel environments. However, work is lacking that would enable us to predict the help or hindrance of shared cognition in teams facing dynamic environments. *What would enable teams with shared cognitive structures to be flexible in radically changing environments—that is, able to quickly and accurately update not only their shared mental models, transactive memory, and TSA, but update the assumptions upon which* *these structures were created?* We propose that two sources of flexibility may help teams in these situations: flexibility embedded in the cognitive structures themselves, and flexibility in the team processes.

Burke and colleagues (2006) suggested that in the face of radical change, team members may require flexible mental models; however, not much is known about what may make knowledge structures particularly flexible or rigid. Some scholars have suggested that flexibility may depend on the structural aspects of the cognitive structures. For example, Weick's observation (1979) that loose coupling in structural configurations allows for adaptation and adaptability may hold not only for organizational- but also for cognitive structures. Lyles and Schwenk (1992) proposed that loose coupling between core and peripheral features in cognitive structures facilitates organizational adaptation. Work by Yayavaram and Ahuja (2008) indicates that the structure by which different knowledge elements are coupled together or the way they are subdivided into different clusters may affect the ability to recombine knowledge elements for innovation.

Additionally, the level of abstraction of knowledge structures may be related to their adaptability to different task situations. At the highest level of abstraction, team members may develop a form of metacognitive knowledge, referring to an understanding of their cognitive structures and conditional knowledge that facilitates deciding on when and why to apply various cognitive actions (Doyle & Ford, 1998; Hinsz, 2004; Lorch, Lorch, & Klusewitz, 1993). For example, Lewis and co-authors (2005) showed that when teams were trained in more than one task in the same domain, they developed a more abstract understanding of the task domain, enabling them to recognize common elements between tasks, which in turn facilitated the application of prior knowledge and expertise distribution structures to novel contexts.

Other scholars have looked at team processes that foster flexibility required for adaptive behavior. Whereas most studies on guided team self-corrections and reflexivity indicate that these processes are related to quality and similarity in team knowledge structures under relatively stable circumstances (Blickensderfer et al., 1997; Smith-Jentsch et al., 2008), the extent to which a team explicates and overtly reflects upon its objectives, processes, and strategies is also likely to positively influence the team's ability to adapt to more extreme environmental jolts (Gurtner et al., 2007). For example, Lewis and colleagues (2007) found that, when teams faced changes in membership, invoking reflexivity in team members helped prevent the rigid adherence to obsolete TMSs by the team members who were left behind. Finally, a study by Kray and Galinsky (2003) suggested that the activation of a counterfactual mind-set—that is, focusing team members on what might have been and fostering the formation of alternative representations—may minimize cognitive rigidity resulting from the failure of groups to seek disconfirming information in respect of their initial hypothesis when engaged in problem solving tasks.

Conclusion

In this chapter, we have reviewed recent empirical and theoretical work on three types of shared cognition in teams: shared mental models, TMSs, and TSA. We have focused this review in particular on aspects of shared cognition that affect the adaptability of teams facing dynamic, unpredictable task environments. Additionally, we have suggested that both the inherent structural characteristics of shared cognition and the reflexivity of teams moderate the influence these types of shared cognition have on team performance in such environments.

Our suggestions for future research are included in the body of the review at the end of each section, and we do not reiterate them here. However, our overall reading of the literature reviewed above reminded us of two important aspects concerning research collaboration in the groups and teams literature. First, and following an elegant call for such collaboration (Poole et al., 2005), over the past several years researchers across several disparate academic fields have added much to our knowledge regarding shared cognition in teams, and many signs of cross-field collaboration have begun to appear. For example, the formation of INGRoup—the Interdisciplinary Network for Group Research—in 2006 has provided an annual means for groups' researchers across disciplines such as industrial/organizational psychology, social psychology, organizational behavior, and communication, to meet and explore new agendas and methods for studying team shared cognition and other issues in small group research. A quick perusal of the reference list included here will illustrate the need for such cross-disciplinary dialogue to continue in the area of shared cognition in teams. Such dialogue is particularly important regarding the consistent use of terminology concerning shared cognition in teams, which in turn will increase the ability of researchers to perform cross-study analyses and better summarize our knowledge in this area (Hodgkinson & Healey, 2008).

Additionally, as organizational environments become more complex and fast-paced, and as organizations turn to teams to successfully anticipate and react to these environments, researchers will be challenged to find increasingly accurate means to measure shared cognition and related behaviors in dynamic environments—either simulated or real. Developing better and more accurate measures will likely necessitate "an earnest dialogue with computer scientists and mathematicians who may have the tools necessary to aid us in automating the coding of behavioral data and detecting patterns of behavior in groups" (Ballard, Tschan, & Waller, 2008, p. 345). Ultimately, more precise measures may also lead to better cross-study comparison as well as information for the training of teams working in these environments. What an exciting time to be studying team cognition when new developments in techniques and methods opens up new opportunities to deepen our understanding of, in particular temporal and dynamic, aspects of team cognition that hitherto have remained beyond the grasp of our knowledge.

Chapter 3

Team adaptation and mental model updating: Untangling the effects of team cognition and team interaction patterns on team adaptive performance

Abstract

Based on team cognition literature (Cannon-Bowers, Salas, & Converse, 1993; Klimoski & Mohammed, 1994) and the model of team adaptation proposed by Burke, Stagl, Salas, Pierce, and Kendall (2006), we examined the effect of team cognitive structures on team adaptation to novel circumstances. We tested the relations between mental model updating, team post-change interaction patterns, and team adaptive performance. In addition we tested whether team situation awareness, team members' initial mental model similarity and accuracy, and team communication directly after a task situation change were antecedents of mental model updating. Results from 46 teams working on a fire fighting simulation indicate positive relationships between team mental model updating, post-change team interaction patterns, and team adaptive performance. In addition, post-change team interaction patterns mediated the relationship between mental model updating and adaptive performance.

Introduction

Organizations often deploy teams to cope with the ever increasing dynamism, complexity, and uncertainty of their environments (Burke, Stagl, Salas, Pierce, & Kendall, 2006). As a result, it is crucial for these teams to maintain high levels of performance not only under routine circumstances but also in case of complex and unpredictable non-routine situations (Ilgen, 1999). In non-routine situation teams face unfamiliar and often unexpected problems that could have severe consequences for the team and the organizations in which they function (Waller, 1999). Although many teams spend the majority of their time functioning under normal operational conditions, under infrequent non-routine conditions, consequential differences in effectiveness among teams often become most evident (LePine, 2003; 2005). Team functioning under these circumstances is often crucial for diverting failures and disasters (Stachowski, Kaplan, & Waller, 2009); therefore, much leverage can be gained by identifying elements that contribute to teams' ability to 'think on their feet' and rapidly adapt to novel non-routine circumstances.

As team members accumulate experience in performing a team task, they develop efficient routines and interaction patterns that constitute a major source of the reliability and speed of team performance (Cohen & Bacdayan, 1994; Gersick & Hackman, 1990). However, the applicability of such routines and interaction patterns are strongly dependent on the context in which they have been developed. When the team is faced with a changing task situation, persevering with previously established routines and interaction patterns can become detrimental for team performance (Cohen & Bacdayan, 1994; Gersick, 1988; Gersick & Hackman, 1990; Stachowski et al., 2009). In particular, if changes occur in the underlying task structure —i.e in the relationships among task variables and in the relative effectiveness of specific actions—, teams must reevaluate the applicability of their existing practices and develop new practices for confronting their novel task situation (LePine, 2003; Marks, Zaccaro, & Mathieu, 2000). In order to effectively deal with such non-routine situations, teams must adapt to changes in the task situation and respond with appropriate actions (LePine, 2003). Thus, team adaptation is defined by Burke and colleagues (2006) as "a change in team performance, in response to a salient cue or cue stream, that leads to a functional outcome for the entire team" (p.1190).

Team researchers have depicted adaptation as a number of processes a team has to perform in order to adapt to a new task situation. Marks and colleagues (2000) suggest that teams adapt by surveying their task environments, interpreting the meaning with regard to the team goal, deciding on a strategy for action, and executing these actions. Similarly, Burke and colleagues (2006) suggest that team adaptation occurs as a recursive multiphasic process consisting of a situation assessment phase, a plan formulation phase, a plan execution phase, and a team learning phase. In the present research we build upon these theories of team adaptation by exploring the role of team members' cognitive knowledge structures in team adaptation to novel non-routine circumstances.

In the above mentioned team adaptation models, the authors have emphasized the importance of the structured knowledge team members have regarding their task or team in the team adaptation process. In particular, team mental models—team members' mental representations of knowledge, relationships, or systems—are considered pivotal for successful team adaptation (Cannon-Bowers, Salas, & Converse, 1993). However, previous works, while explicating the role of mental models in team adaptation, often take a static perspective on team cognition, focusing on characteristics such as similarity, accuracy, or quality (Marks et al., 2000; Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000; Resick, Murase, Bedwell, Sanz, Jiménez, & DeChurch, 2010). Yet, research from the field of managerial and organizational cognition suggest that under dynamic task circumstances, it may not be the momentary stable characteristics of mental models that impacts performance, but the ability to update mental models in light of changing task situations (e.g. Barr, Stimpert, & Huff, 1992; Bartunek, 1984; Weick, 1979).

Whereas, some scholars have hinted at the effect of dynamic aspects of mental models on team adaptive performance (e.g. Marks et al., 2000), empirical research on these dynamic effects are lacking. Therefore in the present paper, we test whether team member mental model updating—changing mental models in line with changes in the task situation—is positively related to team performance in a non-routine situation. In addition, we test whether initial mental model similarity and accuracy, team communication in the moments following the change, and pre-change team situation awareness (TSA)—team members' awareness of the relevant elements of the task situation—are antecedents of mental model updating. Finally we investigate whether team post-change interaction patterns mediate the relationship between mental model updating and team adaptive performance. We test our hypotheses in a study of 46 three-person teams performing tasks during a fire fighting simulation requiring an unexpected adaptation in task strategies.

Theoretical background and hypotheses

Boundary condition: Degree of environmental turbulence

Whereas, we argue that team members should update their mental models in response to changes in their task situation, the extent to which they will have to adjust will depend on the degree of environmental turbulence (e.g. Moorman & Miner, 1997). Scholars have distinguished between two qualitatively different types of change: evolutionary and radical change (e.g. Gersick, 1991; Miller & Friesen, 1984). Whereas in evolutionary change the main elements from the previous period may still hold, radical change refers to a complete restructuring of the forces making out the relevant environment, or as Gersick cogently illustrated "the difference between changing the game of basketball by moving the hoops higher and changing it by taking the hoops away" (1991: p. 19). In the present study we focus on non-routine changes that are large enough to require teams to abandon some previously acquired routines and practices, but not so large that all previous knowledge becomes irrelevant.

Team mental model updating and team adaptive performance

The most widely researched aspect of team cognition is probably the notion of shared mental models. Mental models are organized knowledge structures consisting of the content as well as the structure of the concepts in the mind of individuals that represent a specific task or knowledge domain (Kieras, & Bovair, 1984; Orasanu & Salas, 1993). The concept of shared mental models refers to the distribution and overlap of the mental models of the members of a team (Cannon-Bowers et al., 1993). In both field and simulated settings, research on shared mental models indicates that similarity of team members' mental models facilitates team processes and team performance (e.g. Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000; Marks et al., 2000; Smith-Jentsch, Mathieu, & Kraiger, 2005; Webber, Chen, Payne, Marsh, & Zaccaro, 2000). Moreover, a number of scholars have argued that apart from mental model similarity, the extent to which team members' mental models depict the actual or optimal structure of the team or task is also important for team performance (Cooke, et al., 2000; Rentsch & Hall, 1994). Empirical findings indicate direct effects for mental model accuracy (Cooke et al., 2001; Cooke et al., 2003; Edwards, Day, Arthur, & Bell, 2006; Lim & Klein, 2006; Marks et al., 2000), as well as interaction effects between mental model similarity and accuracy (Marks et al., 2000) in predicting team performance.

Several authors have argued that shared mental models are particularly important for team functioning in non-routine adaptation requiring situations (Cannon-Bowers et al., 1993; Marks et al., 2000). Burke and co-authors (2006) reasoned that similarity in mental models is positively related to team adaptation as this facilitates the team processes that are required for the effective execution of new plans and strategies. In particular, they argued that a shared understanding of the task and other team members' roles helps them monitor each other's performance and provide backup behaviors if necessary. Marks and colleagues (2000) reasoned that whereas under normal circumstances team members have the opportunity to explicitly communicate about and deliberate their actions and strategies, unusual non-routine circumstances generate such time pressure that teams are precluded from such explicit coordination practices and hence rely more strongly on their shared mental models for rapid coordination and interpretation of novel information. Consistent with this reasoning, they found that shared mental models are particularly conducive for team performance in novel environments. Overall, the existing body of research indicates a positive link between shared mental models and team adaptive performance.

Despite the acknowledgement that mental models sometimes can and should change over time (Burke et al., 2006; Marks et al., 2000), empirical studies on team mental models have often provided a rather static picture of team mental models and have not explicitly examined how team mental models may change over time in reaction to changes in the task structure. In those studies in which mental models were assessed at several points in time, researchers were mainly interested in the development and stability of team mental model similarity and accuracy over time; consequently, changes in the underlying structure of those mental models were not examined (Cooke et al., 2003; Edwards et al., 2006; Mathieu et al., 2000; Mathieu et al., 2005; Xinwen, Erping, Ying, Dafei, & Jing, 2006). In a stable task environment, development of team members' mental models may follow a linear development towards increasing convergence with one (or more) optimal model(s). In an unstable environment, however, the trajectory of mental model development is by definition not linear, as a mental model that is effective at one point in time may quickly become suboptimal at a later point in time. For example, many companies in the airline and trucking industries suffered as their managers held on to operational models that had previously been optimal but quickly became outdated after the deregulation of these industries (Audia, Locke, & Smith, 2000). Therefore, a study that aims to assess the quality of team mental models over time in an unstable environment should incorporate this nonlinearity and assess if changes in the task structure are incorporated in the mental models that reflects the task situation. In a simulation study, Marks and colleagues (2000) did assess team mental models under different conditions, and found that high performing teams appeared to flexibly adapt their mental models from routine to novel contexts. However, they did not formally test this proposition and they did not include mental model flexibility or updating as variables in their research model.

While the above-referenced literature emphasizes the positive effects of shared mental models on team adaptive performance, scholars from the field of managerial and organizational cognition have pointed out that cognitive structures such as mental models can also function as barriers to radical change and actually inhibit adaptation to novel circumstances (Reger & Palmer, 1996; Tushman et al., 1986). For instance, Walsh (1995), through applying the distinction between bottom-up versus top-down information processing (Abelson & Black, 1986), articulates the notion that knowledge structures may limit understanding. In contrast to bottom up information processing, during which people's cognitions are driven by the current information context, top-down information processing involves the application of individuals' knowledge structures such as mental models. People acquire these knowledge structures through past experiences in similar situations and use them to make sense of their present environments and to select appropriate actions. Although top-down information processing is often effective and efficient, it is based upon knowledge structures that essentially are simplifications of reality—selective abstractions of situations that focus individuals on specific aspects of their environment while ignoring others. Therefore, if knowledge structures are inadvertently applied to situations for which they are not appropriate—for example if the present situation differs on fundamental aspects from previous situation—this may lead to decrements in performance. More specifically, scholars have argued that in situations requiring structural change, cognitive structures may inhibit adaptation to novel circumstances; when individuals and teams apply cognitive structures that are developed in previous situations to new situations that are fundamentally different, they are at risk of ignoring relevant information and taking inappropriate actions (Reger & Palmer, 1996; Tushman, Newman, & Romanelli, 1986).

Studies of mental model accuracy clearly indicate that it is vital for team performance that team members' mental models appropriately represent the underlying structure of the task situation (Cooke et al., 2001; Lim & Klein, 2006; Edwards et al., 2006). This implies that when a team's task situation changes, alterations in the underlying structure of that situation should be matched with corresponding modifications in team members' mental models, or teams will run the risk of acting on an impoverished or outdated view of reality (Weick, 1979). It is not similarity or accuracy of mental models per se, but rather team members' ability to update their mental models in the light of changes in the task situation that is pivotal to team adaptation. Louis and Sutton (1991) propose that team adaptive performance does not merely depend on how good individuals or collectives of individuals function under routine or non-routine circumstances, but is more likely to be a function of their capacity to sense when a switch is appropriate. Therefore we predict that, when faced with an unexpected change in their task structure, team members' ability to revise and update their mental models to more closely align them with the new task situation will be positively related to the team's ability to perform well and avoid performance level decrements under non-routine circumstances. Note that this implies that not all change in mental models is necessarily beneficial to performance. We expect that specifically updating of the mental models—change that is in line with the changes in the task structure—is of importance for adaptive team performance. Therefore we propose the following hypothesis:

H1: Team members' mental model updating after a non-routine change will be positively related to team adaptive performance.

Initial team mental model similarity and team mental model updating

In addition to the importance of team members' mental model updating, a consistent body of research indicates that similarity in team members' mental models facilitates efficient teamwork and consequently leads to high performance (Cannon-Bowers et al., 1993; Mathieu et al., 2000; Mathieu et al., 2005). However, the role of pre-change mental model similarity in team adaptation to novel circumstances is murky.

Burke and co-authors (2006) emphasized the importance of shared mental models for the formulation and execution of new plans and strategies in novel environments. They stated that "[in] the absence of shared mental models adaptive team performance is not possible, because members do not have compatible views of equipment, tasks, and team member roles and responsibilities, which allow members to adapt proactively" (p. 1194). Similarly, Marks and colleagues (2001) pose that under high environmental dynamism, the positive relationship between mental model similarity and accuracy and team performance will be even more pronounced than under low degrees of environmental dynamism. In a low-fidelity three person team simulation, they found positive main effects, as well as an interaction effect of mental model similarity and accuracy on team adaptive performance. The interaction indicated that team mental model similarity was particularly important for teams with less accurate mental models. Based on this result, they suggest that if team members have similar mental models, these do not necessarily have to be accurate initially because having similar mental models may help them to construct accurate mental models as well.

Although the existing research seems to imply a positive relationship between mental model similarity and team adaption, several scholars have voiced their concern that too much similarity may under specific conditions hinder effective adaptation (e.g. Cannon-Bowers et al., 1993; Klimoski & Mohammed, 1994). Cannon-Bowers and colleagues (1993) wondered if a threshold of similarity in mental models may be surpassed, such that individuals' contributions may become lost and a team's cognitive functioning may become overly rigid. This reasoning seems to imply two mechanisms that may cause a possible negative effect of mental model similarity on team performance: a social psychological and a cognitive mechanism. First, a social psychological mechanism implies a relation between mental model similarity, interpersonal cohesiveness, and a pressure for consensus. Second, a cognitive mechanism implies that mental model similarity is the opposite of cognitive diversity, which is often considered an important requirement for performance in novel environments. In order to derive our hypotheses about the effect of initial mental model similarity on mental model updating we will explore the evidence for these two mechanisms.

Cannon-Bowers and colleagues speculated that teams with overly similar mental models may display characteristics of groupthink (Janis, 1972); team members may become unwilling to abandon incorrect models when they are socially reinforced by the other group members. A reasoning based on the groupthink phenomenon assumes linkages between mental model similarity, group cohesiveness, and a pressure for consensus (Aldag & Fuller, 1993); however, there is little proof for these relationships in the existing literature. Although, Klimoski and Mohammed (1994) argued that perceptions of mental model similarity may lead to high team cohesion by increasing trust and liking among the team members, research linking mental model similarity to social psychological outcome variables, such as cohesiveness is lacking in the extant literature. More importantly, the relationship between cohesiveness and pressures for consensus is highly contested (e.g. Callaway & Esser, 1984; van Woerkom & Sanders, 2010). A study by Kellermanns, Floyd, Pearson, and Spencer, (2008) suggests that, it may be more plausible that mental model similarity and pressure for consensus are separate constructs that may independently and interactively drive team processes and performance. They conducted a study in which they investigated the interaction between mental model similarity and norms for constructive confrontation in work teams. They found that mental model similarity was positively related to work team decision quality when norms for constructive confrontation were low but mental model similarity was negatively related to work team decision quality when norms for constructive confrontation were high. Given that norms for constructive confrontation can be considered antithetical to pressures for consensus, this implies that mental model similarity and pressures for consensus are more likely to be independent interacting factors.

A second more compelling argument indicating a possible negative effect of mental model similarity on adaptive performance proposes a cognitive mechanism. A number of recent studies have reported negative effects of mental model similarity on team performance. First, the study of Kellermanns and colleagues (2008), reported above, indicates that when teams have strong norms for constructive confrontation, mental model similarity may be negatively related to performance. They argue that in contrast to teams with similar mental models, teams with dissimilar mental models have greater diversity of cognitive inputs, which can be put to the team's benefit in case they have constructive norms for team interaction. In addition, scholars have argued that mental model dissimilarity may be indicative of an efficient distribution of roles and responsibilities (Banks & Millward, 2000). For example, Banks and Millwards (2007) make a distinction between similarity in procedural knowledge and similarity in declarative knowledge. They found that whereas similarity in declarative knowledge about the task was positively related to team performance, similarity in procedural task knowledge was negatively related to team performance. Finally, Hamilton and Mohammed (2010) found that in heterogeneous teams, whereas similarity in teamwork mental models was positively related to team performance, similarity in taskwork mental models negatively predicted team performance.

Although the above mentioned studies do not relate specifically to team performance in adaptation requiring situations, an investigation of the role of shared mental models in the cognitive processes of team adaptation provides additional information on the possible negative effects of mental model similarity on team adaptation. First, given that mental models guide perception and interpretation processes (Neisser, 1976; Starbuck & Milliken, 1988), similarity in mental models may be negatively related to the variety of cues that is considered within a team. Similarity may thereby reduce the chance that the team will notice the often relatively atypical cues that may signal a need for change. Second, the development of novel plans and strategies has often been associated more strongly with cognitive diversity than with cognitive similarity (Jehn, Northcraft, & Neale, 1999). The information processing perspective on diversity (van Knippenberg & Schippers, 2007) suggests that because teams with diverse knowledge structures have at their disposal a wider variety of opinions and perspectives, they are more likely to engage in deep information processing to integrate these various viewpoints. Deep information processing in turn is related to team's ability to reconsider assumptions and produce more creative and high quality solutions (de Dreu & West, 2001; Nemeth, 1986).

In sum, because these different research streams point to opposing conclusions regarding the relationship between mental model similarity and mental model updating, we formulate two opposing hypotheses:

H2a: Team members' initial mental model similarity will be positively related to mental model updating after a non-routine change.

H2b: Team members' initial mental model similarity will be negatively related to mental model updating after a non-routine change.

Initial team mental model accuracy and team mental model updating

An analysis of the extant literature also provides us with two opposing perspectives regarding the relationship between initial mental model accuracy and mental model updating. First, given that previous research has consistently linked mental model accuracy to successful performance (e.g. Edwards et al., 2006), initial mental model accuracy may lead to a 'paradox of success'. Research on the 'paradox of success' implies that initial success may hinder adaptation to changing circumstances (Audia et al., 2000; Miller, 1993). A number of studies, mainly on the organizational level, suggest that past success may lead to dysfunctional strategic persistence after a radical environmental change (Audia et al., 2000; Lant, Milliken, & Batra, 1992; Miller & Chen, 1993). For instance, Audia and colleagues (2000) found in a simulation study that individuals who initially experienced high levels of success were more satisfied, sought less information, set higher goals, and became more confident in the effectiveness of their current strategies, which subsequently led to more strategic persistence. Thus, high levels of past success may decrease the motivation to engage in additional cognitive processing and lead to persistence and a lack of change in mental models despite of changes in the environment (Fiske & Taylor, 1984; Kiesler & Sproull, 1982). Hence, it seems reasonable to deduce that individuals and teams with mental models that in the past have consistently led to good performance will be less likely to change these mental models than will individuals and teams with mental models that have not previously been associated with good performance.

On the other hand, initially accurate mental models may provide individuals and teams with a more advantageous starting point to develop new accurate mental models than individuals and teams that did not initially have accurate mental models. Three arguments can be given for this positive relationship between mental model accuracy and mental model adaptation. First, even though some linkages among concepts may no longer hold in the new situation and some others will have to be developed, it is unlikely that all relationships among all concepts will have to be completely restructured. Hence, the net amount of relationships among concepts that has to be changed from an initially accurate mental model to a new accurate mental model is likely to be smaller than from an initially inaccurate mental model to a new accurate mental model. Second, the accuracy of the initial mental model may reflect an underlying ability to construct accurate mental models. For example, Edwards and colleagues (2006) found a positive relationship between team ability and mental model accuracy. This ability may also be beneficial in the adaptation of the initial mental model to the new task situation (LePine, 2005). Third, the positive effect of initial accuracy on performance may generate additional effects that positively affect mental model adaptation. For example, initially accurate mental models may make task performance more efficient and thereby free up cognitive resources that may be used for consecutive processes of task performance and adaptation (Ericsson & Kintsch, 1995; Rouse & Morris, 1986). Efficient teams will have more cognitive resources left for scanning their environments for cues signalling a need for change and for developing appropriate strategies to deal with such change (Thorngate, 1976).

Whether previously accurate mental models will be conducive or detrimental to mental model adaptation is likely to depend on the degree of change in the task situation the team is facing. As we described under the boundary condition of the present study, although the type of change we focus on in this study is quite drastic, it is not as extreme as the radical environmental changes reported, for example, in the studies of Audia and colleagues (2000). Therefore, we expect the arguments for a positive relationship between team members' initial mental model accuracy and mental model updating to be more in line with the present study. Hence we hypothesize that:

H3: Team members' initial mental model accuracy will be positively related to mental model updating after a non-routine change.

Pre-change team situation awareness and team mental model updating

In addition to mental model accuracy, the ability of teams to realize that a change is necessary plays an important role in team adaptation. According to Burke and colleagues (2006), the first phase of team adaptation consists of the individual level cognitive process in which at least one of the team members scans the environment for cues that may indicate a requirement for a change in strategies and procedure. Other scholars have also considered the process whereby a team assesses the situation and have treated the resultant awareness of situational elements as an important antecedent of adaptive team performance (e.g. Cooke et al., 2000; Orasanu, 1990; Salas, Prince, Baker, & Shrestha 1995). Specifically, Mosier, and Chidester (1991) found that in flight crews working in a flight simulator and facing non-routine events, awareness of the information pertinent to the situation explained from 17 to 31 percent of the variance in crews' performance. Endsley referred to situation assessment as "the process of achieving, acquiring, or maintaining situation awareness;" she defined situation awareness as "the perceptions of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (1995, p: 36). The concept of situation awareness should be distinguished from mental models as it refers to the more ephemeral and dynamic knowledge of the actual momentary situation, whereas mental models reflect the underlying abstractions that make up the task-relevant structure and that can be generalized to other comparable situations (e.g. Adams, Tenney, & Pew, 1995; Fracker, 1991).

TSA refers to a team's awareness and understanding of the dynamic situation at any point in time (e.g. Salas et al., 1995). Scholars have given different accounts of how team level situation awareness is constructed from the situation awareness content of the individual team members. Early scholars such as Endsley, (1995) and Wellens (1993) conceptualized TSA in terms of the distribution and overlap of the situation awareness of the individual team members. Other scholars have argued that apart from the characteristics of individual situation awareness, accounts of TSA should also include the team processes that integrate the knowledge of the individual members to a collective team level understanding (Cooke et al., 2000; 2001; Salas et al., 1995; Schwartz, 1990).

Whereas most conceptual work views mental models as antecedents of situation awareness, we follow Burke and colleagues in proposing initial TSA as an antecedent of mental model updating. People tend to update their existing knowledge structures if they face unusual situations or when their expectations about reality are disconfirmed (Kruglanski, 1990; Louis & Sutton, 1991). Teams with accurate and complete awareness of the important elements of their task situation in the pre-change period are likely to timely recognize cues signaling important changes and hence to incorporate these changes into their mental models. Therefore, we propose that initial TSA will be positively related to mental model updating.

H4: Initial TSA will be positively related to mental model updating after a non-routine change.

Team adaptation communication, team adaptive performance, and team mental model updating

Once the change in the task situation has been perceived by the team, members must engage in planning processes in order to adapt their interaction patterns to the new reality of the task (Burke et al., 2006). LePine (2003) found that role-structure adaptation—team communication in which members addressed and adjusted their interaction patterns and smoothly communicated necessary information—was positively related to team adaptive performance. In a simulation with airline crew members, Waller (1999) found that it was not so much the frequency but the timing of adaptation behaviors that was associated with crew performance. In particular, she found that the speed with which teams engaged in task prioritization and task distribution was significantly related to team adaptive performance. Moreover, in a study with nuclear power plant crews, Waller, Gupta, and Giambatista (2004) found that during non-routine situations, high performing crews engaged in more information collection behaviors than lower performing crews. Thus, empirical evidence indicates that during non-routine situations, timely engagement in communication regarding priorities, tasks, and roles positively relates to a team's adaptive performance. In line with these previous studies, we define team adaptation communication as communication taking place in the moments immediately after a change in the task situation that is directed at exchanging information about and making sense of the novel circumstances.

Pearsall, Ellis, and Bell (2010) found that role identification behaviors, which they scored as the sharing of information by team members about their role or asking questions about the responsibilities of others, was positively related to the accuracy of team members' mental models and to the team's transactive memory system. This implies that team member mental model updating may mediate the relationship between adaptation communication and team performance. By discussing priorities, task, and roles, immediately after a change in the task situation, team members may quickly adjust and realign their mental model, which is expected to lead to high performance. Therefore, we propose that:

H5a: Team adaptation communication will be positively related to team adaptive performance.

H5b: The relationship between team adaptation communication and team adaptive performance will be mediated by team mental model updating.

Post-change team interaction patterns as a mediator in the relationship between team mental model updating and team adaptive performance

Whereas, team mental model updating may be crucial to team adaptation, team members' actual task related behaviors or interaction patterns are a more proximal antecedent of adaptive team performance (LePine, 2005). Team interaction patterns are the recurring interlocking patterns of activity, both verbal and non-verbal, that team members perform during a task performance episode. (LePine, 2003; Zellmer-Bruhn, Waller, & Ancona, 2004). Several scholars have placed interaction patterns at the basis of organized behavior (Cohen & Bacdayan, 1994; Katz & Khan, 1978; Weick, 1979). For example, Weick (1979) asserts that organizational processes consist of double interacts, which are sequences of behavior in which one actor acts, a second actor responds, and the first actor acts again in response to the second actor's action. Team interaction patterns consist of the repeated sequences of behaviors often executed by different team members. When team members' actions co-occur at a higher-than-chance frequency, this indicates a stable underlying pattern of behavior (Stachowski et al., 2009). Interaction patterns closely resemble the notion of habitual routines, which are formally defined by Gersick and Hackman (1990) as "when a group repeatedly exhibits a functionally similar pattern of behavior in a given stimulus situation without explicitly selecting it over alternative ways of behaving." However, whereas team habitual routines are considered to be largely automatic (i.e., they are triggered and executed without conscious deliberation), interaction patterns are defined less stringently and hence may be consciously selected and executed as well as automatic.

Previous research offers competing views regarding the relationship between team interaction patterns and team adaptive performance. On the one hand, team interaction patterns are considered to facilitate team adaptive performance because the stability inherent in repetitive patterns increases predictability and thereby facilitates interpersonal coordination of behavior (Kanki, Folk, & Irwin, 1991). Moreover, automaticity of behavior reduces the load on working memory and thereby frees up mental resources, which may be used for other activities, such as scanning the environment and developing alternative action plans (Cohen & Bacdayan, 1994; Thorngate, 1976). However, researchers have also pointed at the fact that habituated interaction patterns may be related to rigidity and an inability of teams to discard interaction patterns that have become dysfunctional and to flexibly develop new ones (Cohen & Bacdayan, 1994; Gersick & Hackman, 1990). Particularly, when situations are perceived as threatening, people tend to become rigid and fall back on well learned responses (Staw, Sandelands, & Dutton, 1981). Whereas well learned responses may be functional under relatively stable circumstances, they can become detrimental when the task becomes non-routine and requires divergent interaction patterns than the ones originally developed. For example, Stachowski and colleagues (2009) found that during a crisis situation, higher performing nuclear power plant crews exhibited fewer, shorter, and less complex interaction patterns than less effective crews.

Another view points out that stability and flexibility may not necessarily be opposite concepts, but may be two sides of the same coin (Farjoun, 2010; Feldman & Pentland, 2003). Farjoun (2010) argues that stability and change are not only separate and conflicting but also fundamentally interdependent as well as mutually enabling. More specifically, stable mechanisms such as routines "while still supporting stable outcomes, also promote adaptability, innovation, and exploration" (2010, p.205). This view is consistent with studies on improvisation, which show that extensive knowledge of standardized practices and routines are a crucial prerequisite for improvisation and innovation (Moorman & Miner, 1998; Vera & Crossan, 2005). Also, Feldman and Pentland (2003) propose this two-sided view of routines as containing a source of inertia as well as flexibility. They conceptualize routines as consisting of an ostensive aspect, embodying the abstract and structural aspects that support stability, and a performative aspect referring to the actual execution of the routine which allows for individual agency and variation. In other words, by their repeated enactment of routines, individuals and teams not only retain and reinforce existing routines but also modify them and create new variations. Hence, it is the existence of available routines that allows for the variations that are required to adapt to novel circumstances. Finally, this view is supported by the finding of LePine (2003) that the amount of newly developed routines after a change was positively related to team adaptive performance. Therefore, we propose that the amount, variety, and complexity of team interaction patterns after the structural change will mediate the relationship between mental model updating and team adaptive performance.

H6: The amount, variety, and complexity of team interaction patterns after the structural change mediates the relationship between mental model updating and team adaptive performance

The research model depicted in Figure 1 gives an overview of the hypotheses tested in the study.

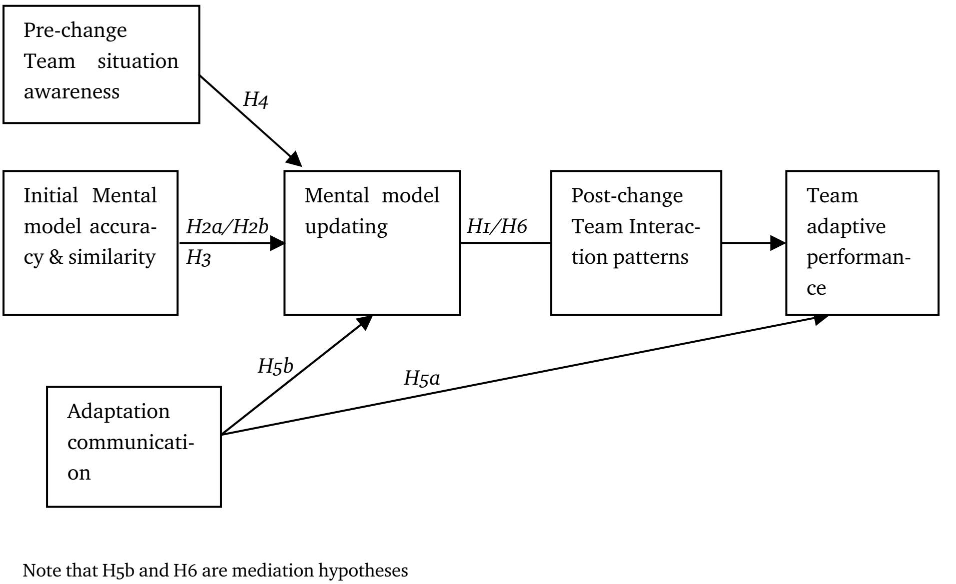

Figure 1. Research model

Methods

Sample

We recruited 138 bachelor students from two samples. The first sample contained 102 students from a large North American business school (NA) and the second sample contained 36 students from a large Western European business school (WE). Students were arrayed randomly into 46 three-person teams. Of the students in the sample, 61 (NA = 45,1 %, WE = 41,7 %) were female. As country of origin 50 (NA = 47.1 %, WE = 5.6 %) indicated a North American country, 35 (NA = 32.4 %, WE = 8.3 %) indicated an Asian country, and 45 (NA = 8.8 %, WE = 89.9 %) a European country. Their average age was 20.9 years (NA= 20.7, WE

= 21.4, SD = 0.9). Although there were differences between the samples in terms of country of origin and there was a small but significant difference in mean age between the samples, independent sample t-tests indicate that students from the two samples did not differ significantly on the main variables tested in this study. All students participated in team simulation sessions that lasted approximately 100 minutes for which they received a small amount of course credit. In addition, in order to motivate goal-directed team functioning, all members of the three highest performing teams received prize certificates worth approximately 10, 25, and 50 USD per team member.

Task

We used a computer-based real-time command-and-control fire fighting simulation called Networked Fire Chief as our research platform. NFC is developed as a psychological research tool to investigate command and control decision making in complex dynamic situations (Omodei, Taranto, & Wearing, 2003). For each team, the simulation runs on three networked computers simultaneously. The teams' task is to minimize the overall damage caused by fire outbreaks occurring at pre-established time points on locations on a map of a village environment. Team members work together from their individual computers and have at their disposal fire trucks and helicopters for extinguishing fires, and bulldozers for clearing grounds (which prevents fires from spreading). Whereas two of the team members are only able to scroll through the map at a detailed level, one of the team members is able to zoom out to an overview map of the complete area. All members have information displayed about the actual and the predicted wind strength and direction (as wind influences the spread of the fire). Team members were seated apart so they could not see each other and could communicate with each other only via a computerized chat function.

Task situation change. Consistent with previous studies on team adaptation, we adopted the task-change paradigm to assess team adaptive performance (Chen, Thomas, & Wallace, 2005; LePine 2003, 2005; Marks et al., 2000). In this paradigm, teams are trained in one context until they possess a basic proficiency in executing the team task. Then some aspect of the task situation changes so that the team must adapt its behaviors to appropriately address the new task context (Lang & Bliese, 2008). We programmed the NFC simulation so that halfway the time period of the team task, important changes would occur in the strength and direction of the wind and in the size and intensity of fires. These changes in the task situation were not immediately apparent to the team members as fires occurred at irregular intervals and team members needed to deduce the effects of the wind on the spreading of the fires. Due to these changes, tactics and interaction patterns that are optimal in the first half of the simulation become suboptimal in the second half of the simulation.

We conducted a pilot test with 12 teams to assess if our a priori derived optimal strategies actually lead to the highest performance. From this pilot test we derived that in the first half of the simulation, the optimal strategy is to have the team member with the overview function scan the environment for newly developed fires and communicate this information while other members use helicopters and fire trucks to extinguish these fires as rapidly as possible. Because extinguishing fires is much faster than bulldozing land, preventing fire from spreading is not an effective strategy in the first half of the simulation. In the second half of the simulation, fire intensity increases significantly and fires become much more difficult to extinguish. Moreover, the wind becomes substantially stronger and blows into the direction of the villages. These circumstances render it more optimal to prevent the fires from spreading instead of immediately trying to extinguish all fires. Teams performed best if they focused their effort on bulldozing land ahead of the wind and extinguishing fires at the frontline, a strategy also used by firefighters in bushfire situations in the field (AIIMS, 2005).

Procedure

Sessions lasted about 100 minutes in total and contained an introduction phase, a practice trial phase, and a simulation phase. In the introduction phase, students filled in a general background questionnaire and were instructed on the use of the simulation by means of a standardized presentation. After the presentation followed a 15 minutes practice trial during which the team members could familiarize themselves with the controls and coordination requirements of the simulation. Following the practice trial, students were given five minutes to communicate via a computerized chat function to develop a strategy; immediately after this communication, subjects' mental models were assessed with a written instrument (explained in more detail below).

After completing this instrument, students were notified that the actual simulation would start. The simulation trial duration was 30 minutes; the non-routine change in task structure began after 15 minutes. During the simulation, at three time points (at 5, 10, and 15 minutes), the simulation was frozen, the screen was blanked, and a situation awareness questionnaire was administered to all three team members. After 20 minutes, team members filled in the second mental model instrument. After the simulation, students filled in a final questionnaire, and then they were debriefed and thanked.

Measures

Team situation awareness. We employed a query measure of situation awareness to assess the extent to which team members were aware of task relevant knowledge at specific points in time (Cooke et al., 2001; Endsley, 1995). We applied a freeze task in which at three time points the simulation was momentarily paused, the screen set to blank, and the team members were asked to answer a number of questions about the situation. Questions related to their awareness of critical elements of the situation: present locations of fire, wind direction, and wind speed. A map of the task environment was used in which the team members could indicate the present wind direction and speed and the presence of fires. Situation awareness accuracy was subsequently measured by comparing the situation descriptions of the team members with objective data registered by the simulator. Because teams differed in the speed at which they extinguished fires, in the TSA measure we included only fires that started immediately before the freeze measurement.

Because different specifications exist concerning how team level situation awareness is shaped and constrained by its individual-level constituents (Chan, 1998; Kozlowski and

Klein, 2000; Uitdewilligen, Waller, & Zijlstra, 2010), we transferred situation awareness accuracy to the team level in two ways: as total accuracy and as coverage. Total accuracy is an additive measure (Chan, 1998) that refers to the total number of correct answers of all the team members. Coverage on the other hand is a compilational measure (Kozlowski & Klein, 2000) that takes into account the fact that TSA may not simply be an aggregate of the situation awareness of the individual members, as team members may distribute their responsibility for aspects of the environment (Ensdley, 1995; Wellens 1993). Therefore, TSA coverage refers to the total of unique accurate answers the team members give. The difference between the two measures is that for calculating total accuracy, all correct answers are added up into the final score, whereas for calculating coverage, correct answers that are given by more than one team member are counted only once.

Team members' mental models. We used association matrices (Edwards, 2006; Mathieu et al., 2000: 2005) to assess two types of team mental models: system mental models and task mental models. System mental models refer to team members' understanding of the development and spreading of fires and task mental models represent team members' associations among the task goals and activities. By means of a detailed task analysis of the simulation and the technical documentation, and with the help of a focus group consisting of people who were experts on the simulation (Mathieu et al., 2000), we derived seven concepts that are most critical for understanding the development of the fires: (a) fire intensity, (b) spreading of fire, (c) landscape flammability, (d) direction of wind, (e) speed of wind, (f) burnt area, and (g) difficulty of extinguishing fires, and seven concepts that were considered most critical for minimizing the impact of the fire: (a) extinguishing fires, (b) bulldozing land, (c) checking world map, (d) team communication, (e) team leadership, (f) locating vehicles, (g) locating fires.

Team members were asked to fill in matrices in which they indicated how strong they considered each of these concepts to be related to all other concepts. Statistics about the distribution off the mental model measures are reported in table 1. Mental model similarity is assessed by the quadratic assignment proportion correlation between the mental models of the different team members. The quadratic assignment proportion is a measure of association among the matrices based on a Pearson's correlation coefficient on the corresponding cells of the data matrices (Mathieu et al., 2005). While the values can in principal range from -1 (completely reversed) to + 1 (completely similar), values in our sample ranged from .01 to .72 for the system mental model and from -.10 to .59 for the task mental model, which indicates that all teams at least had a basic level of similarity. In order to assess initial team mental model accuracy we calculated the average quadratic assignment proportion correlation of each team member's mental model with a referent mental model. In order to derive a referent mental model, we asked six subject matter experts to independently complete the mental model measures. As subject matter experts we used six additional bachelor students whom we extensively trained to perform the team task under normal task circumstances. The use of trained subject matter experts for deriving expert mental models is common in the literature and has been proven to provide reliable referents for assessing mental model accuracy (Acton, Johnson, & Goldsmith, 1994; Edwards et al., 2006). We averaged the mental models of the referent groups to yield referents for the system mental model and the task mental model. Values in our sample ranged from .13 to .64 for the system mental model and from -.05 to .61 for the task mental model.

System mental model change was measured in two ways: as absolute change and as updating. Absolute change was measured as the average of the reverse of the quadratic assignment proportion correlation between team members' mental models before and after the change. In other words, our measure of absolute mental model change reflects the mean dissimilarity between mental models at time 1 and time 2, with values ranging between -1 (completely similar) to + 1(completely dissimilar). Values in our sample ranged from -.92 to .32 for the system mental model and from -.65 to -.03 for the task mental model, indicating that, although team members' did change their mental models over time, very drastic changes were not common. Although, absolute change only reflects whether team members did change their mental models from the period before the change to the period after the change, it does not reflect the direction of this change. Therefore, we also derived measures of mental model updating that reflect whether team members updated their mental models in alignment with the changes in the task situation. Whereas in the first half of the simulation wind speed and direction were relatively unimportant factors, in the second half they became crucial input factors for teams' strategies. Team members needed to take into account the wind in order to efficiently prioritize which fires to extinguish first and to decide where they would apply bulldozers to prevent fires from spreading. For example, it would be strategically more efficient to give high priority to a fire that, due to the wind direction, would spread towards a village, rather than to give high priority to a fire that would spread in the direction of a lake.

In order to derive our measure of mental model updating, we first used UCINET (Borgatti, Everett, & Freeman, 1992) to calculate for each team member the relative centrality of each of the concepts of their mental model. We calculated per team member the average centrality of the wind by averaging their centrality for the concepts of wind speed and direction. Finally, we averaged the centrality scores over the three team members. The resulting measure can be understood as the percentage of the centrality score of the wind relative to the centrality score of the other concepts in the mental models. Values in our sample ranged from 9.31 percent to 15.20 percent for wind centrality before the change and from 10.87 percent to 15.18 percent after the change. Values for bulldozer centrality ranged from 7.07 percent to 12.94 percent before the change and from 5.41 percent to 11.97 percent after the change. In order to assess system mental model updating we will enter into the regression equations the centrality of the wind score after the change while we control for the initial centrality of the wind. By entering the initial centralities before entering the post-change centralities, the post-change values represent the residual or change in centralities from the pre-change to the post-change period (Cohen, Cohen, West, & Aiken, 2003).

We conducted the same steps for the task mental model updating measure, which we assessed as the average change in the centrality of bulldozing in team members' mental models. Whereas, in the first half of the simulation bulldozing land constituted a suboptimal strategy, after the non-routine change, bulldozing land ahead of the fires to prevent it from spreading became an optimal strategy. Because the wind drove the fires rapidly into the direction of the villages, the fastest way to stop it was by creating a barricade with the bulldozers below the wind so it could not spread any further. Therefore we assess an adaptive change in the task MM by the increase in the average centrality of bulldozing.

Table 1. Ranges, means and standard deviations of mental model measures.

	Min.	Max	Mean	SD
System MM similarity t1	.01	.72	.29	.17
Task MM similarity t1	-.10	.59	.21	.16
System MM accuracy t1	.13	.64	.41	.12
Task MM accuracy t1	-.05	.61	.39	.14
System MM abs. change	-.92	.32	-.49	.28
Task MM abs. change	-.65	-.03	-.34	.16
Wind centrality t1	9.31%	15.20%	12.45%	1.30%
Wind centrality t2	10.87%	15.18%	12.91%	1.06%
Bulldozer centrality t1	7.07%	12.94%	10.03%	1.35%
Bulldozer centrality t2	5.41%	11.97%	9.75%	1.37%

Adaptation communication. To measure adaptation communication, we employed direct measures of the team communication data in the five minutes immediately following the change in the task situation (LePine, 2003; Waller et al. 2004). We used an additive index (Pearsall et al., 2010) of two behaviors—task distribution and information sharing—that were found to be related to team adaptive performance in previous studies (LePine, 2003; Waller, 1999). Task distribution was coded in accordance with the method used by Waller (1999) as including all statements in which team members gave commands or assigned tasks to other team members, when they requested help, or when they indicated that they would execute a task themselves. Example statements for this category are “Is someone controlling the east?” and “Pat, if you [bull]doze in front of the houses at 60,30 I will take the fire at 12,48.” Information sharing was coded in accordance with Waller (1999) as all statements in which team members reactively or proactively shared task information with other team members. Task information contained information about the location or characteristics of fires or vehicles as well as about general characteristics of the task situation. Example statements for this category are “Big fire at 60,30,” and “Watch the wind guys.”

Team interaction patterns. In line with (LePine, 2003) we used a measure of role structure adaptation based on recurring patterns of task-related activity. We used indicators of interaction patterns (Stachowski et al., 2009) to capture the structure of the post-change interaction. As an input for pattern recognition we ordered the behavioral data recorded by the NFC simulation in a temporally ordered string of events containing the action that was executed (move, stop, fight, or treat), the vehicle on which the action was executed (helicopter, fire truck, or bulldozer), the person who executed the action (member 1, member 2, or member 3), and the time at which the action was executed. Due to technical problems behavioral data of 7 teams was lost and hence all analyses involving interaction patterns only involve the remaining 39 teams. We used THEME, a pattern recognition software algorithm (Magnusson, 2000; Ballard, Tschan, & Waller, 2008) to identify patterns in the interaction sequences of the team members. THEME software searches for patterns in temporally ordered event data by first searching for simple co-occurrences of events, and then combining these into more complex hierarchically ordered patterns. To be conservative, we set the confidence interval to derive patterns at 0.005, indicating that patterns were only retained if they occurred at a less than 0.5 percent probability level. In order to control for the effect of the total number of actions on the number of patterns that could be identified, we set the minimum number of times a pattern should occur, to the median frequency of all event types (Noldus manual, 2004). We derived indicators for the total number of interaction patterns, the number of unique interaction patterns, the average number of switches between team members, the average number of team members in a pattern, the average length of the patterns, and the average hierarchy level of the patterns.

Team adaptive performance. Team performance is measured as the percentage of the total area that could have been burnt but that was saved by the team. Consistent with other research, team adaptive performance was measured as the team's performance score of the period after the change had taken place (LePine, 2003).

Game experience. We included a control variable for team members' computer/video game experience because researchers have suggested that team member game experience may impact team performance on computer based simulation tasks (Wilson et al., 2009). We measured game experience with the single questionnaire item "Please indicate how often you played computer games on average during the last year (in hours per week)."

Results

Descriptives

A Kolmogorov-Smirnov test revealed that the observed team adaptive performance distribution differed significantly from a normal distribution ($p < 0.01$). An inspection of the distribution of team adaptive performance scores indicates that although the majority of teams had scores between minus 1.778 and minus 4.264 (N = 24, M = -2.813, SD = 0.829), the additional teams manifested highly deviating scores varying from minus 6.050 to minus 47.942 (N = 22, M = -19.903, SD = 12.912). This indicates the existence of bifurcation effect which suggests that under non-routine situations teams bifurcate into high- and low-performing clusters as some teams are able to deal with the change whereas others get caught in a negative downward spiral (Waller, 1999; Waller et al., 2004; Waller, Roe, Gevers, & Raes, 2005). Therefore, in order for the scores to more closely approximate a normal distribution, we applied a reciprocal transformation ($1/ (X_{Highest} - X_i)$), as this reduces the impact of extreme scores. Means, standard deviations and intercorrelations among all the variables included in the hypotheses are included in Table 2.

Table 3 shows the means and standard deviations of the pattern indicators derived with the THEME pattern recognition software. We assessed the dimensionality of the six measures of interaction patterns using principal component analyses on the pattern indicators both before and after the change. From the factor analysis we derived a one factor solution with an eigenvalue of 4.685, explaining 78.1 percent of the total variance. Because all variables have high factor loadings ($> .789$) on the single factor, we aggregated the six measures of interaction patterns into a single underlying dimension of pattern complexity by averaging the z scores of the individual measures. Pattern occurrences in the post-change period are depicted in Table 3.

Table 2. Means, Standard Deviations, and Correlations

		N	Mean	SD	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.
1.	Aver. game experience	46	2.68	2.86																	
2.	System MM similarity t1	46	0.29	0.17	0.02																
3.	System MM accuracy t1	46	0.41	0.12	0.17	0.48***															
4.	System MM abs. change	46	-0.49	0.28	0.08	-0.22	-0.23														
5.	Wind centrality t1	46	0.12	0.01	-0.13	-0.36*	0.14	0.10													
6.	Wind centrality t2	46	0.13	0.01	0.00	-0.21	0.12	0.20	0.49***												
7.	Task MM similarity t1	46	0.21	0.22	-0.03	0.05	0.25†	-0.09	0.19	0.11											
8.	Task MM accuracy t1	46	0.39	0.14	-0.03	0.22	0.05	-0.13	-0.24	-0.17	0.66***										
9.	Task MM abs. change	46	-0.34	0.16	0.01	0.04	0.09	0.04	0.05	0.22	-0.35*	-0.43**									
10.	Bulldozer centrality t1	46	0.10	0.01	0.13	0.06	0.23	-0.12	0.18	0.25	-0.27†	-0.44**	0.42**								
11.	Bulldozer centrality t2	46	0.10	0.01	0.11	0.01	0.28†	-0.18	0.12	-0.19	0.00	-0.28†	0.30*	0.27†							
12.	TSA Sum	46	14.19	3.16	0.17	-0.02	-0.07	0.13	-0.23	0.08	0.05	-0.04	0.03	-0.04	-0.01						
13.	TSA Coverage	46	8.67	1.75	0.10	-0.15	-0.15	0.10	-0.25†	-0.08	-0.08	-0.12	0.03	-0.01	0.31*	0.51***					
14.	Information Exchange	46	9.02	5.10	0.15	0.23	0.10	-0.08	-0.24	-0.01	-0.11	-0.05	-0.06	0.07	0.01	0.19	0.27†				
15.	Task discussion	46	5.39	4.30	0.28†	-0.01	-0.07	-0.06	-0.25†	0.06	0.08	0.24	-0.14	-0.05	-0.13	0.14	0.14	0.54***			
16.	Patterns routine	39	0.00	0.90	0.01	0.30†	0.04	-0.22	-0.21	-0.35*	0.32†	0.43**	-0.38*	-0.35*	-0.05	0.06	-0.02	0.12	0.13		
17.	Patterns non-routine	39	0.00	0.88	0.20	-0.06	0.13	-0.05	-0.24	0.05	0.28†	0.11	-0.08	0.01	-0.09	0.17	0.08	0.13	0.05	0.05	
18.	Adaptive performance	46	70.85	12.20	0.27†	0.09	0.27†	-0.12	-0.02	0.38**	0.11	0.11	0.03	0.24	-0.06	0.22	-0.01	0.30*	0.12	-0.17	0.46**

†p < .10. * p < .05. ** p < .01.

Table 3. Descriptive statistics of interaction pattern analysis

	Mean	SD
Nr. of events	598.67	104.42
Nr. of unique interaction patterns	10.59	9.07
Total nr. of interaction patterns	284.64	249.18
Average pattern length	2.12	0.58
Average pattern hierarchy	1.14	0.43
Average nr. of switches between members	0.30	0.41
Average nr. of team members in pattern	1.22	0.46

Test of Hypotheses

Mental model updating and team adaptive performance

Hypothesis 1 poses that mental model updating after the non-routine change is positively related to team adaptive performance. To test this hypothesis we conducted hierarchical linear regression with absolute change as well as with updating of both mental model measures on teams' adaptive performance scores. In order to assess the effect of updating we first entered the centrality of the wind and the centrality of bulldozing in the pre-change period as control variables. Then, in a second step we entered centrality of the wind and centrality of bulldozing to assess the effect of the changes in these variables on team adaptive performance (Cohen, Cohen, West, & Aiken, 2003). As can be seen from table 4 (step 1), none of the absolute mental model change measures was significantly related to team adaptive performance. Moreover, neither the initial centrality of bulldozing in the task mental model nor the initial centrality of the wind in the system mental model were positively related to team adaptive performance. However, as can be seen from table 4 (step 2), updating of the system mental model was significantly and positively related to team performance—the more teams increased the centrality of wind characteristics in their understanding of the situation, the better they performed in the post-change period. Updating of the task mental model, however, was not significantly related to team adaptive performance. So, these results provide mixed support for hypothesis 1.

Table 4. Regression results for the effect of change in mental models and interaction patterns on adaptive performance

	Step 1	Step 2	Step 3	Step 4
Average game experience	0.25	0.23	0.37*	0.29*
Wind centrality before change	-0.01	-0.25	-0.03	-0.16
Bulldozer centrality before change	0.22	0.16		
System MM absolute change	-0.11	-0.20		
System MM absolute change	-0.06	-0.14		
Wind centrality after change		0.54**	0.62**	0.50
Bulldozer centrality after change		0.01		
Total number of actions			0.11	-0.01
Patterns before change			-0.02	-0.05
Patterns after change				0.34*
Total R^2	0.13	0.33	0.33	0.41
R^2		0.20**		0.09*

†p < .10. * p < .05. ** p < .01.

Antecedents of mental model updating

Hypothesis 2a proposes that initial mental model similarity will be positively related to mental model updating; whereas hypothesis 2b poses that initial mental model similarity will be negatively related to mental model updating. Hypothesis 3 proposes that initial mental model accuracy will be positively related to mental model updating. To test these hypotheses we conducted hierarchical linear regressions with post-change wind centrality as the dependent variable, controlling for pre-change wind centrality. As can be seen from table 5 neither initial mental model accuracy (step 2) nor similarity (step 3) had a significant effect on mental model updating. Thus this provides no support for Hypothesis 2a, Hypothesis 2b, and Hypothesis 3.

Table 5. Antecedents of mental model updating

	Step 1	Step 2	Step 3	Step 4	Step 5
Average game experience	0.06	0.06	0.05	0.02	-0.03
System MM Wind centrality t1	0.64***	0.49***	0.45**	0.48**	0.52***
System MM accuracy t1		0.04	0.10	0.10	0.11
System MM similarity t1			-0.10	-0.10	-0.09
TSA sum				0.23	0.22
TSA coverage				-0.08	-0.09
Task discussion					0.17
Information exchange					0.02
Total R^2	0.25	0.25	0.25	0.29	0.32
R^2		0.00	0.01	0.04	0.03

†p < .10. * p < .05. ** p < .01.

Hypothesis 4 poses that pre-change team situation awareness positively predicts team mental model updating. To test this hypothesis we added TSA sum and TSA coverage to the equation predicting post change wind centrality. As Table 5 (step 4) shows, neither measure of TSA predicts updating, providing no support for Hypothesis 4.

Team adaptation communication, mental model updating, and adaptive performance

Hypothesis 5a predicts that team adaptation communication is positively related to team adaptive performance. As Table 6 indicates, the beta coefficient for task discussion is not significant and the beta coefficient for information exchange in predicting team adaptive performance is marginally significant, lending limited support for Hypothesis 5a.

Hypothesis 5b predicts that the relationship between team adaptation communication and team adaptive performance is mediated by mental model updating. In order for this hypothesis to hold, the following conditions should hold: (1) Adaptation communication should predict team adaptive performance, (2) Adaptation communication should predict mental model updating, (3) Mental model updating should predict team adaptive performance, and (4) the relationship between team adaptation communication and team adaptive performance should decrease if mental model updating is added to the equation (Baron & Kenny, 1986). The first condition receives limited support as information exchange is a marginally significant predictor for team performance. However, as Table 5 (step 5) indicates, neither task discussion nor team information exchange has a significant effect on mental model updating. Hence, the second condition for mediation does not hold and Hypothesis 5b is not supported.

Table 6. Regression results for the relationship between adaptive communication and adaptive performance

	Step 1	Step 2
Average game experience	0.27†	0.26
Task discussion		-0.13
Information exchange		0.34†
Total R^2	0.07	0.16
R^2		0.08

$^{\dagger}p < .10$. * $p < .05$. ** $p < .01$.

Post-change interaction patterns, team mental model updating, and adaptive performance

Hypothesis 6 predicts that teams' post change interaction patterns will mediate the relationship between mental model updating and team adaptive performance. In order for this hypothesis to hold, the following conditions should hold: (1) mental model updating should predict team interaction patterns, (2) Interaction patterns should predict team adaptive performance, (3) mental model updating should predict team adaptive performance, and (4) the relationship between mental model updating and team adaptive performance should decrease if the variable for post-change interaction patterns is added to the equation (Baron & Kenny, 1986).

In order to test the relationship between mental model updating and post-change patterns we regressed pattern interactions after the change on wind centrality after the change, controlling for the total number of actions, interaction patterns before the change, and wind centrality before the change. Table 7 shows that system mental model updating marginally predicts pattern complexity, providing partial support for the first condition. In order to test the effects of post-change interaction patterns on team adaptive performance, we first excluded the non-significant variables from our equation predicting team adaptive performance and we added the total number of actions, and pre-change interaction patterns as control variables. As can be seen from Table 4 (step 4), post-change interaction patterns significantly predict team adaptive performance, thus providing support for the second condition. As we have seen before, mental model updating significantly predicts team adaptive performance, providing evidence for the third condition. Finally, as Table 4 (step 4) shows, the beta-coefficient of mental model updating predicting team adaptive performance decreases after interaction pattern complexity is added to the equation. In addition, a Sobel test indicates a marginally significant mediation effect (t = 1,96, SD = 0.37, p = 0.05). Together these equations provide support for the partial mediation effect of Hypothesis 6.

Table 7. Regression results for the effects of system mental model updating on interaction pattern complexity after the change.

	Step 1	Step 2
Average Game experience	0.23	0.23
Total number of actions	0.27	$0.33^{\dagger}$
Patterns before change	0.01	0.10
Wind centrality before change	-0.17	$-0.31^{\dagger}$
Wind centrality after change		$0.34^{\dagger}$
Total R^2	0.16	0.23
R^2		$0.08^{\dagger}$

$^{\dagger}p < .10$. * $p < .05$. ** $p < .01$.

Discussion

As organizations increasingly employ teams as mechanisms for dealing with environmental change and turbulence, it becomes more crucial to unravel factors that underlie and contribute to team adaptation. Our study focused on developing understanding of the cognitive aspects of team adaptation. More specifically, we investigated the role of team mental model updating, TSA, team adaptation communication, and team interaction patterns in a simulation study involving 46 three-person teams. Our results provide important findings in several areas.

First, whereas the body of literature on team mental models has accumulated over the last 20 years, empirical investigations of many temporal aspects of team mental models, such as flexibility and change, have been lacking. Although some scholars have hinted at the importance of mental model flexibility for team adaptive performance (Marks et al., 2000; Burke et al., 2006), our study is the first to empirically demonstrate that mental model updating is positively related to team adaptive performance. More specifically, our results indicate that it is not a change in mental models per se, but specific change in alignment with the change in the task situation that predicts post-change team functioning.

In our study only updating of the system mental models and not of the team task mental models significantly predicted team adaptive performance. An explanation for this difference could be that whereas teams' system mental models directly reflect the team's task situation, the team's task mental model reflects aspects such as task processes and strategies that are one step further removed from the task situation (Cannon-Bowers et al., 1993). Therefore it could be that, whereas the system mental model has to be changed in line with the changes in the task situation, there may be equifinality in the way in which team members can change their task mental models—it may be that there is not one but several strategies teams can choose to deal with a novel task situation (Mathieu et al., 2005).

Based on the results of the pilot tests we expected that the best strategy for teams after the change would be to rapidly use bulldozers to prevent the fire from spreading, and that the recognition of this optimal strategy would be reflected in the increased centrality of bulldozing in team members' mental models. However, teams may adapt in several ways to unexpected changes, and it is difficult to specify a priori if one form of adaptation is the only or even the optimal way to adapt (see also LePine, 2003). For instance, some high performing teams appeared to be able to maintain high performance even though they did not make much use of the bulldozers in the post-change period. Instead they let the fire burn over a small strip and then extinguished the fire in front of a burnt area. In this way, the burnt area itself served as a barrier that prevented the fire to spread further. An additional analysis of the actual behavior of team members indicates that the number of times team members applied the bulldozers was actually negatively related to team adaptive performance. It appears that the less adaptive teams did use the bulldozers but did not include information about the wind direction and speed in deciding where to apply their bulldozers. Hence, they did make use of their bulldozer more often but they did not select the optimal locations for bulldozing.

Contrary to our expectations, we failed to find evidence for an effect of initial mental model accuracy on mental model updating. Based on existing literature (Burke et al., 2006; Edwards et al., 2006), we argued that initial mental model accuracy would provide teams with a fertile starting ground that would help them to recognize the need for change and adapt their knowledge structures accordingly. Following the 'paradox of success' logic it could be argued that high initial accuracy could actually decrease adaptation because it may lead to initial success and consequently to strategic persistence and cognitive rigidity (Audia et al., 2000; Miller, 1993). If this reasoning would hold in our study, we should expect to see strong negative correlations between initial mental model accuracy and absolute mental model updating. However, whereas we do find a negative correlation between initial mental model accuracy and absolute mental model change for the task mental model, for the system mental model there is no significant correlation between initial mental model accuracy and absolute mental model change. So, teams with initially more accurate mental models do not necessarily cling more rigidly to these mental models. It seems that more in general, under dynamic conditions, initial accuracy in mental models may be less relevant than under more stable conditions (Marks et al., 2000).

In addition, although existing literature suggest a relationship between initial similarity in mental models and team's ability to update their mental models in line with changes in their relevant task situation (Burke et al., 2006; Cannon-Bowers et al., 1993; Marks et al., 2000), we did not find evidence for this relationship. Neither, did we find evidence for the opposing view that similarity in knowledge structures may negatively impact adaptation by reducing the amount of information that teams perceive and process. A possible explanation for these non-significant effects may be that the positive and negative effects of initial mental model similarity may counteract each other. Teams with initially similar mental models may derive the benefits of high quality coordination as well as the drawbacks of conformity and rigidity (Cannon-Bowers, et al., 1993). Together these findings suggest that in dynamic situations, it is not the specific state of team members' mental models before the change but the ability of the team members to update their mental model in response to changes in the task situation that drives adaptive team performance.

Furthermore, we failed to find evidence for an effect of TSA on mental model updating. Neither TSA sum nor TSA coverage were positively related to mental model updating. Our hypothesis regarding the positive effect of TSA on mental model updating was based on the reasoning that the first step in team adaptation relies on a team's ability to sense cues that signal the need for change (Burke et al., 2006; Louis & Sutton, 1991). Only if teams recognize that crucial aspects of their task situation have changed, are they able to incorporate these changes in to their mental models. A possible explanation for the non-significant effect of TSA may be that it is not sufficient for team members to be aware of basic task information, instead team members also need to communicate this information to each other in order to combine distinct information elements and make sense of the information in light of their task goals. In order to test this explanation we conducted an additional regression analyses in which we investigated the moderation effect of information sharing on the effect of TSA coverage on mental model updating. The beta coefficient for the interaction between TSA coverage and team information exchange is positive and marginally significant ($\beta = 0.27$, $p = 0.065$). This suggests that TSA may be a necessary but not a sufficient condition for team members to update their mental models of the task situation. The awareness of simple cues is important, but additional team processes are required to translate these cues into the actual realization that a change is necessary.

Finally, we found a strong and significant relation between post-change team interaction patterns and team adaptive performance. The more, longer, and more complex patterns teams applied in the post-change period, the higher their adaptive performance. Moreover, Team adaptation patterns mediated the relationship between mental model updating and team adaptive performance, indicating that teams that incorporated the change in their task situation into their system mental model, reacted to this change by developing and applying interaction patterns that fitted the novel task situation.

At first sight, this finding seems to be in contradiction with previous research on the benefit of interaction patterns under non-routine circumstances. Stachowski and colleagues (2009) found that during a crisis situation, higher performing nuclear power plant crews exhibited fewer, shorter, and less complex interaction patterns than less effective crews. However, Stachowski and colleagues' (2009) study focused on interaction patterns derived from communication; in the present study, interaction patterns were measured from the micro-behavioral data recorded in the simulation. Hence, this difference in findings may be explained by the level at which routines were assessed in the two studies. Complexity in communication patterns may indicate a lack of automatic processing of information on a more tactical or strategic level—e.g. if communication is extremely standardized, it is likely that team members are sticking closely to well-trained protocols. Complexity in behavioral interaction patterns, on the other hand, occurs at a much lower level—the duration of a single interaction pattern is maximally a few seconds and represents only a fraction of the team performance episode. In many adaptive situations, it is likely that whereas higher level routines have to be adapted to fit the novel situation, many lower level routines will remain functional under the new circumstances. Moreover, teams' ability to rapidly develop novel routines for new task situations may be an important component of team adaptability (LePine, 2005). It is up to future research to further detangle these effects and more precisely pinpoint what types of routines are beneficial and what types are detrimental to team performance under non-routine circumstances.

Limitations

Because we measured mental models only at two time-points, this did not allow us to trace and pinpoint exactly when cognitive restructuring of team members' mental models took place. We chose to implement our post-change mental model measure at five minutes after the change, following previous work that indicates that the speed of team adaptation is crucial for team adaptive performance (Waller, 1999) and our analysis of the simulation that indicated in order to maintain high performance levels, teams should update their understanding of the situation within five minutes after the change. However, given that we only had one post-change measurement of mental models, we could not measure the actual speed of adaptation.

Another limitation of the study is that by using averages for team mental models, our treatment of cognitive change is relatively simplistic. Our methods do not address whether the recognition of cues signaling the need for change and subsequent updating of mental models is initiated by single team member or whether members conjointly engage in these processes. Future research could extend these findings by tracing more accurately which team members signal a need for change and how cognitive changes are communicated and dispersed within teams.

In addition, our measure for mental model updating assumes that when faced with a change in the task structure, team members adapt their knowledge structures to more closely resemble the underlying task situation. Research from the field of learning, however, indicates that when confronted with novel situations, instead of abandoning previously established associations between variables, individuals are more likely to add information in terms of qualifiers to their existing associations (i.e. Bouton, 2002). If we translate this mechanism to the context of mental models, qualifiers would indicate under what circumstances a particular mental model would be appropriate for a situation. Because the mental model measures we used in this study are situation specific—team members were asked to indicate how they understood their present situation—we could not draw any conclusions about whether team members simply adapted the parameters in their mental models or if they included situation qualifiers that indicated under what specific situations those parameters would hold. The goal for our research, however, was not to realistically depict the cognitive structure of team members' mental models, but to investigate whether adaptive change in team members' mental models plays a role in team adaptation. Research with more elaborate mental model measures is required to more accurately depict how such adaptive changes are incorporated in team members' knowledge structures.

Endsley (1995), in her definition of the theory of situation awareness, poses that situation awareness is a hierarchical construct consisting of three levels. The first level refers to an understanding of the basic elements of the environment, the second level to an integration of these elements into an understanding of the situation, and the third level refers to an anticipation of the near future. In the present study, we measured TSA as team members' knowledge about important information from the task situation and hence we only focused on the first level of situation awareness without measuring the higher level interpretations of this information. However, as Weick (1995) indicated, sensemaking is a connection of cues and existing knowledge structures. Hence, additional research would be needed to unravel the effects of higher level situation awareness on team adaptation.

Finally, a limitation is that the task and setting may limit the generalizibility of the results and conclusion that can be drawn from this study. We used a simulated laboratory environment because we aimed to test basic cognitive and behavioral mechanisms underlying team adaptation. However, two specific aspects of this design warrant caution for overgeneralizing the results to field situations. First, because of the relatively short time span of the simulation, teams had only limited time to adapt and had to do so while executing the task. As Zaheer, Albert, and Zaheer indicated "theory that is valid for one time interval may not be valid for another." (1999, p. 725). Because, in field situations with a longer time span team adaptation may occur over a longer time period and teams may have more possibilities to set aside time for adaptation process, the cognitive mechanisms underlying team adaptation may diverge from the short-term adaptation that was the focus of the present study. Second, the participants had no previous experience with the simulation used in the study. Therefore, team members' mental models and interaction patterns were developed during the simulation and there was likely little impact of pre-established mental models and interaction patterns. A benefit of using a novel task is that variety in task skills is limited; however, team adaptation in novel tasks may diverge from team adaptation in situations were team members have strongly established mental models and interaction patterns. Finally, given that the variables in the study were not experimentally manipulated, we are precluded from making definite causal statements about the effects tested in the study. Even though we have provided our reasoning on the direction of effects based on sound theoretical bases, the possibilities of reversed causality and possibly untested confounders can not be completely excluded.

Conclusion

Faced with changing task conditions, team members will need to act quickly and rapidly update their understanding of the situation in order to develop novel tactics and strategies that fit the novel situation (Burke et al., 2006; LePine, 2003). In the present study we investigated the role of a number of cognitive aspects of team adaptation that have hitherto been underexposed in empirical research. In contrast to common approaches in the existing literature we adapted a dynamic approach to the measurement and conceptualization of team mental models and our results suggest that mental model updating is an important precursor to team adaptive performance. Moreover, we found that the complexity of post-change team interaction patterns was positively related to team adaptive performance and mediated the effect of mental model updating.

Chapter 4

Team cognition and team performance trajectories in a complex environment: Combining internal and external alignment

Abstract

Theories on the role of team cognitive structures in team performance seem to lead to different inferences. On the one hand, shared mental model theory focuses on similarity in cognitive knowledge structures among team members, while on the other hand transactive memory theory emphasizes the benefits that can be gained from cognitive diversification. We propose a model of team cognition that integrates these divergent viewpoints by applying the notions of internal and external cognitive alignment. In order to deal with complex adaptive environments, teams require cognitive variety in order to be able to process the complexities of their external environment and they require cognitive integration mechanisms, such as similarity, in order to deal with internal alignment. We present and test a model of the effects of team internal and external cognitive alignment on task performance over time. Our findings indicate that both internal and external cognitive alignment are crucial for team performance trajectories. In addition we investigated the role of team information search trajectories—that is, the extent to which team members actively sought out task information at different moments in time—in the relationship between team cognitive structures and performance trajectories. Although team internal and external alignment predict team information search trajectories and team information search predicts team performance trajectories, no conclusive evidence was found for a mediation effect of team information search. Finally, we found evidence for a moderation effect of team external alignment on the effect of team information search on team performance trajectories.

Introduction

In organizations, no single individual is able to form an adequate understanding of or manage the workload associated with technically complex systems in dynamic environments. Not surprisingly, teams are considered to be the appropriate working arrangements for task performance in such environments (Sundstrom, DeMeuse, & Futrell, 1990). Medical teams require surgeons and anesthetists as well as surgical nurses. Flight crews consist of pilots and co-pilots both having their own responsibilities during the flight. Operations crew members are each responsible for specific subsystems of a chemical plant. Team knowledge embedded in the diverse knowledge structures of the individual members is considered to constitute a key resource for teams working in these complex environments (Grant, 1996; Okhuysen & Eisenhardt, 2002). The division of expertise necessitates the coordination of team members' individual efforts to ensure that the team performs as an integrated entity (e.g. Faraj & Sproull, 2000; Faraj & Xiao, 2006). Because contemporary team tasks are increasingly cognitive in nature, gaining insight into team cognitive structures and cognitive process is crucial for understanding team task execution and predicting and explaining team performance (Hinsz, Tindale, & Vollrath, 1997).

However, in their review of research and theory on teams in organizations, Ilgen, Hollenbeck, Johnson, and Jundt (2005) observed that the two constructs dominating the recent team cognition literature seems to implicate opposing conclusions regarding cognitive integration and differentiation. Whereas shared mental model theory (Cannon-Bowers, Salas, & Converse, 1993; Klimoski & Mohammed, 1994) calls attention to the benefits of similarity in cognitive knowledge structures among team members, transactive memory theory (e.g. Liang, Moreland, & Argote, 1995; Wegner, Guiliano, & Hertel, 1985) emphasizes the differentiation of cognition among the team members. The question remains: How can cognitive diversity and cognitive integration conjunctively drive team performance? In order to answer this question and thereby provide an integrated account of the role of different types of team cognition structures on team performance we develop a model of team internal and external cognitive alignment.

Proponents of cognitive diversity have often drawn on Ashby's (1956) notion of requisite variety and the related concept of cognitive complexity to indicate the need for team cognitive variety (Harrison & Klein, 2007; Walsh, 1995). Thereby they emphasize the alignment of the team's knowledge structure with the external environment—complex environments should be matched with complex knowledge structures in order to ensure that all relevant aspects of the environment are taken into account in team decisions. Shared mental model theorists on the other hand, have drawn on theories of coordination and the notion of shared expectations, thereby emphasizing the internal alignment of team members' actions and cognitions within the team (Cannon-Bowers, Salas, & Converse, 1993; Klimoski & Mohammed, 1994). In this paper, we argue that internal and external alignment are not necessarily opposing concepts and that adaptive teams require both in order to thrive in complex and dynamic environments.

In response to recent calls to investigate how teams develop and change over time (e. Arrow, Poole, Henry, Wheelan, & Moreland, 2004; Kozlowski, Gully, Nason, & Smith, 1999), in this paper we take a dynamic approach to team functioning by looking at the temporal trajectories of team information search processes and team performance. With trajectories we refer to the dynamic development of these variables over the lifetime of the team. Analysis of trajectories provides a nuanced picture of how teams develop on these variables over time and also enables us to establish not only whether team cognitive structural variables impact team processes and performance but also when this impact is most salient.

The paper proceeds as follows. First, we introduce the notion trajectories in team information search and team performance trajectory and provide some reasons why the study of trajectories should be preferred over the study of final outcomes. Then, we introduce the notions of team cognitive similarity and diversity, which we consider as emergent team properties of the team, and show how they materialize in the multi-level constructs of shared mental models and transactive memory systems. We introduce our model of internal and external alignment to clarify the complementary roles of similarity and diversity, and present some hypotheses. We test our research hypotheses in a study with 64 student teams performing in a complex management simulation.

Theoretical background

Team information search trajectories and team performance trajectories

We conceptualize team functioning not merely as an end product or retrospective summary of the result of team actions but as the dynamic trajectory of team information search behavior and team performance indicators over time. A dynamic conceptualization of these constructs recognizes that information search levels and performance outcomes at different time moments are interdependent and manifest particular trajectories over time (Kozlowski et al., 1999; Landis, 2001; Mathieu & Rapp, 2009). These trajectories are influenced and shaped by internal team factors as well as external contextual factors.

In the theoretical and empirical literature on team performance, a number of theoretical notions provide propositions regarding the development of performance trajectories over time. Bifurcation theory proposes that whereas during relatively stable periods, between team variance in performance will be low, during non-routine periods variance in performance between teams will rapidly increase (Waller, Roe, Gevers, & Raes, 2005). Skill acquisition literature indicates that task performance develops in a negatively accelerated fashion, in which after initial rapid growth, increase in performance levels off (Argote, 1993; Kanfer & Ackerman, 1989). Midpoint equilibrium theory poses that teams engage in a major transformation—represented by qualitative change in their activities—roughly around the temporal midpoint of their lifetime (Gersick, 1988). Finally, some scholars have drawn attention to the effect of early team activities on later team performance (Ericksen & Dyer, 2004; Chidambaram & Bostrom, 1996: Mathieu & Rapp, 2009). Mathieu and Rapp (2009), for instance, found that the formulation of high quality team charters and performance strategies, early on, affected the development of team performance over time. However, despite the formulation of the abovementioned theories, literature relating team cognition variables to specific parameters of team performance trajectories seems to be lacking.

Similar to team performance, team information search is likely to occur in varying levels at different moments in time. For instance, lifecycle theories pose that groups engage in different types of processes during specific phases of their lifecycle (e.g. Tuckman & Jensen, 1977). Whereas lifecycle theories have been contested in the teams' literature (e.g. Seeger, 1983; Seers & Woodruff, 1997), alternative temporal models of team development also suggest dynamic patterns of information search behavior over time. For example, Gersick (1988), found that team members engaged in elaborate information collection about outside requirements just after half of the time they had been allotted to complete their task had passed. However, similar to the research on team performance trajectories, there is a dearth of empirical studies that assess the development of information search patterns over time, their antecedents and consequences.

In the present paper we model team performance and team information search as temporal phenomena. A temporal phenomenon is defined by Roe as "an observable event, or series of events, happening to a particular object" (2008, p. 41). A phenomenon is characterized by a demarcated time interval with clear and theoretical meaningful beginning and end points that manifest a pattern of dynamic changes in the attributes comprised by the phenomenon over time (Roe, 2008). This approach allows us not only to investigate whether team cognition structures influence team information search and performance, but also to more precisely pinpoint at what moments in the team performance episode these variables have the strongest effects and how team cognitive structures affect the trajectories of development of the temporal phenomena. So, in the present study we investigate how the dynamic phenomena of team performance and team information search, bounded within the time period of a two week team task, unfold over time, and how they are influenced by team cognitive structures. Given the paucity of theoretical and empirical research on the relationship between team cognition and team performance trajectories, we formulate our hypotheses regarding these trajectories in global terms—e.g. in terms of positive trajectories referring to a general increase in the level of the construct over time. We provide a more thorough explorative discussion of the trajectories in the discussion section of the paper.

Emergence of team cognitive properties: cognitive convergence and divergence

By focusing on cognition as a team level construct, properties emerge that cannot be represented by the mere aggregation of the cognition of the individual members of the team. Team cognition refers to the "knowledge architecture" of a team (DeChurch & Mesmer-Magnus, 2010)—the structural properties that emerge from the relationship among the knowledge of the individual team members. Kozlowski and Klein define a phenomenon as emergent if "it originates in the cognition, affect, behaviors, or other characteristics of individuals, is amplified by their interactions, and manifests as a higher-level, collective phenomenon" (2000: 55). Emergent team level constructs such as overlap and division of knowledge (Klimoski & Mohammed, 1994), and a transactive memory system (TMS) (Wegner, Giuliano, & Hertel, 1985) are essentially team level properties which are epistemologically different from individual level knowledge (Cook & Brown, 1999). Numerous studies have demonstrated that emergent team level cognitive properties are crucial antecedents of team performance (Liang, Moreland, & Argote, 1995; Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000). However, only few studies have investigated how different emergent team cognition properties interact and conjointly impact team performance. Therefore, in the present study we assess different team emergent cognitive properties and analyze their unique and combined impact on team performance.

Kozlowski and Klein (2000) distinguish between two basic types of emergence: composition emergence is characterized by convergence of the lower level constituents and compilation emergence is characterized by divergence of the lower level constituents. Whereas, composition results in shared unit properties that are essentially similar in content and meaning—that is, isomorphic—between the lower and the higher level constructs, compilation emergence results in differentiation in lower level elements and therefore, the higher level construct refers to the pattern or configuration of the individual characteristics. Within the team cognition literature these two polar forms of emergence have been represented by the concepts of shared mental models and TMSs. For example, in their extensive meta-analysis of the cognitive underpinnings of team performance, DeChurch and Mesmer-Magnus (2010) pose that a TMS is consistent with compilation emergence as a team's TMS is composed of the diverse set of knowledge and skills of the individual team members and their awareness of who knows what. They argue further that the shared mental model literature concerns a composition form of emergence as it refers to the extent to which team members' mental models are similar to each other or to an external referent model.

Theorists have provided arguments for the beneficial effects of both team cognitive composition and team compilation constructs. Researchers have associated diversity in underlying knowledge structures with the ability to generate a wide range of perspectives and alternative solutions (Milliken & Martins, 1996; Simons et al., 1999). The integration of these various viewpoints is considered to lead to deep information processing, the emergence of new insights (Jehn, Northcraft, & Neale, 1999; Levine, Resnick, & Teasley, 1993), and the team's ability to reconsider assumptions, thereby coming to more creative and high quality solutions (De Dreu & West, 2001; Nemeth, 1986; van Knippenberg, De Dreu, & Homan, 2004). Moreover, researchers studying TMSs have considered diversity to be an indication of role diversification and cognitive specialization – that is, a team's possession of a wide range of knowledge, skills, and abilities (e.g. Austin, 2003; Moreland, 1999). Cognitive specialization may occur if members have distinct team roles and consequently develop knowledge structures considering their own specific subtasks, thereby ensuring cognitive efficiency and an optimal use of team resources (Banks & Millward, 2000; Hollenbeck et al., 1995; Mohammed & Dumville, 2001).

Conversely, theories of shared mental models (Cannon-Bowers et al., 1993: Klimoski & Mohammed, 1994), and the similar concept of shared schemas (Rentsch & Hall, 1994), emphasize the need for convergence of cognition within teams in order to optimize team functioning. Mental model researchers argue that similarity in team members' knowledge structures helps team members to develop shared expectations, which facilitate the execution of interdependent actions (Cannon-Bowers et al., 1993). Not surprisingly, the ambiguity of the effects of integration and diversification of knowledge has let to a call for clarification of the way in which these seemingly opposing properties affect performance outcomes (Guzzo & Salas, 1995; Moorman & Miner, 1997). In order to shed some light on this issue, we first provide a short overview of the multi-level emergent concepts of team mental models and TMSs from which we conclude that the concepts should not be seen as diametrically opposed as sometimes is indicated. Next, we introduce our model of internal and external alignment and we place these concepts within this model and reason how they relate to each other and conjunctively drive team performance. In addition, we discuss the notion of team information search as an important mediator in the relationship between team cognitive structures and team performance.

Team Mental Models

Mental models (MMs) are defined by Rouse and Morris (1986) as knowledge structures that enable humans to describe, explain, and predict a system with which they interact. For example, a machine operator may posses a MM that depicts the cause and effect relations of the internal functioning of a machine. To the extent that this MM properly mirrors the actual functioning of the machine, the operator will be able to deduce what the parameters on the machine display signify about the system's state and he or she will be able to infer the consequences of alternative actions. As such, MM based reasoning is a form of top-down information processing, meaning that cumulated knowledge from past experiences is used to make sense of information environments and to guide action (Walsh, 1995).

Previous research has consistently indicated a link between the similarity of team members' MMs and team task performance in a number of different domains, including both field studies (Lim & Klein, 2006; Rentsch and Klimoski, 2001; Smith-Jentsch, Mathieu, & Kraiger, 2005; Webber, Chen, Payne, Marsh, & Zaccaro, 2000) and simulations (Cooke, Kiekel, & Helm, 2001; Ellis, 2006; Marks, Zaccaro, & Mathieu, 2000; Mathieu, Heffner, Goodwin, Cannon-Bowers, & Salas, 2005; Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000). Shared MMs impact team performance through their effect on team interaction processes (Klimoski & Mohammed, 1994), specifically coordination, communication, and collaboration (Marks et al., 2000; Mathieu et al., 2005; Mathieu et al., 2000). Coordination processes refer to those behaviors that are aimed at attuning the resources and activities of individual team members towards the concerted goal directed behavior of the team as a unity (Cannon-Bowers, Tannenbaum, Salas, & Volpe, 1995). Shared MMs are considered to facilitate implicit coordination by providing mutual expectations from which accurate, timely predictions can be drawn about the behavior and information requirements of other group members (Cannon-Bowers et al., 1993; Rico, Sánchez-Manzanares, Gil, & Gibson, 2008; Wittenbaum, Vaughan, & Stasser, 1998). Moreover, team members with similar MMs may communicate information that is required by others at the time it is required, and in a way that is understood by the recipient (Fussel & Krauss, 1987; Krauss & Fussell, 1991). Finally, the presence of shared MMs within a team may decrease the amount of time required for clarifying and agreeing upon strategies and decrease the occurrence of friction due to cognitive divergence and misunderstanding (Bettenhausen & Murningham, 1985; Swaab, Postmes, van Beest, & Spears, 2007).

Although the majority of empirical studies on shared MMs focus on similarity among team members' knowledge structures, scholars have recognized the benefits of having divergent but compatible MMs (Cannon-Bowers & Salas, 1993; Klimoski & Mohammed, 1994). Cannon-Bowers and colleagues (1993) suggest that it is not the overlap in MMs but the common expectations that team members derive from these models that drives team performance and Cannon-Bowers and Salas conclude that "in any given team, some knowledge will have to be shared, other knowledge similar, and yet other knowledge distributed or complementary" (2001, p. 1999).

Empirical evidence suggests that sometimes dissimilarity in MMs relate positively to team performance. Levesque, Wilson, and Wholey (2001) found, contrary to their predictions, that in software development teams, MMs became less instead of more similar over time. Their results indicated that as team members became increasingly specialized, the amount of interaction decreased which subsequently led to less similar MMs. They did not, however, relate diversity in MMs to team outcomes. In a study on university work teams, Kellermans, Floyd, Pearson, and Spencer, (2000) found that norms for constructive conflicts moderated the relationship between MM similarity and decision quality; whereas teams with weak norms for constructive conflict benefitted from similar MMs, teams with strong norms for constructive conflict actually benefitted more from dissimilar MMs. Banks and Millwards, (2007) found that whereas similarity in team members' declarative knowledge was positively related to team performance, similarity in procedural knowledge negatively predicted team performance. Cooke and colleagues (2003) found that high performing teams showed high accuracy of knowledge structures regarding their own roles and lower similarity in taskwork knowledge. The above examples indicate that specialization of team members' task knowledge with their individual role may be reflected in dissimilar task MMs.

Diversification due to specialization in team members' MMs is an important element of the distributed cognition perspective of team MMs (Banks & Millward, 2000; Hutchins, 1995). The theory of distributed cognition indicates that it is not so much overlap in knowledge that is required, but the team as a whole must be able to jointly understand and operate on the complexity of the whole system (Hutchins, 1995). For example, Banks and Millward (2000) propose and test a model of distributed MMs in which team members holds specific aspects of the overall system model and team decisions arise from 'running' this shared MM. So, although similarity in MMs is important for team functioning, particularly in complex environments, it may at least be as important that the team members' MMs jointly cover the relevant task environment. Because transactive memory theory focuses on this distributed aspect of team cognition we now turn to a discussion of TMSs.

Transactive Memory Systems

Transactive memory theory was originally developed by Wegner and colleagues to explain how people in intimate relationships develop efficient implicit systems for remembering and retrieving information (Wegner, 1985, 1987). The general idea behind transactive memory theory is that groups can optimize their knowledge base when each member develops expertise in a specific area and in addition they develop an awareness of who holds what knowledge. Building on Wegner's early work, researchers have expanded the scope of transactive memory theory to the group level (Liang, Moreland, & Argote, 1995) and have broadened its content to also include the division and knowledge of team members' skills or expertise (Moreland & Myaskovski, 2000), and external relationships (Austin, 2003). A TMS is considered a compilation form of emergence as it propels towards divergence in the knowledge and skills of the individual group members (DeChurch & Mesmer-Magnus, 2010). When a team develops an efficient division for storing and retrieving task information, each member develops expertise in a specific area and consequently team members' knowledge becomes more and more diversified (Hollingshead, 2001).

However, researchers have distinguished different components of a TMS and apart from compilational components they have also identified compositional forms of emergence that are indispensable for the functioning of a TMS (e.g. Austin, 2003; Brandon & Hollingshead, 2004; Faraj & Sproull, 2000; Wegner, 1991; Lewis, 2003). For example, Austin defines transactive memory consensus as "the extent to which group members agree about who has what knowledge" (2003, p. 867) and Brandon and Hollingshead (2004) identify transactive memory sharedness—the degree to which members have a shared understanding of the division of expertise within the group— as one of the three core dimensions of a TMS. So, transactive memory consensus or sharedness, are closely related to the notion of team MM similarity—a shared understanding of teammates, knowledge, skills, abilities, preferences, and tendencies (Cannon-Bowers et al., 1993).

In addition, compositional forms of emergence may play an important role in the interaction processes related to a TMS. Scholars have emphasized the importance of the process components of a TMS system, consisting of the dynamic interaction processes involved in encoding, storing and retrieving information among the group members (Hollingshead, 2001; Lewis, 2003). More specifically, several scholars have considered coordination as a manifestation of a high quality TMS (Lewis, 2003; Liang et al, 1995; Moreland & Myaskovsky, 2000). Therefore, given that research on shared MMs indicates that the effectiveness of team interaction processes is facilitated by the convergence of structural knowledge, about the team and the task (Mathieu et al., 2005; Mathieu et al., 2000) it is not surprising that Ellis (2006) found that similarity and accuracy of team interaction models were positively related to the functioning of a team's TMS.

So, a TMS is a complex multi-dimensional construct containing both compilational aspects and compositional aspects. Researchers seem to agree that although TMS theory emphasizes the benefits of cognitive diversification, the compositional components have a pivotal role in tying together these diversified components into collective team level functioning (Austin, 2003; Lewis, 2003).

Differences in Focus between Shared MM and TMS Research

A look at the divergent settings in which empirical research on shared MMs and TMSs has been conducted may shed some light on the gap between both perspectives. Research on TMSs in groups has mainly focused on knowledge intensive production tasks and knowledge worker teams (e.g. Austin, 2003; Lewis, 2003; Liang et al., 1995), while research on shared MMs has primarily been conducted on teams executing action tasks (e.g. Cooke, et al., 2001; Marks et al., 2000; Mathieu et al., 2000). Whereas in the former the use and integration of knowledge may be more central to task performance, in the latter the coordination among team members' actions may play a crucial role. This focus on different task types may explain why MM similarity and TMSs have occasionally been regarded as opposing constructs (Ilgen et al., 2005). However, although at first sight, theories on cognitive similarity and theories on cognitive variety seem to lead to incompatible propositions, the abovementioned reviews show that this is not the cvase. SMM theory does not focus exclusively on similarity, nor does TMS theory focus exclusively on diversity. Also, researchers from both fields seem to acknowledge that often both similarity and diversity are required to function effectively in complex task environments. In order to bring together these viewpoints into one overlapping framework, in the next section, we introduce the notions of external and internal alignment and we derive hypotheses of how aspects of shared MMs and TMSs conjointly impact team performance.

HYPOTHESES

In this section we construct our research model of external and internal alignment. The complete research model is depicted in figure 1 and the corresponding hypotheses are derived below.

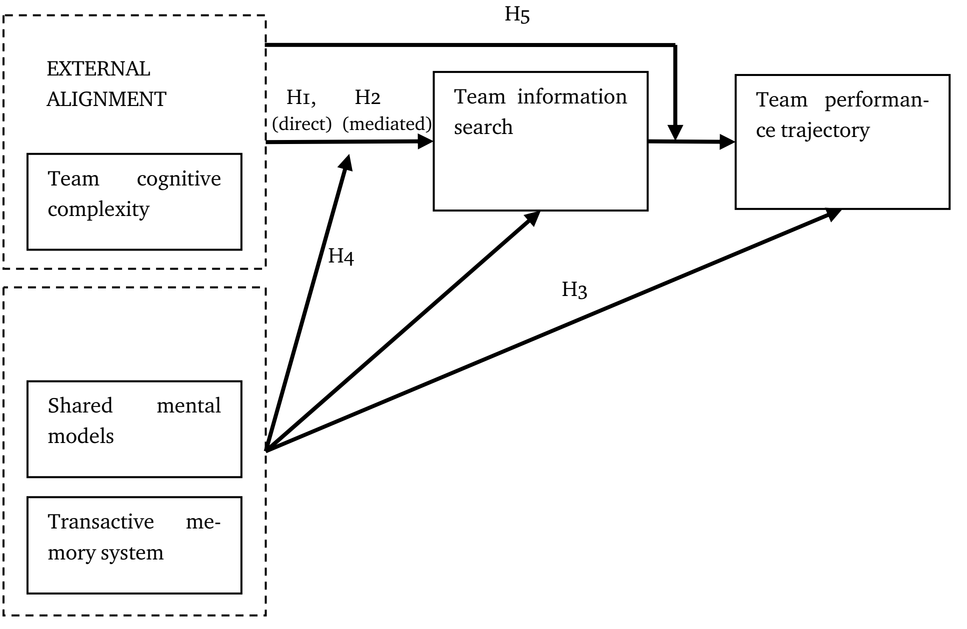

Figure 1. Research model of the effects of external and internal alignment on team performance trajectories in complex environments

External alignment

We define external alignment as the extent to which team members' knowledge structures represent all relevant aspects of the task environment. So, external alignment refers to the notion that for teams functioning in complex and dynamic environments it is important that their knowledge structures are sufficiently aligned with the complexities and challenges of that external environment. This notion is closely related to the concept of requisite variety, which states that in order for an entity to be able to control a complex system, the entity as a whole must contain a commensurable amount of complexity as the system itself (Conant & Ashby, 1970). Accordingly, scholars mainly in the field of strategic decision making have emphasized the importance of complexity in cognitive knowledge structures for making decisions in multifaceted and ambiguous environments (e.g. Bartunek, Gordon, & Weathersby, 1983; Calori, Johnson & Sarnin, 1994; Ginsberg, 1990; Prahalad, & Bettis, 1986; Weick, 1979). Likewise, others have warned against the dangers of holding overty simplistic knowledge structures, specifically under conditions of extreme and unexpected environmental change (Kiesler & Sproull, 1982; Miller, 1993; Turner, 1976).

The complexity of a system is determined by both the number of elements in the system and the extent to which these elements interact with each other (Ashby, 1956; Simon, 1996). In parallel, scholars have portrayed cognitive complexity[4] as a function of the number of concepts an individual or group uses to describe a system and the number and nature of relationships that are distinguished among these concepts (Bartunek et al., 1983; Ginsberg, 1990; Schroder, Driver, & Streufert, 1967). Because MMs are essentially interpretations and simplifications of an external system (Fiske & Taylor, 1984), they may compromise the ability to make decisions in complex environments (Walsh, 1995; Weick, 1979). Starbuck and Milliken (1988) posited that knowledge structures function as a lens, which filters the information that is received from the environment and determine how this information is interpreted. Thus, the complexity of an individual's or team's knowledge structures is positively related to the ability to notice anomalous information and form alternative interpretations.

Consistent with the notion of cognitive complexity, many authors have considered teams to be the optimal arrangement for complex tasks, as the variety of knowledge present within a team may most closely approach the complexity required for many contemporary organizational tasks (Cooke et al., 2003). So, the complexity of a system or problem is matched with the cognitive complexity of the team arrangement. For instance, the regulation of deviations of the human body—a system of tremendous complexity—requires the joint effort of a number of medical specialists (e.g., anesthesiologists, surgeons) in order to compile the variety of expertise needed for diagnose and operation. Moreover, various studies have shown a positive relationship between people's expertise in a field and the complexity of their cognitive maps (Lurigio & Carroll, 1985; Rentsch, Heffner, & Duffy, 1996). Hence, diversification of cognition, achieved by means of a division of expertise, constitutes an effective mode for attaining the required level of complexity. Therefore we hypothesize the following:

H1: In a complex environment, teams' external alignment is positively related to their performance trajectories, such that teams with more complex MMs will improve their performance faster than teams with less complex MMs.

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[4] Other researchers (e.g. Kelly, 1955) have considered complexity as a personality trait; however we here restrict the use of the complexity concept to refer to the complexity of individual's or team's cognitive structures of specific systems, without explicitly positing a relationship between the complexity of these structures and personality characteristics.

Team information search

A team's external cognitive alignment is particularly important for the processing of information from its environment. In complex and dynamic environments, the extent to which teams take into account all aspects of their environments is crucial for task performance (Burke et al., 2006; Hollenbeck, Ilgen, Sego, Hedlund, Major, & Philips, 1995; Waller, 1999). Teams must collect information in order to recognize the need for change in their task strategies and to make informed decisions on team actions. For instance, the literature on team situation assessment indicates that particularly in highly dynamic task situations, continuous scanning of the relevant task environment is crucial for team performance and viability (Artman, 2000; Mosier & Chidester, 1991).

Previous literature suggests that there is a crucial linkage between team cognitive structures and team information search processes. The information processing view of teams implies that the compilation of team members' knowledge structures significantly influences the information that is attended to by the team and how this information is processed (Hinsz et al., 1997). More specifically, because knowledge structures focus attention onto specific aspects of the situation and determine how this information becomes interpreted, more complex and elaborate team level knowledge structures are likely to result in a wider coverage of the relevant environment, which in turn will lead to higher performance (Mogford, 1997; Starbuck & Milliken, 1988). Therefore, we propose that:

> *H2: In a complex environment, the relationship between teams' external alignment and team performance trajectories is mediated by the teams' information search behavior.*

Internal alignment

Whereas, external alignment relates to a teams' requisite variety with its external environment, we define internal cognitive alignment as the extent to which team members' knowledge structures are aligned with each other in such a way that they enable efficient knowledge sharing and integration. Several authors have emphasized the role of team processes in the integration of the knowledge of the individual members (Cooke, Salas, Cannon-Bowers, & Stout, 2000; Faraj & Xiao, 2006; Grant, 1996; Okhuysen & Eisendhart, 2002; Simons et al., 1999). However, whereas team members without much experience working together may depend mainly on processes for integrating knowledge, over time, as team members gain experience in cooperatively working together, these knowledge integration processes may crystallize into cognitive integration mechanisms. Both research on SMMs and research on TMSs indicate that, through repeated interaction, teams develop cognitive integration structures and mechanisms linking together the variety of knowledge and skills held by the various members of the team, thereby facilitating team level information processing (Gurtner et al., 2007; Hollingshead, 2001; Lewis, 2004; Lewis et al., 2005; Rulke & Rau, 2000). We propose in order for teams to thrive in complex environment, they require both internal and external alignment.

Although some evidence indeed indicates that complex environments are associated with the formation of complex knowledge structures (Calori, Johnson, & Sarnin, 1994; Hodgkinson & Johnson, 1994; Stabell, 1978), the functional link between team cognitive complexity and performance has not been unanimously supported. In a management simulation study Walsh and colleagues (1988) found that low coverage – and hence low complexity – of the information environment was positively related to team performance. Kilduff (2000) found a positive relationship between cognitive diversity early in the team's lifecycle and final team performance; however if cognitive diversity sustained during the lifecycle of the team, this had a negative effect on performance. McNamara, Luce, and Thompson (2002) found that top management teams did not require a maximal level of complexity; instead a manageable amount of complexity was positively associated with firms' financial performance. A review of research on the relationships between the environment, complexity, and performance led Walsh to conclude that "(t)he most surprising aspect of the findings to date in this broad area of inquiry is the lack of support for many of the research hypothesis derived from Ashby's (1956) logic" (1995: 302). In addition, the research stream on diversity in teams indicates that the relationship between team cognitive diversity and team performance is not at all straightforward (Milliken & Martins, 1996; van Knippenberg & Schippers, 2007). Thus, an important issue in team cognition research is to find out the conditions under which team cognitive complexity can be beneficial for team performance. Therefore, we propose that the existence of internal cognitive alignment may constitute an important prerequisite for a team to benefit from its external cognitive alignment.

Although cognitive diversification may constitute a necessary condition for the attainment of the cognitive complexity required to function in a diverse and dynamic environment, it is not a sufficient condition. The more cognitive diversity there is present within the team, the more coordination is required for combining together the pieces of distributed cognition and guaranteeing effective interactions (Faraj & Xiao, 2006; Nonaka & Takeuchi, 1995; Weick, 1979). Although the aggregate of the knowledge structures of the individual members may give insight into the team's potential coverage of the information domain, it does not suffice to assess its realized coverage – the extent to which this potential in knowledge structures is actually used in the decision making process (Walsh et al., 1988).

According to proponents of the view of distributed cognition, the team and not the individual should be taken as the unit of analysis when investigating team cognition (Banks & Millward, 2000; Hutchins, 1995). Taking the team as the level of analysis draws attention to how the information processing of the constituent parts—the team members—link together to constitute team level information processing (Hinsz et al., 1997). Similarly, Schroder and colleagues (1967) argued that the integrative complexity of a system is not only composed of the diversity in the parts of the system but is also made up of their interconnectedness. Hence, the extent to which the cognitive architecture of the team as an entity can be considered complex not only depends on the complexity of and the variety in individual member's knowledge structures but also on the extent to which the knowledge structures of the members are interconnected.

A plenitude of research has indicated that there is a substantial gap between the availability of diverse knowledge within a group and the group making functional use of that knowledge (Simons et al., 1999; Stasser & Titus, 1992). A wide variety of studies indicates that information sharing, although pivotal to team performance, only takes place under stringent conditions (Brodbeck et al., 2007; Mesmer-Magnus & Dechurch, 2009; Stasser, 1988). An explanation for this is that diverse knowledge structures may lead to 'representational gaps' (Cronin & Weingart, 2007) or 'interpretive barriers' (Dougherty, 1992) which impede team level knowledge integration. Moreover, the lack of mutual understanding may lead to frustration and disruptive conflict (Cronin & Weingart, 2007; van Knippenberg & Schippers, 2007). Therefore, teams require cognitive structures that facilitate internal alignment in order to solve inherent issues of teams' cognitive diversity. Therefore, we propose that apart from direct effects of these team internal alignment constructs, they also interact with team cognitive complexity in predicting team performance trajectories.

> *H3: In a complex environment, teams' internal alignment will be positively related to teams' performance trajectories.*

> *H4: In a complex environment, the relationship between external alignment and performance trajectories will be moderated by internal alignment structures, such that teams with complex MMs will improve their performance faster in case they also have similar MMs and a well functioning TMS.*

Interaction effects of team information search and team MM complexity

Apart from a direct effect of team cognitive complexity on team information search, we also expect team cognitive complexity to affect the extent to which team information search actually translates into improved performance. Given that knowledge structures function as a lens that filter what information is accessed and how this information becomes processed (Starbuck & Milliken, 1988), one would expect that if team members have more complex knowledge structures, they are likely to take into account and accurately process more task relevant information than teams with less complex structures. For example, Burke and colleagues (2006) noted that whereas the recognition of cues signaling a need for change is the first step towards successful team adaptation, once a cue pattern is perceived, a series of cognitive processes based on existing MMs takes place that turn these cues into an understanding of the situation. Also, the theory of absorptive capacity (Cohen & Levinthal, 1990) indicates that teams must have an adequate amount of related prior knowledge in order to be able to process and capitalize upon new information. Therefore, we propose that:

> *H5: In a complex environment, the relationship between team information search and performance trajectories will be moderated by team MM complexity, such that high levels of team information search will have positive effects on performance trajectories for teams that have more complex MMs.*

Methods

Temporal research design

Our research hypotheses require a temporal design in which we look at the development trajectories of team information search and team performance over time. In order to test these hypotheses we collected team performance and team information search measures at multiple points in time. In order to fully capture the longitudinal nature of this data we applied random coefficient modeling (RCM) (Bliese and Ployhart, 2002). RCM is a data analysis technique consisting of two stages. In the first stage—the level-1 analysis—we assessed the form of the change trajectories of these variables over time. In the second stage—the level-2 analysis—we tested whether our team cognition variables accounted for significant differences among teams in the form of these trajectories. In order to illustrate our findings we display figures with fitted curves we derived by computing the information search and performance trajectories for high and low values on the cognitive alignment variables.

Sample

Participants included 371 students enrolled in the bachelor of international business at a Dutch university. Students were randomly assigned into 64 teams ranging from five to seven members. Of the students 207 (55.8%) were German, 77 (20.8%) were Dutch, and 87 (23,5%) had other nationalities. Their mean age was 20.35 years (SD = 1.35) and 174 (46.9%) of the students were female. Team size ranged from five to seven members with 25 (39.1%) teams consisting of five members, 28 (43.8%) teams consisting of 6 members, and 11 (17.2%) teams consisting of 7 members. The simulation, which will be explained below, constitutes an obligatory part of the first year curriculum and students received extra credits for filling in the measures and questionnaires used in this study. Data were collected in two consecutive years and due to the nature of the team level MM measures we included in the analyses only teams of which all members handed in the MM measures, leaving us with 64 out of the total of 126 teams. Complete teams did not differ significantly from incomplete teams in terms of the dependent variable team performance ($t = -.808$, $p = .422$).

The simulation

The Global Business Game (GBG; Wolfe) is a web-based simulation in which team members have to work together as the management team of a globally competitive company in the video equipment industry. The simulation is an obligatory requirement for the students and is part of a two week course at the end of the first year international business bachelor. Thirty five percent of their individual grades for the course is determined by their team's performance ranking in the simulation.

The interactive simulation captures the essential elements a globally competitive firm faces, and the main strategies and operating methods available to such a firm. All teams start with the same household video and equipment company with limited assets and specialized competencies. They have to set out a strategy for their company regarding production, marketing, logistics, and internationalization by making decisions on a large number of variables concerning the operation of their factories (e.g. wage rates, number of plants, number of line supervisors, quality control, production planning), logistics (e.g. shipping methods, factory locations), marketing and sales (e.g. number of sales officers, prices, advertising budget), and finances (e.g. dividend, stock issues, capital sales). Decisions—regarding the quarterly strategy of the company—have to be taken on a daily basis and the outcomes of teams' decision are published the next day.

Procedure

Before the start of the course, team members were randomly assigned to their team. During the two week period, there were six class-based meetings in which team members did get feedback on their strategies and got the opportunity to ask questions about the simulation to experienced tutors. First, students were instructed to read the GBG manual to develop an understanding of the simulation. After this they received an on-line multiple-choice test with twelve questions testing their understanding of the simulation. This test was a prerequisite for the simulation, so students that failed this assessment had to study and redo the test until they obtained satisfactorily performance. Then, team members could practice the operation of the simulation during a two day practice period. The simulation lasted for nine days and included seven decision periods. At the third plenary session of the first week, team members were required to individually complete the MM exercise and TMS questionnaire.

Measures

Mental model complexity. During the plenary session, one of the researchers gave a short presentation, explaining how to complete the MM exercise, then team members were provided with a list of 72 concepts, categorized into the three main areas of marketing and sales, manufacturing, and finances, and one sheet only containing a rectangle with the word 'profit' printed in the middle. Participants were requested to construct a mental map on this sheet, representing their understanding of the simulation. They did this by selecting from the concept sheet those concepts they used in their understanding of the simulation, and drawing lines between concepts they considered to be related to other concepts in their maps. They were told that their concept maps would be rated, and if they would be graded as sufficient and they would have filled in the additional questionnaire, they would receive half a point extra on their final grade.

This method resembles a causal mapping or concept mapping technique as used in a number of previous studies (Eden, Jones, & Sims, 1983; Thordsen, 1991). Mohammed and Klimoski (2000) make a distinction between elicitation, referring to the technique used to determine the content component of the MMs, and representation, referring to the technique for determining the structure of the MMs. MM assessment techniques differ in the extent to which elicitation and representation can be freely determined by the participant—versus being pre-specified by the researcher. With the present method, the structure is not pre-specified in that, apart from the location of profit in the middle, students were free to locate concepts at any place they considered most suitable for their own understanding. However, the concepts were partly fixed, in that participants could only choose from 72 pre-specified concepts from the concept sheet. Students were instructed that they were free to pick and use as many of these concepts as they deemed necessary for depicting their understanding of the simulation. Unlike the often used measurement method of similarity ratings (Mathieu et al., 2000; DeChurch & Mesmer-Magnus, 2010), the number of concepts and links participants can use in their model is not completely fixed in the present measurement approach. This allows us to assess MM complexity and similarity as separate constructs. At the beginning of the academic year students received a mind mapping exercise in which they were trained to schematically depict their learning material in a visual mind map representation, so all students were familiar with the basic idea behind mind mapping and had some previous experience with this.

We derived the concepts on the concept sheet from a thorough scanning of the student manual of the GBG. We selected all concepts on which relevant decisions could be taken in the simulation (e.g. advertising budget, vacation days, dividends, ten year bonds), and all concepts that represent important inputs for those decisions (e.g. product quality, worker absenteeism, lost sales, overdraft, bond rate, market share). The list derived in this way was revised and assessed for completeness and consistency by a subject matter expert—the course coordinator, with six years of experience in teaching the simulation.

For the analyses of the MMs we entered each individual concept map into a matrix in which each link between two concepts is represented by a 1 on the intersection of the two concepts in the matrix. Based on the work of Nadkarni and Narayanan (2005) we derived three indicators of MM complexity. The first indicator, comprehensiveness, refers to the total number of concepts in the map. Since, based upon our review of the simulation manual, we limited the maximum number of concepts that could be used to 72, this aspect captures the extensiveness of the MM, or the extent to which the participant made use of the offered concepts. The second indicator, density-1, is defined by the number of links between concepts divided by the number of concepts used in the map. This aspect captures the ratio of the number of linkages used to the number of concepts in the map and reflects the density or connectedness of the concepts within the map. The third concept proposed by Nadkarni and Nayaranan (2005), density-2, is defined by the number of links in the map relative to all possible links. However, since for the present study, the number of all possible links was equal for all participants, this measure reflects the total number of links in the map.

Because the study by Nadkarni and Narayanan (2005) indicated that the three measures of complexity are likely to load strongly on one underlying factor we conducted an exploratory factor analysis with varimax rotation. The results indicated that a common factor consisting of the three aspects of complexity explains 78.46 % of the total variance with factor loadings of .88 for comprehensiveness, .79 for density-1, and .98 for density-2. Therefore, we averaged the three aspects of MM complexity into one combined score.

Mental model similarity. We calculated MM similarity as the total amount of overlapping linkages used within the team, controlled for team size. We constructed a team level matrix in which each square specified the number of team members that had indicated that particular link on their concept sheet. We calculated MM similarity as the sum of all linkages held by all team members minus the sum of linkages held by only one team member multiplied by one divided by the number of team members (MM similarity = (SumTotal – SumUnique)*1/N, where N = Number of team members, SumUnique = Sum of linkages that are by held only one team member, SumTotal = Sum of all linkages held by all team members).

Information Search. Information search was assessed with two measures that were directly derived from the logged data of the GBG simulation. For each time period, the simulation stores information on how often each of the 38 different information pages of the simulation have been visited by the members of a team. The information pages cover a wide variety of information that can be important for team decision making; for example, the firms' balance sheet, production schedule, sales promotions, and subcontracting agreements. For each team, we assessed the total number of pages visited (search depth) and the number of unique pages (search breadth) visited per time period. An exploratory factor analysis on the averages of these two constructs over the seven time periods indicates that a common factor explains 80.63 % of the total variance with factor loadings of .90 for both search depth and search breadth. Therefore, we averaged the two measures into one combined score for information search.

Transactive memory system. The teams' TMS was measured with the TMS scale developed by Lewis (2003). The scale consists of 15 items that assess three dimensions of a TMS, with five items for each dimension: knowledge specialization (i.e. the tendency of group members to focus on different aspects of the task), task coordination (i.e. the ability of the team members to work together efficiently), and credibility (i.e. members' beliefs about the reliability of other members' knowledge). Each item was scored on a 5-point Likert-type scale ranging from 1 (strongly disagree) to 5 (strongly agree). Cronbach's alpha for the scale was .66. A mean Rwg(j) of .93, based on a slightly (positively) skewed distribution, provided evidence of intermember agreement (James, Demaree, & Wolf, 1984), and an ICC(1) of .22 and ICC(2) of .62 provided support for acceptable intermember reliability (Bliese, 2000). Therefore, we aggregated the individual responses to a single team score (e.g., Lewis, 2003, Pearsall, Ellis, & Bell, 2010).

Team performance. In accordance with reasoning of Mathieu and Rapp (2009) on the use of performance indexes in management simulations, we operationalized team performance as a weighted index of five team performance indexes: after-tax profits in the home country currency (40%), rate of return on assets (20%), earnings per share (20%), rate of return on owner's equity (20%), and stock price (20%). Scores on the team performance indexes were reported after each decision period and provided the input for team members' final course grade.

Team size. Because team size may influence team performance as well as the functioning of a team's TMS and team MMs (Wheelan, 2009) we included team size as control variable in our analyses.

Results

Correlations. Table 1 displays correlations and descriptive variables among all study variables. Notably, MM complexity and MM similarity show a high correlation (.80). This is not completely surprising given that MM similarity was measured as the amount of overlap in linkages among team members. Because teams with more complex MMs use more linkages on average they can also be expected to have more overlapping linkages. However, given the theoretical distinction between MM similarity and MM complexity we decided to proceed with both variables included in our analyses.

An inspection of the development of correlations over time indicates that MM complexity and MM similarity show increasing correlations with performance and information search over time. The correlation between TMS and performance first seems to decrease from time 1 till time 3 before it increases from time point 4 until it levels off at time 7 and the correlation between TMS and performance is at a maximum around time 3–5. Information search and performance show increasing correlation values that become significant from time point 5 onwards. Clearly, the patterns of results exhibit a strong temporal element with the strength of correlations depending on the time point within the simulation trajectory.

Table 1. Means, Standard Deviations, and Correlations

		M	SD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1.	MM Complexity	0.00	0.88																
2.	TMS	3.52	0.22	-.16															
3.	MM Similarity	19.51	11.32	.80***	-.19														
	Information Search																		
4.	Time 1	0.52	0.65	-.06	-.01	-.07													
5.	Time 2	0.31	0.77	-.14	.14	-.11	.60***												
6.	Time 3	0.37	0.76	-.10	.40**	-.08	.27**	.53***											
7.	Time 4	0.24	0.87	.04	.20	-.08	.37**	.52***	.60***										
8.	Time 5	-0.11	0.80	.10	.26*	.02	.34**	.42**	.66***	.74***									
9.	Time 6	-0.45	0.79	.14	.13	.05	.33**	.37**	.57***	.64***	.62***								
10.	Time 7	-0.88	0.73	.22†	.15	.16	.29*	.33**	.52***	.62***	.60***	.63***							
	Performance																		
11.	Time 1	-0.62	0.27	-.01	.25*	-.01	-.01	-.14	.12	.12	.07	.14	.08						
12.	Time 2	-0.60	0.34	.03	.14	.07	.16	.05	.11	.10	.12	-.04	-.09	.52***					
13.	Time 3	-0.51	0.41	.15	.05	.21†	.22†	.17	.13	.09	.09	.00	.01	.15	.46***				
14.	Time 4	-0.16	0.59	.30*	.15	.11	.24†	.13	.10	.09	.15	.15	.16	.18	.37**	.50***			
15.	Time 5	0.28	0.88	.21	.33**	.03	.34*	.29*	.27*	.32*	.38**	.27*	.26*	.16	.34**	.24†	.62***		
16.	Time 6	0.59	0.94	.36**	.33**	.15	.27*	.31*	.27*	.34**	.34**	.35**	.28*	.18	.41**	.32*	.68***	.85***	
17.	Time 7	1.02	1.17	.41***	.20	.20*	.27*	.34**	.32**	.40**	.37**	.44***	.38**	.16	.34**	.27*	.44***	.67***	.83***

Note. †$p < .10$. * $p < .05$. ** $p < .01$, ***$p < .001$.

Random coefficient modeling framework. For our RCM analyses we followed the recommendations of Bliese and Ployhart's (2002) and Singer and Willett (2003). RCM has the advantage that it can assess and account for nonindependence of observations measured over time and can incorporate time varying, as well as time stable predictors. For a recent example of RCM analysis on team performance in a management simulation see Mathieu and Rapp (2009).

To build our longitudinal model of team performance and team information search, we followed the guidelines by Bliese and Ployhart (2002). We started with a simple regression model without any random effects as a baseline and proceeded with consecutively more complex models, at each step adding random effects. According to the recommendation by Bliese and Ployhart (2002), at each step in which we added additional random effects, we used chi-square difference tests based on the models' loglikelihood ratios to compare the change in fit between the more parsimonious and the more complex model. Consistent with the recommendations of Bliese and Ployhart (2002) we applied a two step procedure. In the first step—level-1—we established the fixed function for time and in the second step—level-2— we added our predictor variables in order to test our hypothesized relationships. All models were estimated with the open source software R (R Development Core Team, 2004) and the random effects models were estimated with the use of the NLME library written by Pinheiro and Bates (2000).

We used orthogonal polynomials to index the linear, quadratic, and cubic growth curve parameters. Orthogonal polynomials decompose a trend into different uncorrelated estimates of its temporal components (Ployhart, Holtz, & Bliese, 2002; Mathieu & Rapp, 2008). With orthogonal parameters, the intercept represents the value of the construct at the midpoint of the team performance episode, the slope parameter represent the linear growth rate of the construct, the quadratic parameter represents the quadratic form—u-shape—of the trajectory, and the cubic parameter represents the cubic form characterized by two inflection points—a flat lying reversed s-shape.

Within and between-team variance in performance and information search. As a first step, we examined the ICC(1) for the time varying criteria variables team performance and team information search. The ICC(1) indicates how much of the variability in the criteria variables is attributable to within versus between team differences over the seven performance episodes (Bliese, 2000). Our analysis reveals an ICC(1) of .17 for team performance indicating that between team variance explained 17% of the total variance in performance over time and within team variance explained 83% of the variance over time. The ICC(1) for team information search was .18 indicating that between team variance explains 18% of the total variance in team information search over time and within team variance explains 82% of the variance. These values indicate that considerable between team, as well as within team differences exist in team performance and team information search (Bliese, 2000).

Level 1 analysis

The next step in our longitudinal analysis is determining the fixed functions for time— the sample level (average) development trajectory of team performance and team information search over time. In this step we started with the baseline model and consecutively added a random intercept, slope, and quadratic and cubic polynomials. Additionally we tested for autocorrelation and heteroscedasticity in the model error structures.

Fixed functions of performance and information search. Results for the fixed function for team performance, shown in Table 2, show that both the linear (12.22, $p < 0.001$) and quadratic parameter (2.87, $p < 0.001$) are positive and differ significantly from zero, whereas, the cubic parameter (-1.13, $p > 0.05$) is negative and fails to reach significance. Hence, the final quadratic model indicates positive and u-shaped growth in performance. Results for the fixed function for information search breadth, shown in Table 3, show that both the linear and quadratic parameters are negative and differ significantly from zero (-9.35, $p < 0.001$; -3.08, $p < 0.001$, respectively), whereas, the cubic parameter fails to reach significance (-0.47, $p > 0.05$). Hence, the final quadratic model indicates a declining, and inversed u-shaped trajectory of team information search.

Table 2. Results of Fixed Functions for Time Predicting Team Performance

Variable	Model 1:Linear		Model 2: Quadratic		Model 3: Cubic	
Intercept	-0.87***	(0.06)	0.00	(0.03)	0.00	(0.03)
Linear	0.29***	(0.02)	12.22***	(0.73)	12.22***	(0.73)
Quadratic			2.87***	(0.73)	2.87***	(0.73)
Cubic					-1.13	(0.73)
Goodness of fit						
Akaike's information criterion	1019.25		997.33		995.72	
Bayesian information criterion	1031.55		1013.72		1016.20	
Deviance (-2 log-likelihood)	-506.62		-494.67		-492.86	

Note. †p < .10. * p < .05. ** p < .01, ***p < .001.

Table 3. Results of Fixed Functions for Time Predicting Information Search

Variable	Model 1:Linear		Model 2: Quadratic		Model 3: Cubic	
Intercept	0.66***	(0.07)	0.00	(0.04)	0.00	(0.04)
Linear	-0.22***	(0.02)	-9.35***	(0.77)	-9.35***	(0.77)
Quadratic			-3.08***	(0.77)	-3.08***	(0.77)
Cubic					-0.47	(0.77)
Goodness of fit						
Akaike's information criterion	1066.188		1043.601		1043.915	
Bayesian information criterion	1078.489		1059.994		1064.394	
Deviance (-2 log-likelihood)	-530.094		-517.801		-516.958	

Note. †p < .10. * p < .05. ** p < .01, ***p < .001.

Determining variability in growth parameters. The fixed models, reported above, assume no variability in the growth parameters across teams. In this random part, we loosen this assumption by consecutively allowing for random variability in the intercept, slope, quadratic, and cubic parameters. The results of these analyses are reported in table 4 and table 5.

First, for team performance the model with a random intercept significantly improved the quadratic base model ($\chi^2_{diff(1)}$ = 117.01, p < 0.001). Second, the model with a random slope significantly improved the model with only a random intercept ($\chi^2_{diff(2)}$ = 211.45, p < 0.001). Third, the quadratic model significantly improved the model with only a random slope ($\chi^2_{diff(4)}$ =91.09, p< 0.001). Fourth, we tested whether a model with a random cubic parameter would improve upon the model with a random quadratic parameter. In this random model the cubic parameter became significant (and -1.13, p < 0.05) and the model significantly improved the quadratic model ($\chi^2_{diff(5)}$ =47.8, p < 0.001). It is interesting to note here that in the random slope model, the intercept parameter is negatively related to the slope parameter and in the final cubic model the intercept parameter is negatively related to the cubic parameter.

For team information search, the model with a random intercept significantly improved the quadratic base model ($\chi^2_{diff(1)}$ = 180.87, p < 0.001). Second, the model with a random slope significantly improved the model with only a random intercept ($\chi^2_{diff(2)}$ = 16.32, p < 0.001). Third, the model with a random quadratic parameter significantly improved the model with a random slope ($\chi^2_{diff(4)}$ =18.37, p < 0.001). Fourth, we tested whether a model with a random cubic parameter would improve upon the model with a random quadratic parameter. However, the cubic parameter was not significant and the model with the cubic parameter showed decreased fit ($\chi^2_{diff(5)}$ =2.82).

Table 4. Results of determining variability in the growth parameters of team performance over time

	Model 4: Intercept		Model 5: Slope		Model 6: Quadratic		Model 7: Cubic	
Intercept	0.00	(0.06)	0.00	(0.06)	0.00	(0.06)	0.00	(0.06)
Linear	12.22***	(0.57)	12.22***	(1.04)	12.22***	(1.05)	12.22***	(1.05)
Quadratic	2.87***	(0.57)	2.87***	(0.41)	2.87***	(0.55)	2.87***	(0.56)
Cubic							-1.13*	(0.47)
Variance components								
Intercept	0.21		0.02		0.24		0.25	
Linear			0.03		61.85		63.93	
Quadratic					11.07		13.46	
Cubic							7.78	
Residual	0.32		0.17		0.13		0.10	
Goodness of fit								
Akaike's information criterion	882.32		674.88		642.98		605.17	
Bayesian information criterion	902.81		703.56		683.96		666.60	
Deviance (-2 log-likelihood)	-436.16		-330.44		-311.49		-287.58	

Note. †p < .10. * p < .05. ** p < .01, ***p < .001.

Table 5. Results of determining variability in the growth parameters of information search over time

	Model 4: Intercept		Model 5: slope		Model 6: Quadratic	
Intercept	0.00	(0.07)	0.00	(0.07)	0.00	(0.07)
Linear	-9.35***	(0.54)	-9.35***	(0.70)	-9.35***	(0.70)
Quadratic	-3.08***	(0.54)	-3.08***	(0.50)	-3.08***	(0.60)
Variance components						
Intercept	0.30		0.29		0.31	
Linear			0.01		17.20	
Quadratic					8.65	
Residual	0.29		0.25		0.23	
Goodness of fit						
Akaike's information criterion	864.74		852.42		840.05	
Bayesian information criterion	885.23		881.11		881.03	
Deviance (-2 log-likelihood)	-427.37		-419.21		-410.03	

Note. †p < .10. * p < .05. ** p < .01, ***p < .001.

Determining the error structure. Finally, we tested for autocorrelation and heteroscedasticity in the models' error structures. For team performance, our analyses revealed no evidence of first order autoregressive autocorrelation for the cubic model (0.082, χ^2_{diff} = 0.77, p = 0.38) and a model including test for heteroscedasticity failed to converge. For information search, our analyses revealed no evidence of first order autoregressive autocorrelation for the quadratic model and the model including test for heteroscedasticity failed to converge.

Level 2 Analyses: predictors of team performance trajectories.

In the first part of the RCM analyses we examined the relationship of team performance and information search with time. In this second part of the RCM analyses we add our predictor variables—MM complexity, MM similarity, and TMS— to predict variance in the trajectory parameters. All level-2 models include a control variable for team size. In addition, in order to assess for longitudinal mediation (Ployhart & Pitariu, 2010) we assessed if (1) MM complexity, MM similarity, and TMS predict team performance, (2) MM complexity, MM similarity, and TMS predict information search, (3) information search predicts team performance, and (4) the relationship between MM complexity, MM similarity, and TMS decreases if information search is added to the equation. In building our models, we first test models predicting only the intercept—holding the slope, quadratic, and cubic factors to be fixed. In this way we test the effect of our independent variables on the dependent variables without accounting for time. Then we test a model predicting all variable components of the level-1 model—the temporal trajectories of the dependent variables.

Test of Hypotheses

Inspection of table 6, reveals that in a model in which the relationship between team cognition variables and performance is fixed over time (Model 8), MM complexity (0.33, $p < 0.01$) and TMS (0.18, $p < 0.01$) significantly predict team performance. This indicates that teams scoring high on these variables—on average over time—perform higher than teams scoring low on these variables. However, this model does not take into account that the team cognition variables may impact team performance differently at different moments in time. Therefore, we ran model 9 with random trajectory parameters that allow the relationships to vary over time. As hypothesis 1 suggests, MM complexity, significantly and positively predicts the intercept (0.32, $p < 0.05$) and the slope (6.14, $p < 0.001$), and negatively predicts the cubic parameter (-2.19, $p < 0.01$) of the performance trajectory.

Figure 2 depicts fitted curves of the development trajectories of team performance over time for teams with low MM complexity (one SD below the average) and teams with high mental model complexity (one SD above the average). As the figure shows, performance for teams with high mental model complexity, first slightly goes down, but from time period one onwards it increases more rapidly than for teams with less complex MMs. Furthermore, whereas for teams with lower MM complexity performance growth increases towards the final round, growth in team performance of the teams with high MM complexity levels of towards the end.

Following the recommendation of Singer and Willett (2003), we derived Pseudo-R^2 statistics for the variance components associated with each temporal parameter by calculating the relative decrease in the residual variance associated with that parameter from the base model—including only the control variable—to the present model. The Pseudo-R^2 statistics of model 9 indicate that relative to the base model, the model including MM complexity, MM similarity, and TMS explains 23 % of the intercept variance, 27 % of the slope variance, 1 % of the quadratic variance, and 34 % of the cubic variance. Altogether, these results provide support for hypothesis 1 on the effects of team external alignment on team performance trajectories.

Table 6. Results of models predicting the temporal trajectory of team performance

Variable	Model 8: Intercept		Model 9: Trajectory		Model 10: Info. Search	
Intercept	-0.07	(0.47)	0.07	(0.27)	0.13	(0.27)
Linear	12.22***	(0.56)	12.22***	(0.91)	13.30***	(1.02)
Quadratic	2.87***	(0.56)	2.87***	(0.55)	3.85***	(0.71)
Cubic	-1.13*	(0.56)	-1.13*	(0.42)	-0.65	(0.51)
Size	0.01	(0.08)	-0.01	(0.05)	-0.01	(0.05)
MM Complexity	0.33**	(0.11)	0.32**	(0.11)	0.30**	(0.11)
TMS	0.18**	(0.06)	0.18**	(0.06)	0.17**	(0.06)
MM Similarity	-0.10	(0.10)	-0.09	(0.10)	-0.09	(0.10)
Linear x MM Complexity			6.14***	(1.75)	5.77***	(1.67)
Quadratic x MM Complexity			0.19	(1.06)	0.01	(1.05)
Cubic x MM Complexity			-2.19**	(0.81)	-2.20**	(0.83)
Linear x TMS			2.46**	(0.94)	2.20*	(0.89)
Quadratic x TMS			0.40	(0.57)	0.27	(0.57)
Cubic x TMS			-1.09*	(0.43)	-1.04*	(0.45)
Linear x MM Similarity			-2.04	(1.55)	-1.95	(1.47)
Quadratic x MM Similarity			0.93	(0.94)	0.91	(0.93)
Cubic x MM Similarity			2.32**	(0.72)	2.25**	(0.73)
Information Search					0.06	(0.04)
Linear x Info. Search					2.01**	(0.76)
Quadratic x Info. Search					0.79	(0.64)
Cubic x Info Search					-0.06	(0.48)
Pseudo R^2						
Intercept	0.35		0.23			
Slope parameter			0.27			
Quadratic parameter			0.01			
Cubic Parameter			0.34			

Note. † $p < .10$. * $p < .05$. ** $p < .01$, *** $p < .001$.

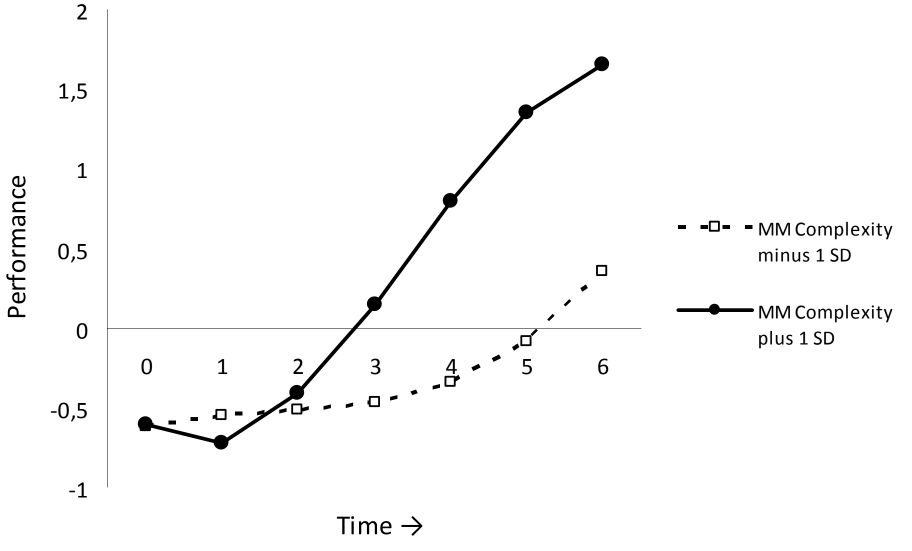

Figure 2. Team performance over time for teams with low and teams with high mental model complexity

Hypothesis 2 predicts that the relationship between MM complexity will be mediated by team information search. In order for this hypothesis to hold, the following conditions should hold: (1) MM complexity should predict the team performance trajectory, (2) MM complexity should predict the information search trajectory, (3) information search should predict the team performance trajectory, and (4) the relationship between MM complexity and team performance should decrease if information search is added to the equation (Baron & Kenny, 1986). The first condition is true, as we reported above that MM complexity positively predicted team performance trajectories.

Regarding the second condition, Table 7 shows that in a model in which the relationship between the variables is fixed over time (Model 7), MM complexity does not significantly predict team information search. However, as can be seen in Model 8, when the trajectory parameters are allowed to vary, MM complexity positively predicts the slope of information search over time (2.65, $p < 0.05$). As can be seen from the fitted curves displayed in figure 3, although information search decreases over time for all teams, it decreases less for teams with high MM complexity than for teams with low MM complexity. The Pseudo-R^2 statistics of model 8 indicate that relative to the base model, the model including MM complexity, MM similarity, and TMS explains 0 % of the intercept variance, 14 % of the slope variance, and 17 % of the quadratic variance.

Regarding the third condition, model 10 of table 6 shows that team information search positively predicts the slope of team performance over and above the team cognition variables (2.01, $p < 0.01$). Because in this model information search is a time-varying predictor, this changes the meaning of the individual growth parameters, and therefore interpretation of R^2 values based on the variance components would be meaningless (Singer & Willett, 2003). Finally, given that the inclusion of team information search to the model only marginally decreases the beta's of MM Complexity in predicting team performance (Intercept: from 0.32 to 0.30, Slope: from 6.14, to 5.77) and given that the respective beta's remain significant, this does not provide conclusive support that information search actually functions as a mediator in the relationship between MM complexity and team performance. So, although MM complexity does predict the team information search trajectory and team information search does predict the team performance trajectory, the expected mediation in hypothesis 2 is not supported.

Table 7. Results of models using MM complexity, TMS, and MM similarity in predicting Information search

Variable	Model 7: Intercept		Model 8: Trajectory	
Intercept	0.01	(0.61)	0.38	(0.56)
Linear	-9.35***	(0.54)	-8.47***	(2.09)
Quadratic	-3.08***	(0.54)	-4.55*	(1.80)
Size	0.00	(0.10)	-0.05	(0.10)
MM Complexity	0.11	(0.15)	0.09	(0.15)
TMS	0.14†	(0.08)	0.14†	(0.08)
MM Similarity	-0.07	(0.13)	0.00	(0.01)
Linear x MM Complexity			2.65*	(1.29)
Quadratic x MM Complexity			-0.59	(1.11)
Linear x TMS			0.65	(0.69)
Quadratic x TMS			-1.41*	(0.60)
Linear x MM Similarity			-0.05	(0.10)
Quadratic x MM Similarity			0.08	(0.09)
Pseudo R^2:				
Intercept	0.05		0.00	
Linear parameter			0.14	
Quadratic parameter			0.17	

Note. †p < .10. * p < .05. ** p < .01, ***p < .001.

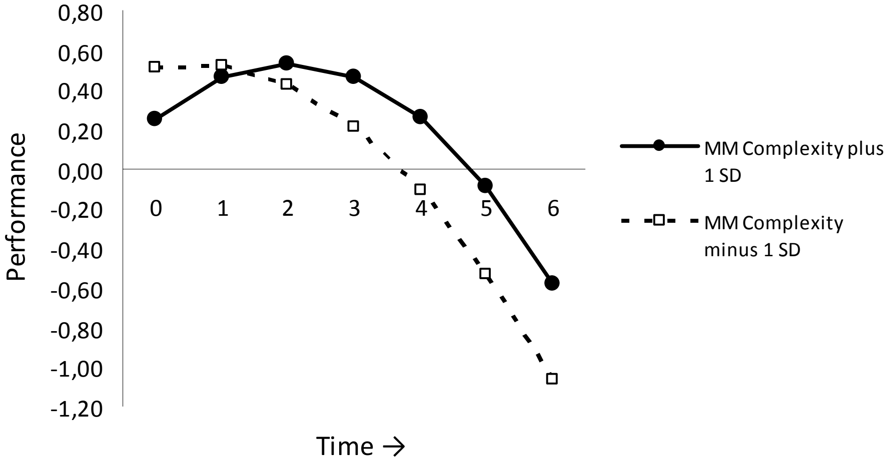

Figure 3. Information search over time for teams with low and teams with high mental model complexity

Hypothesis 3 predicts that a team's MM similarity and TMS positively impact team performance over time. As can be seen from model 9 of table 6, a team's MM similarity significantly and positively predicts the cubic parameter (2.32, $p < 0.01$) of the team performance trajectory. As depicted in figure 4, this implies that teams with low MM similarity have a performance trajectory with two inflection points, slightly decreasing initial performance, that picks up after time point one and levels of towards the end, whereas teams with high MM similarity teams seem to benefit particularly during the beginning and towards the end of the team task. As can be seen from model 9 of table 6, a team's TMS significantly and positively predicts the intercept (0.18, $p < 0.01$) and the slope (2.46, $p < 0.05$), and negatively predicts the cubic parameter (-1.09, $p < 0.05$) of the performance trajectory. Figure 5 depicts fitted curves of the development trajectories of team performance over time for teams with low TMS (one SD below the average) and teams with high TMS (one SD above the average). As the figure shows, performance for teams with high TMS, first slightly goes down, but from time period one onwards it increases more rapidly than for teams with low TMS. Furthermore, whereas for teams with lower TMS performance growth increases towards the final round, growth in team performance of the teams with high TMS levels of towards the end. Altogether, these results provide support for hypothesis 3 on the effects of internal cognitive alignment on team performance trajectories.

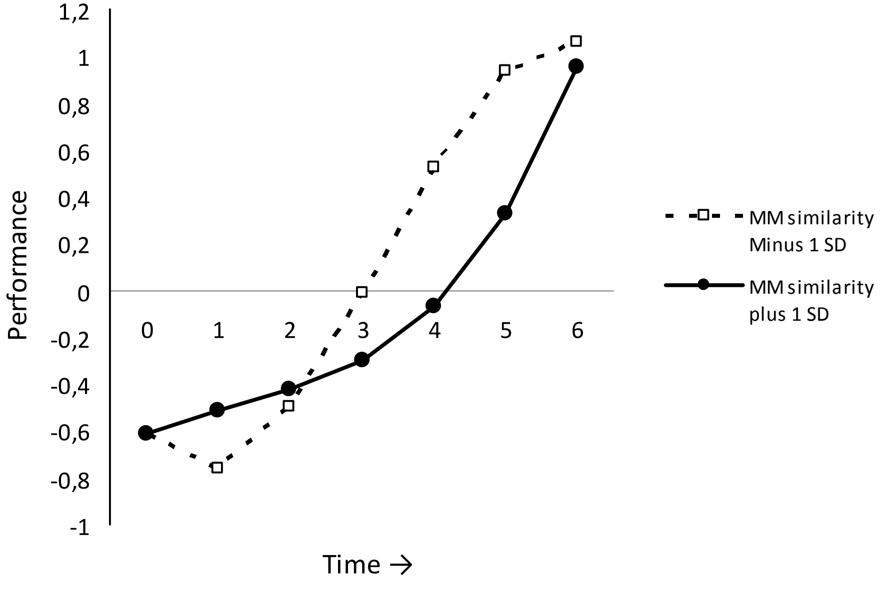

Figure 4. Team performance over time for teams with low and teams with high mental model similarity

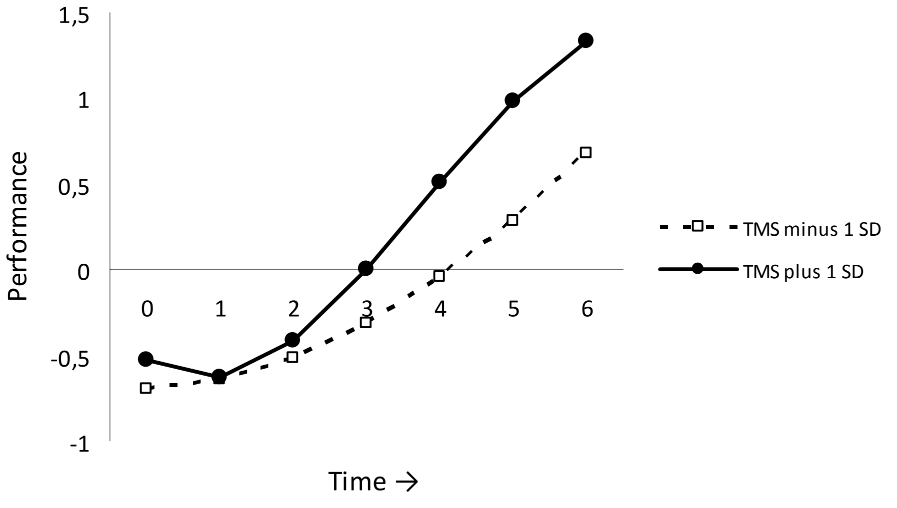

Figure 5. Team performance over time for teams with low and teams with high transactive memory systems

Hypothesis 4 predicts that in complex environments, a team's external alignment and internal alignment will interact in predicting team performance trajectories, such that teams will benefit more from MM complexity to the extent that they have well functioning TMSs and high MM similarity. Model 11 from table 8 shows that the interaction between MM complexity and MM similarity does positively predict the cubic parameter of the team performance trajectory (0.88, $p < 0.001$). In addition, model 12 from table 8 shows that the interaction between MM complexity and TMSs does negatively predict the cubic parameter of the team performance trajectory (-1.11, $p < 0.01$). As depicted in figure 6, this implies that for teams with both high MM complexity and high TMS, after an initial lag in performance growth, these teams show a rapid increase in performance, which levels of again towards the final rounds, whereas for teams scoring lower on one of these variables, performance continues to increase at a similar pace. However, given that the overall pace of performance growth was lower for teams that scored lower on one of these variables the net result of the joint effect of MM complexity and TMS on performance remains positive. Altogether, these results provide limited support for hypothesis 4 on the interactive effects of teams' external and internal cognitive alignment on team performance trajectories. Significance of the cubic parameters indicates that the interaction between internal and external alignment teams explains differences in the specific form of the performance trajectories; however, given that the intercept and linear and quadratic parameters were not significant, this does not imply that the interaction leads to higher performance growth overall.

Table 8. Results of models using interactions of MM complexity with MM similarity and TMS in predicting performance

Variable	Model: 11 Interaction		Model: 12 Interaction	
Intercept	0.09	(0.28)	0.04	(0.26)
Linear	12.79***	(1.02)	12.29***	(0.93)
Quadratic	2.55***	(0.59)	2.77***	(0.55)
Cubic	-1.74***	(0.43)	-1.29**	(0.42)
MM Complexity	0.34**	(0.12)	0.27**	(0.08)
MM Similarity	-0.08	(0.11)	0.18**	(0.06)
Size	-0.01	(0.05)	-0.01	(0.04)
Linear x MM Complexity	6.62***	(1.85)	4.79***	(1.28)
Quadratic x MM Complexity	-0.12	(1.06)	0.33	(0.76)
Cubic x MM Complexity	-2.73***	(0.78)	-1.17*	(0.58)
Linear x MM Similarity	-1.71	(1.67)		
Quadratic x MM Similarity	0.45	(0.96)		
Cubic x MM Similarity	1.71*	(0.70)		
MM Complexity x MM Similarity	-0.05	(0.04)		
Linear x MM Complexity x MM Similarity	-0.82	(0.56)		
Quadratic x MM Complexity x MM Similarity	0.46	(0.32)		
Cubic x MM Complexity x MM Similarity	0.88***	(0.23)		
Linear x TMS			2.47*	(0.95)
Quadratic x TMS			0.50	(0.56)
Cubic x TMS			-0.98*	(0.44)
MM Complexity x TMS			0.04	(0.04)
Linear x MM Complexity x TMS			0.49	(0.73)
Quadratic x MM Complexity x TMS			-0.72†	(0.43)
Cubic x MM Complexity x TMS			-1.11**	(0.33)
Pseudo R^2:				
Intercept	0.01		0.00	
Linear parameter	0.02		-0.01	
Quadratic parameter	0.03		0.05	
Cubic Parameter	0.36		0.26	

Note. †p < .10. * p < .05. ** p < .01, ***p < .001.

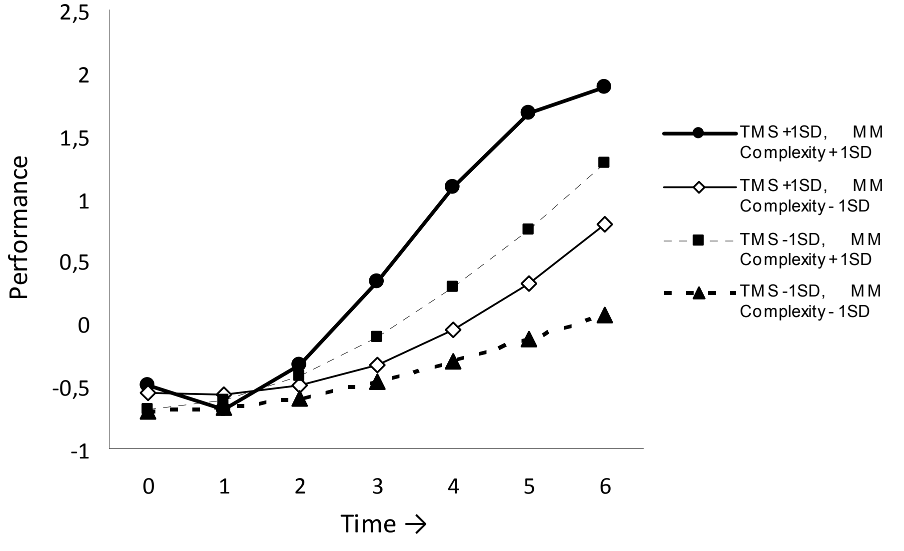

Figure 6. Interaction effects of transactive memory system and mental model complexity

Hypothesis 5 predicts that in complex environments, team information search and MM complexity will interact, such that teams will benefit more from information search to the extent that they have higher MM complexity. As can be seen from model 13 on table 9, the interaction between team information search and MM complexity significantly and positively predicts the intercept (0.20, $p < 0.001$) and the slope (2.52, $p < 0.05$), and marginally and negatively predicts the cubic parameter (-1.46, $p < 0.10$) of the performance trajectory. As can be seen from figure 7 this implies that after an initial lag, performance of teams with both high information search and high MM complexity increases much more rapidly than performance of teams that score lower on performance on one of these variables. Altogether, these results provide support for hypothesis 5.

Table 9. Results of model using interaction of team information search and mental model complexity in predicting performance

Variable	Model 13: Interaction	
Intercept	0.10	(0.26)
Linear	13.18***	(1.05)
Quadratic	3.97***	(0.69)
Cubic	-0.56	(0.53)
MM Complexity	0.24*	(0.07)
Information Search	0.08*	(0.04)
Size	-0.01	(0.04)
Linear x MM Complexity	5.51***	(1.26)
Quadratic x MM Complexity	1.44†	(0.84)
Cubic x MM Complexity	0.33	(0.66)
Linear x Information Search	2.58***	(0.77)
Quadratic x Information Search	0.72	(0.64)
Cubic x Information Search	-0.25	(0.49)
MM Complexity x Information Search	0.20***	(0.05)
Linear x MM Complexity x Info. Search	2.52*	(1.05)
Quadratic x MM Complexity x Info. Search	0.07	(0.96)
Cubic x MM Complexity x Info. Search	-1.46†	(0.78)

Note. †p < .10. * p < .05. ** p < .01, ***p < .001.

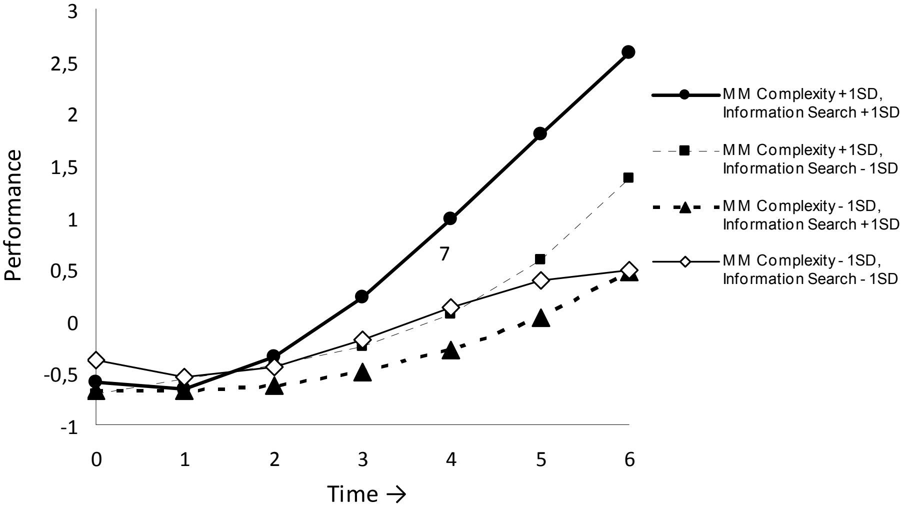

Figure 7. Team performance over time for teams with low and with high mental model complexity and with low and high Information search

Discussion

Although our understanding of individual team cognition concepts is steadily increasing, studies designed to explicitly investigate how different types of team cognition influence each other and interactively drive team performance are still scarce. Each team cognition construct reflects only part of the cognition taking place in a team during task execution. In order to attain a full understanding of the relationship between team cognition and team performance, constructs should be clearly specified, compared, and integrated. In addition, their conjunctive effects on team performance should be investigated.

We argued that teams functioning in complex dynamic environments require knowledge structures that ensure both external and internal cognitive alignment. An abundance of external alignment without the required integration mechanisms is likely to result in disintegration, with teams functioning more as separate individuals than as concerted goal directed entities (Brodbeck et al., 2007; Cronin & Weingart, 2007). From the other extreme, an abundance of internal alignment without external alignment will likely create a myopic inward focused team, insensitive to the complexities of its environment and unable to adapt to changing external circumstances (Burke, Stagl, Salas, Pierce, & Kendall, 2006).

The results of our study; however, provide a more nuanced picture regarding these relationships. On the one hand, both external alignment and internal alignment add unique predictive validity in predicting team performance trajectories. Team MM complexity as well as MM similarity and teams' TMSs positively predicted growth parameters of the team performance trajectories. On the other hand, the interaction effects of team external and internal alignment show mixed results. Whereas MM similarity positively interacted with MM complexity in predicting the cubic trajectory of team performance, TMS showed a negative interaction with MM complexity and the cubic growth parameter. These effects imply that the interaction between external alignment and internal alignment predict the form of the trajectories of team performance, however because the linear and quadratic parameters were not significant, the interaction does not significantly predict the overall growth in team performance. Therefore, we conclude that the external and internal alignment have additive but no compensatory effects on overall performance growth.

The results also point at the role of team information search as an important driver of team performance trajectories. The development trajectory of team information search indicates that although information search decreased over time for all teams, this decrease was less pronounced for teams with more complex MMs. Moreover, the breadth and depth of the information that was accessed did become increasingly important as the simulation progressed. This general pattern seems to indicate that all teams spent much time in the beginning of the simulation on exploring the different information pages of the game; however, whereas teams with less complex MMs rapidly decreased their search behaviour after this initial exploration, teams with more complex MMs remained more motivated to collect additional information during the passage of the simulation. Contrary to our expectations, team information search did not significantly mediate the relationship between team MM complexity and team performance trajectories; however, MM complexity did interact with information search in predicting team performance. Consistent with the metaphor of 'mental model as perceptual filters' (Starbuck & Milliken, 1988) and the theory of absorptive capacity (Cohen & Levinthal, 1990), teams with complex MMs seem to benefit most fully from accessing a wide variety of information. This interactive effect may also explain why teams with more complex MMs continue to engage in information search: relative to teams with less complex MMs, teams with more complex MMs, benefit more from information search in terms of increased team performance.

Prior research on shared MMs has aimed to demonstrate the positive impact of shared MMs on team performance. The accumulating evidence indicates that similarity in MMs indeed is an important antecedent for the quality and effectiveness of team processes. However, research on shared MMs has mainly investigated action teams for which deep information processing and the integration of distributed cognition may not be essential for successful task performance. When studying teams engaged in more complex cognitive tasks consisting of highly dynamic environments, such as project teams or crisis management teams, it may not be sufficient to look only at similarity and accuracy in MMs (Uitdewilligen, Waller, & Zijlstra, 2010). Instead, richer and more idiosyncratic aspects of MMs, such as MM flexibility and complexity may be more closely related to performance in complex and dynamic situations (Curseu, Schruijer, & Boros, 2007).

Scholars have argued that sometimes too much similarity in MMs may actually be detrimental for performance because in complex tasks it is more efficient if team members have diversified MMs, so that each members' model covers a particular aspect of the overall team task (Banks & Millward, 2007; Cooke, Kiekel, Salas, Stout, Bowers, & Cannon-Bowers, 2003; Mohammed and Dumville, 2001). However, given the often used similarity ratings approach for measuring team MMs, MM similarity and overall coverage of the task environment are opposites on the same dimension. Because the number and concepts of the models are fixed by the researcher, the more similar team members' MMs are, the smaller the amount of possible structures they cover. In contrast to the similarity rating technique that is most often used in MM research (DeChurch & Mesmer-Magnus, 2010) the free concept mapping approach used in this study allows for the independent assessment of MM similarity and coverage of the relevant task environment—which we assessed as MM complexity. As can be seen from the results of the present study, MM complexity and MM similarity were, although highly correlated, both positively as well as interactively predictive of performance trajectories.

Internal and external alignment and temporal trajectories. A number of scholars have argued that we should move away from a static or variable approach of studying team processes and performance to a more dynamic approach that investigates how team processes and characteristics develop and change over time (Marks et al., 2001; Roe, 2008). More in particular, scholars have long argued for taking into account not only what relations exist between variables, but also of finding out when and how long a variable affects another variable (George & Jones, 2000; Mitchell & James, 2001), or as McGrath (1988: 265) indicated "a known time relation between variables of interest is essential to the interpretive logic of all of our study designs". In this study we heeded these calls with the application of RCM techniques to our longitudinal data. This made it possible to assess and predict the patterns of team information search and team performance over time. Our results clearly show the additional benefits of a longitudinal approach. Although, the analyses indicate that team internal and external alignment do predict variance in overall team performance, the trajectory analyses provides a more nuanced picture of how and at what time points these variables have their most crucial impact on team functioning. A number of observations on the temporal trajectory of team performance are worth noting.

First, there appears to be a lag before the effects of team cognitive structures become visible in our team performance measure. More specifically, consistent with theoretical reasoning of Waller and colleagues (2005) teams bifurcate on performance from the third session onwards. Second, the team cognition variables most markedly affect the rate at which performance increases. Both MM complexity and a team's TMS quality have some but limited impact on initial team performance. The main impact of these variables is on the rate of development of team performance over time, in such a way that they distinguish teams with moderate from those with accelerated development patterns. Third, this difference in growth patterns levels off toward the end of the simulation. Whereas, teams with less beneficial cognitive structures—and less steep growth curves—continuously grow until the end of the simulation, the steeper performance trajectories of teams with more beneficiary cognitive constellations level off towards the end. We will now provide a number of possible explanations for these differences in temporal trajectories.

Lag. In order to reach eventual high performance, teams may need to forgo initial performance. McGrath (1991) noted that apparent inefficiencies in group performance may actually indicate that the group is involved in other activities—e.g. member- support functions or technical or political problem solving—that may not directly relate to the type of efficiency the researcher is tracking. Teams' initial actions and choices often have strong effects on team development later on in a team's lifespan (Chidambaram & Bostrom, 1996; Ericksen & Dyer, 2004). For example, initial investments in the construction of high quality team charters and taskwork strategies or in the construction of a shared understanding of the task may greatly benefit later performance (Mathieu and Rapp, 2009; Pearsall, Ellis, & Bell, 2010). However, such initial investments often do not immediately translate into higher performance. For instance, early investment of time and resources may dampen initial team performance levels but provide teams with salutary mechanisms that later on may results in higher levels of team performance (Erickson & Dyer, 2004).

Differences in the rate of performance growth. An explanation for difference in rate of performance growth perceived from the third session onward, may be that the effects of team cognition variables becomes more prominent as effects of previous periods accumulate and interact over time, causing upward or downward spirals (Lindsley, Brass, & Thomas, 1995). Team performance trajectories follow a path dependent process in which initial decisions set in motion a self-reinforcing process that establish the boundaries and conditions for future decisions. The effect of good initial decisions may provide a team with a positive basis for subsequent decisions—for example because of an increased availability of resources, a wider variety of information, or an increased number of options to choose from—while wrong initial decisions may complicate later decisions—for example by depleting resources or causing unnecessary constraints. In this way a deviation amplifying loop is established in which the teams that initially performed well become even better and the teams that initially performed less well, become even worse (Hackman 1990).

Another explanation for difference in growth rate trajectories may be that an inherent increase of complexity over time is embedded within the simulation. Teams start with a relatively simple company operating in a single country with not yet fully developed competition. After a few rounds, the companies start to grow, teams become active in multiple countries and the industries start to mature. As international competition increases and companies become involved in multiple countries, environmental complexity increases (Calori, Johnson, & Sarni, 1994; Porter, 1986). Therefore the complexity of the environment and the need for higher level information processing is likely to increase over time. Given that complex information structures are particularly useful in complex environments (Calori et al., 1994; Weick 1979), this would explain the increasing strength of the relationship between cognitive structures and team performance over time.

Negatively accelerating growth. Although, the team cognition variables positively impact team performance trajectories, the effects of these variables level off toward the end of the simulation. Note that this specific pattern of the performance trajectory is similar to those generally observed in studies on individual as well as collective learning curves (Argote, 1993, Argote, Gruendfeld, & Naquin, 1996; Mazur & Hastie, 1978). The most general explanation for this phenomenon is the existence of a ceiling effect: there may be a maximum on the performance scores teams may be able to attain and the closer teams approach that maximum the more difficult it is to improve. However, several alternative explanations may exist for why teams with initial high growth rates show negatively accelerated performance curves towards the end of the simulation.

First, scholars have pointed out that groups are often aware of the passage of time and the approaching end point of their project or groups' life, and that this time awareness has a profound impact on team functioning (Gersick, 1988, 1989; Waller, 2000). The teams in this study were clearly aware of the anticipated end time of the simulation. Because teams were evaluated based on their final—cumulative—performance, awareness of the approaching termination of the simulation may have caused complacency in teams with very high performance scores. If during the final rounds of the simulation, high performing teams perceive that their cumulative performance goals have been reached and their final score is secured, they are likely to decrease their effort, which may explain the negative acceleration of the performance curves towards the end of the simulation.

Second, an explanation for this negative acceleration can be found in research by Landis (2001) on the stability of team performance over time. In a study on professional basketball teams, Landis found that whereas the intercorrelations between performance indicators in adjacent periods were positive, the size of these correlations decreased and even became negative as the number of intervening time periods increased. Based on this result, Landis argued that when a limited amount of resources must be allocated among teams, an organization may sometimes use a politically driven model in which more resources are allocated to more poorly performing teams. The same argument can be applied to the present study. It could be possible that whereas instructors may initially have provided more information and advice to better performing teams, later on as performance differences between teams increased instructors may have started to invest more resources on the poorer performing teams in order to keep them from going bankrupt and to keep the variance in performance between teams within limits.

LIMITATIONS

A limitation of the present project is that, even though team information search and team performance were measured repeatedly over time, team cognitive structure variables were not. Our study was based on the assumption that cognitive structures that were formed during the initial training phase would remain relatively stable during the subsequent performance episodes; however, the veridicality of this assumption remains untested in the present study. Whereas some studies on the effects of cognitive structures—particularly of shared MMs—on team performance show stable effects over time (e.g. Edwards et al., 2006; Mathieu et al., 2000; 2005) others indicate that teams' cognitive structures can undergo substantial changes during repeated team member interactions (Cooke et al., 2003; Hollingshead, 2001; Lewis, 2004; Levesque et al., 2001).

Although, several scholars have pointed at the role of team MM accuracy in team effectiveness (e.g. Cooke et al., 2000; Rentsch & Hall, 1994), in the present study we did not derive indicators for team MM accuracy. Team MM accuracy refers to the extent to which the MMs of the team members adequately represent the structure of the system it models, and is often assessed by comparing participants' MMs with an optimal or 'true' referent model (Edwards et al., 2006; Stout, Salas, and Kraiger, 1997). This reasoning; however, is based on the assumption that one or more optimal referent models exist and can be derived by the researcher (Mathieu et al., 2005). In relatively simple situations in which the number of combinations MMs can assume and the amount of contingencies are limited, MM accuracy will constitute a meaningful construct. However, in very complex situations, such as the one represented in the present study, the sheer amount of different task situations and possible linkages between concepts makes it impossible to derive optimal referent models to which participants' models can be compared in order to derive accuracy measures. Therefore, in this type of situation, MM complexity may constitute a better measure for the quality of MMs, as complex knowledge structures indicate that individuals and teams have at their disposal a larger variety of possible models, each of which can be most appropriate in a different situation. For example, whereas in a market where demand surpasses supply, production capacity may be the most important driver for sales volume, in a market where supply surpasses demand, marketing efforts may be more crucial. The more complex a MM, the higher the chance that it will contain both accurate sub models. Therefore, we pose that in complex dynamic task situations MM complexity takes precedence over MM accuracy.

Finally, we only assessed one type of MMs, while team cognition researchers have generally agreed that different types of MMs may be active simultaneously in teams (Cannon-Bowers and colleagues, 1993; Klimoski and Mohammed, 1994). MMs have often been classified into two overarching dimensions, namely task MMs—representing aspects of the task itself, such as task processes, strategies, and likely scenarios—and team MMs—representing team members' interaction and communication patterns, roles, and responsibilities (Mathieu et al., 2000). The MMs we assessed, most closely resemble task MMs, as they do refer to team members' understanding of the simulation. Several studies show that, in particular similarity in team interaction MMs may be beneficial for team processes (DeChurch & Mesmer-Magnus, 2010). Therefore, the results of the present study only apply to task MMs and additional research is needed to unravel the interactions between characteristics of both team and task MMs.

Conclusion

Gaining an understanding of how teams can leverage and maximally utilize the knowledge, skills, and abilities of the individual members, constitutes one of the main challenges for team research for the coming years. The last decades have witnessed the introduction of a number of emergent team level cognitive concepts, which have significantly improved our understanding of team performance. The time has come for research on team cognition to go beyond single construct approaches and develop more integrated theoretical frameworks that link together these constructs and indicate how they conjunctively influence team information processing and performance. One of the main questions surfacing in team cognition research is how both convergent and divergent cognitive structures can drive team performance. We have developed and tested a model of the role of team cognitive structures in complex and dynamic environments in which we argue that teams require both internal and external cognitive alignment. Moreover, we found that a temporal approach to analyzing and assessing the effects of these cognitive structures on team performance added a more nuanced picture of when and how these team cognition variables impacted team performance over time. To conclude, in order to enable teams to prosper and thrive in turbulent environments it should be ensured that teams' knowledge structures both match the requisite variety of the external environment and are sufficiently aligned internally to assist in navigating the intricacies of internal team processes.

Chapter 5*

Talking to the room: Collective sensemaking during crisis situations

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Abstract

In this chapter we investigate the nature of a team's cognitive adaptation processes. We present a case study on a single team in which we investigate how this team alters its understanding of an unexpected dynamic situation over time. We analyzed a sample of the audio communication of the operations team of NEADS— the organization responsible for coordinating the air defense of the northeast quadrant of the United States during the terrorist attacks of September 11, 2001. From our analyses of the data we conclude that in ambiguous situations, teams construct temporary 'working hypotheses' of the situation that enable them to maintain sense and coordinate their actions. The formation and abandonment of these working hypotheses over time consisted of an iterative process of using and discarding working hypotheses as events unfolded and sensemaking occurred.

Introduction

For organizations operating in complex, dynamic environments, the ability of operational teams to construct an adequate understanding of an evolving situation rapidly is critical for timely action. Emergency medical teams gather information, make diagnoses and take appropriate action in order to save lives (Marsch *et al.* 2005). When there is a malfunction, nuclear power plant control room crews gather information from multiple systems and quickly piece together clues that pinpoint the source before safety is compromised (Waller, Gupta & Giambatista 2004). Airline flight crews quickly adapt to unexpected weather and mechanical events by reorganizing tasks and responsibilities, and land safely as a result (Waller 1999). Clearly, unless the necessary information is collected quickly and appropriate understanding is drawn from it, the probability of taking appropriate action under such critical, time-pressured situations is severely compromised.

It is no surprise, then, that numerous scholars have directed their research efforts toward understanding and improving the ability of teams and organizations to collectively 'make sense' out of evolving crises. Various models have been constructed in different disciplines regarding how the formation of collective understanding develops so that relevant aspects of a situation are shared and distributed among the different members of an organization (Endsley 1995; Gorman, Cooke & Winner 2006; Roth, Multer & Raslear 2006; Wellens 1993). The concept of *sensemaking* seems ubiquitous in work on crisis situations. Sensemaking constitutes the social process by which members of an organization collectively interpret and explain sets of ambiguous information from the environment (Weick 1995). Given that crisis situations typically involve unexpected, complex and dynamic events (Pearson & Clair 1998), sensemaking would seem to play a pivotal role in the ability of teams and organizations to act quickly and effectively. In fact, several researchers have documented the occurrence of behavior termed 'talking to the room' during crises, as team members use undirected talk to repeat new information to 'the room' (i.e., to no particular recipient) in order to facilitate collective sensemaking (Pettersson, Randall & Helgeson 2004).

Sensemaking has its place, but organizations that relied on sensemaking processes to ensure timely and effective action during crises would be remiss, if not criminally liable, if they failed also to provide their members with adequate training. Naturally, the members of responsible organizations receive extensive initial and recurrent training in the use of protocols designed to aid their sensemaking and actions during crisis situations. Most hold professional licenses formalizing their levels of expertise and training. For example, most licensed nuclear power plant crew members receive recurrent simulator training every six weeks, during which they practice noticing, diagnosing and responding to various non-routine events. In general, training in organizations responsible for addressing crises often focuses on the appropriate application of existing protocols to simulated situations (Perrow 1984). This application not only requires making sense of information, but also requires the rapid application of existing protocols once sensemaking provides a working hypothesis.

But what happens when information emanating from an emerging crisis begins to form a pattern over time that deviates from the expectations of existing protocols and working hypotheses? How deviant information, and how much of it, is required to trigger the realization that a protocol and its underlying hypothesis are no longer plausible for a given situation? Weick and Sutcliffe (2001; see also Langer 1992) suggest that 'mindful' organizations and their actors iteratively revisit working hypotheses in light of incoming information; however, given the time constraints faced by organizations reacting to crisis situations, the constant questioning of a working hypothesis may introduce interruptions that diminish cognitive resources required for implementing complex procedures (Speier, Vessey & Valacich 2003). Additionally, the ability of individuals under extreme stress to abandon an initial hypothesis in a timely manner may be compromised by reactions such as attentional tunneling (Yeh & Wickens 2001) or threat rigidity (Staw, Sandelands & Dutton 1981).

The purpose of our chapter is to investigate, using a case study, the working hypotheses activated over time in one organization's operations team during an extreme crisis. Time plays a central role in our chapter in two ways. First, we focus on a crisis that emerges, piece by piece, over time, and cumulates into an event of previously unimagined proportion. Second, the organization charged with responding to the crisis must react to and contain the emergent crisis as quickly as possible. It has to fight time, literally. We attempt to ascertain if and when this organization's working hypotheses change as the crisis unfolds, to describe this pattern of change, and to understand it in terms of collective sensemaking. The case concerns the organization responsible for defending the airspace over the northeast quadrant of the United States: Northeast Air Defense Sector (NEADS). In order to address the questions and issues discussed above, we briefly review the literature concerning sensemaking and working hypotheses. We then present an analysis of the communication among NEADS members as they attempt to understand and respond to the emergent events of September 11, 2001. After discussing that analysis, we close with implications for theory and organizations.

Sensemaking and working hypotheses

As noted by Weick, "The basic idea of sensemaking is that reality is an ongoing accomplishment that emerges from efforts to create order and make retrospective sense of what occurs" (1993: 635). Especially during turbulent critical situations that consist of completely unexpected and incomprehensible events, sensemaking is of crucial importance for reducing confusion, guiding action and preventing organizational disintegration. In contrast to situation assessment (Endsley 1995), sensemaking is oriented towards plausibility, not accuracy (Weick 1995). A plausible interpretation constitutes an acceptable account of the available facts and thereby provides a meaningful basis for actions. Support for this point comes from work on recognition primed decision-making (RPD), which focuses on understanding how people use experience to make rapid decisions under conditions of time pressure and uncertainty (Pliske, McCloskey & Klein 2001). Descriptions of actual RPD indicate that proficient decision makers, in order to make decisions in ambiguous situations, engage in the construction of working hypotheses in the form of rapid 'story-building' to mentally simulate the events that they think have resulted in the present conditions (Pennington & Hastie 1993). For instance, research in complex naval command-and control environments indicates that when situations are too novel or complex to categorize by simple feature-matching, decision-makers postulate relationships through very brief stories that link together the available pieces of information into a coherent whole (Kaempf, Klein, Thordsen & Wolf 1996). An essential point to note regarding these conceptualizations of sensemaking is the recognition that during crisis situations not all information is presented initially but instead becomes available *over time*. Noting this point, Weick, Sutcliffe and Obstfeld (2005) describe sensemaking as a process of continually creating, updating and rewriting the working hypothesis or story of what has occurred, thereby maximally aligning the current plausible understanding to the available information.

If interpretation processes are aimed at plausibility, they are likely to be guided by previous expectations and existing knowledge structures. A large body of research indicates that individuals, when interpreting their environments, employ top-down information processing structures that are based on past experience in similar situations, and that doing so helps prevent information overload and facilitate efficient information processing (Sarter & Woods 1991; Endsley 1995; Mogford 1997). The application of knowledge structures greatly enhances information-processing efficiency and decision-making (Thorngate, 1980), but also imposes severe limitations on decision-makers' abilities to understand their current information environment (Kiesler & Sproull 1982; Walsh 1995). Because top-down knowledge structures are essentially interpretations and simplifications of an external system, individuals and groups can fall into the trap of acting on an impoverished or outdated view of reality (Weick ,1979). If knowledge structures are linked to (over)trained or routinized protocols, adherence to obsolete interpretations may become more likely (Gersick & Hackman 1990; Vaughan 1996). Research on the occurrence of disasters has linked the application of collectively accepted and rationalized knowledge structures to the failure to discover lurking danger (Turner 1976).

Conversely, the implicit formulation of an incorrect working hypothesis may actually facilitate the integration of data and ultimately lead to productive sensemaking. In other words, the formulation of a hypothesis – even if incorrect – may be better than having no hypothesis at all (Dörner 1996). A working hypothesis may help organizational members coordinate information-gathering and task distribution duties, and may induce activation (and reduce panic) among individuals facing an unexpected crisis situation, even if task distribution and other arrangements must be altered later in the face of new information. For example, research on medical diagnostics has indicated that, faced with a limited number of symptoms and signs, physicians almost instantly develop hypotheses about a patient's illness based on their previous knowledge structures. The generation of hypotheses is followed by a stage in which the physician engages in active information search and compares and tests hypotheses against the presence or absence of further symptoms (Charlin, Tardif & Boshuizen 2000; Elstein, Schulman & Sprafka 1978). Without initial working hypotheses, however, the subsequent updating and testing might follow a haphazard path, possibly passing over important questions or information.

In sum, based on the existing literature concerning sensemaking and working hypotheses, we suggest that (1) teams and organizations responsible for responding to crisis events are likely to be well-trained in the application of existing protocols; (2) initial collective sensemaking triggers the activation of trained protocols and their underlying hypotheses; and (3) in mindful organizations, the appearance of and careful consideration of information incongruent with working hypotheses will trigger the updating of those hypotheses. We now turn to an examination of these points as they inform and are to be found in the case study.

Methods

Case setting

According to *The 9/11 Commission Report* (2004: 4), 'On September 11, 2001, 19 men were aboard four transcontinental flights. They were planning to hijack these planes and turn them into large guided missiles, loaded with up to 11,400 gallons of jet fuel'. The men hijacked, in order, American Airlines flight 11, United Airlines flight 175, American Airlines flight 77 and United Airlines flight 93. The men took control of all four flights within a timespan of forty-four minutes.

The organization responsible for coordinating the air defense of the northeast quadrant of the United States on that day was the Northeast Air Defense sector (NEADS), based in Rome, New York. As part of the North American Aerospace Defense Command (NORAD), NEADS' primary mission was to defend its sector against external attacks (9/11 Report, 2004: 16). In order to facilitate its mission, NEADS could order fighter aircraft into action from two locations: Otis Air National Guard Base in Cape Cod, Massachusetts, and Langley Air Force Base in Hampton, Virginia.

During an aircraft hijack, NEADS personnel were expected to follow a clear hijack protocol that involved coordinating information and action with the Federal Aviation Administration (FAA), mainly through communication with air traffic controllers. As detailed in *The 9/11 Commission Report* (2004: 18), the protocol in place for responding to a hijacking presumed that:

- The hijacked aircraft would be readily identifiable and would not attempt to disappear from radar;
- There would be time to address the problem through the appropriate NORAD and FAA chains of command; and
- The hijacking would follow the traditional form of requests for demands to be met, and not follow the form of converting a commercial jet into a guided missile.

The organizational structure of NEADS on that day, in terms of active operational personal, included a crew of approximately thirty-six (about thirty Americans and six Canadians) who worked on the NEADS operations center floor (Bronner 2006). These individuals worked in separate functional areas, including the ID (information) Section, Radar Control, Weapons Team, and hierarchical command positions. They were expecting a day of training.

Data

In order to examine the pattern of sensemaking at NEADS on September 11, 2001, we used data primarily from two sources: *The 9/11 Commission Report* (2004), and a subsequent article titled '9/11 Live: The NORAD Tapes' by Michael Bronner (2006). The 9/11 report is the final report of the national commission established to investigate the terrorist attacks of September 11, 2001, and much of the initial portion of that 567-page report is based on transcribed audio recordings of conversations among personnel at NEADS, the Federal Aviation Administration and other organizations on that day. The Bronner article focuses exclusively on communications at NEADS; in the article, the author strives to 'reconstruct the chaotic military history of that day . . . ' (Bronner 2006). To construct his account, from the perspective of NEADS, of the 100 minutes during which the hijackings and their aftermath first transpired, Mr Bronner transcribed segments from thirty separate audio recordings gleaned from the approximately thirty hours of NEADS audio recordings provided to him by NORAD. Although our request for the full thirty hours of recordings has not, to date, been responded to by NORAD, we were able to access the actual audio recordings of the thirty excerpts used by Mr Bronner.

Coding and analysis

Of the thirty transcribed audio recordings published by Mr Bronner, we omitted two. The first recording concerned non-task communication before the crisis began, and the final recording, in our opinion, provided insufficient information to code it for our analysis. Furthermore, we added transcriptions of three recordings not present in the Bronner collection but available from *The 9/11 Commission Report*. The Bronner transcripts appear in order in our analysis, numbered beginning with '2' and ending with '29', while the 9/11 report transcripts are coded 'a', 'b' and 'c', respectively. The Bronner transcripts provided the hour, minute and second of the beginning of the recording, but *The 9/11 Commission Report* provided only the hour and minute. All transcripts noted the organizational affiliation or identity of the speaker(s).

We first coded the thirty-one transcripts in our data set as to sender. The twenty-four transcripts of communications by NEADS members appear in Table 1. Only transcripts of communications by NEADS members are included in our analysis of working hypotheses. The seven remaining transcripts concern information sent by parties outside NEADS, and appear in Table 2. Of these seven transcripts, six were taken from the Bronner collection and one was taken from *The 9/11 Commission Report*.

In the second step of our coding, we examined the twenty-four transcripts for similarities as to the apparent working hypothesis contained in the communications. Examination revealed three distinct hypotheses. The most obvious cluster of transcripts (transcripts 2, 3, 7, 12 and 15) involved comments or questions about training. Given that an actual commercial passenger airplane hijacking had not occurred in the United States in a decade, few if any NEADS personnel had ever been involved in responding to an actual hijacking. As the events of the morning unfolded, several comments were made to ascertain the training versus 'real world' status of the information, indicating the initial belief that the situation was a training exercise.

The training hypothesis quickly gave way to the realization that an actual hijacking had occurred, and that trained protocols were the appropriate response (transcripts 4, 6, 8, 10, 13 and 16). For example, transcript 8 indicates that a classical hijacking script had been triggered consisting of the sequence of events in which, after some initial turmoil, the hijackers would land the airplane and make public their demands. Protocols for 'normal' hijackings, as detailed above, were followed even as news of multiple hijackings was shared by NEADS members (transcripts 13 and 16).

The third cluster of transcripts indicated the realization that the hijackings were actually attacks and would not follow the normal sequence of diverted aircraft and pronouncements of hijackers' demands. This cluster of transcripts is anchored by transcript 'a', which immediately follows the realization of NEADS members that the second aircraft, United 175, had crashed into the World Trade Center (although NEADS knew of the first crash, members were at this time unsure if the aircraft was a commercial flight or a small civilian aircraft). After the communication noted in transcript 'a', the possibility that the United States was under attack gradually began to be accepted as the dominant working hypothesis. In fact, only one subsequent transcript, transcript 16, can arguably be categorized as incongruent with this hypothesis. The next transcript, number 17, indicates a clear deviation from standard hijack protocol. All following transcripts are consistent either with this deviation or specifically with the attack hypothesis.

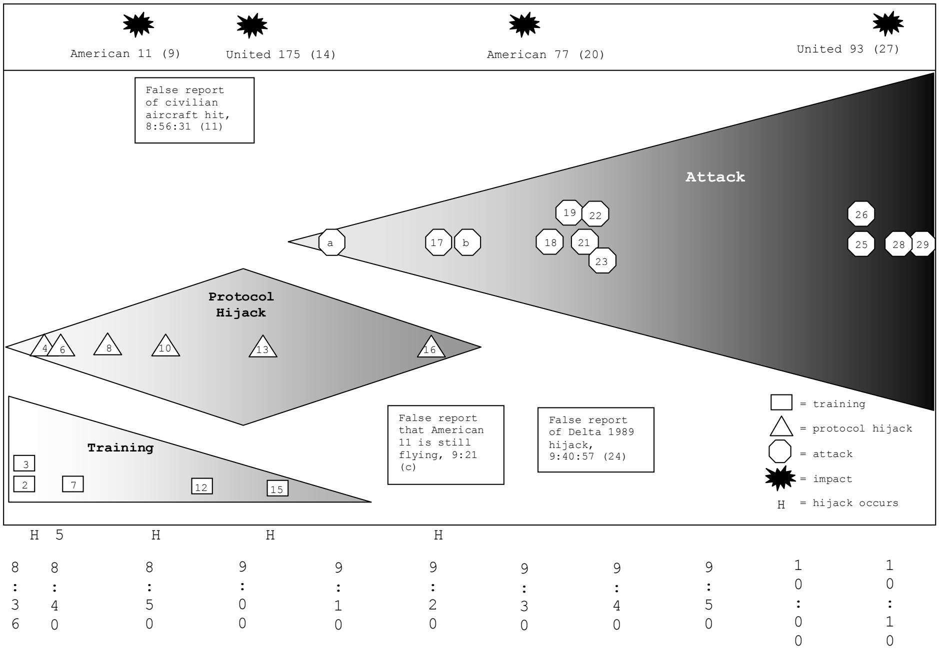


Figure 1. Emergent Hypotheses at NEADS

Table 1. NEADS Communication Categorizations

Working Hypothesis	*Graph No.*	*Time*	*NEADS Statements*	*Source(s): 1=Bronner(2006), 2=9/11 Report (2004)*	*Comments*
Training simulation	2	8:37:52	Is this real-world or exercise?	1 (p. 264); 2 (p. 20)	Indication of initial training mindset.
	3	8:37:56	Is that real-world?	1 (p. 266)	Indication of initial training mindset.
	7	8:43:06	I've never seen so much real-world stuff happen during an exercise.	1 (p. 267)	This comment indicates adherence to the training assumption
	12	8:57:11	Think we put the exercise on the hold. What do you think?	1 (p. 268)	An effort to decrease the sense of panic by use of humor (Bronner, 2006); however, comment indicates the possibility of simulation still remotely exists.
	15	9:04:50	I think this is a damn (simulation) input, to be honest.	1 (p. 268)	Perhaps wishful thinking (Bronner, 2006), or perhaps lingering belief that the situation is simulated.
Hijack fitting training protocols	4	8:37:58	Major Nasypany, you're needed in ops pronto.	1 (p. 266)	Following protocol for hijacking. This officer later remarked that he thought "Somebody started the exercise early" (Bronner, 2006: 266).
	6	8:40:36	Okay, he said threat to the cockpit!	1 (p. 266)	"Threat to the cockpit" triggers a heightened but trained protocol response, including the launch of fighter jets to "establish a presence" and discreetly escort hijacked aircraft.
	8	8:46:36	And probably right now with what's going on in the cockpit it's probably really crazy. So, it probably needs to – that will simmer down and we'll probably get some better information	1 (p. 267)	Assumption that hijackers, following past hijacking events, will later make their demands known. (The hijackers also added to this illusion with statements overheard by the FAA, such as "There is a bomb on board and are going back to the airport, and to have our demands [unintelligible]. Please remain quiet." (2: 29))
	10	8:52:40	Send 'em to New York City still. Continue! Go!	1 (p. 267)	Sending the fighters "still" may indicate adherence to the normal hijack protocol.
	13	9:03:17	They have a second possible hijack!	1 (p. 268)	Still no indication here of the identification of a coordinated attack.
	16	9:21:37	Another hijack! It's headed towards Washington!	1 (p. 270)	No indication of coordinated attack, but now realization of multiple locations.
Coordinated attack	a	9:08	We need to talk to the FAA. We need to tell 'em if this stuff is gonna keep on going, we need to take those fighters, put 'em over Manhattan… At least we got some kind of play.	2 (p. 24)	This statement indicates an initial realization that "this stuff" -- multiple hijacks and/or attacks -- may continue, and "play" or possible combat operations may be necessary. NEADS has knowledge at this point about the WTC attacks.
	17	9:21:50	I think we need to scramble Langley (fighter	1 (p. 275)	Escalation of military presence in the face of a now-possible attack

		jets) right now. And I'm – I'm gonna take the fighters from Otis and try to chase this guy down if I can find him.		with at least three hijacked aircraft. "Chasing down" a hijacked aircraft deviates considerably from the protocol of "discreet" escort (see 9/11 Commission: 18).
b	9:23	These guys are smart. They knew exactly what they wanted to do.	2 (p. 27), our transcription.	Realization that the attack is well-planned and coordinated.
18	9:32:20	Have you asked – have you asked the question what you're gonna do if we actually find this guy? Are we gonna shoot him down if they got passengers on board? Have they talked about that?	1 (p. 275)	Clear realization that an attack, not only a series of hijacks, is transpiring. The question concerns the rules of engagement. Authority to shoot can come only from the President.
19	9:34:12	What do you mean, "We'll get back to you"? Just do it!	1 (p.276)	Indication of stress and conflict between NEADS operator and Navy air traffic control in the coordination of fighters; NEADS controllers believe another attack is imminent and want fighters rerouted.
21	9:36:23	OK…I got a aircraft six miles east of the White House! Get your fighters there as soon as possible…	1 (p. 276)	Clear realization of the threat of an attack on the White House.
22	9:37:56	Hold on… where's Langley at? Where are the fighters?	1 (p. 276)	Attempt to find fighters to protect the White House – diversion from standard hijack protocol.
23	9:38:50	We need to get back up there – I don't care how many windows you break!… Goddammit! OK, push 'em back!	1 (p. 276); 2 (p. 27)	Attempt to redirect fighters to protect the White House. The stress of the situation is quite apparent.
25	10:07:08	Intercept and divert that aircraft away from there.	1 (p. 281)	The demand to intercept shows a deviation from standard hijack protocol.
26	10:07:39	Do you hear that? That aircraft over the White House. What's the word?…Intercept and what else?…Aircraft over the White House.	1 (p. 281)	The "word" refers to clearance to shoot down attackers.
28	10:10:31	Negative. Negative clearance to shoot… Goddammit!	1 (p. 282); 2 (p. 31)	Refusal of command to grant NEADS' request for authority to shoot down attackers' aircraft. The request indicates threat of attack.
29	10:15:00	Oh, he's down down?	1 (p. 282); 2 (p 31)	Realization that United 93 has crashed.

Table 2. NEADS Notifications and False Reports Received

Graph No.	*Time*	*Sender*	*Others' or NEADS Statements*	*Source(s): 1=Bronner (2006), 2=9/11 Report (2004)*	*Comments*
5	8:39:58	Boston air traffic control	Boston: He's being hijacked. The pilot's having a hard time talking to the – I mean, we don't know… I guess there's been some threats in the cockpit.	1 (p. 266)	Notification of hijack, threats to cockpit.
9	8:51:11	NEADS, via CNN broadcast	NEADS: A plane just hit the World Trade Center… Saw it on the news.	1 (p. 267); 2 (p. 20)	Realization of first impact.
11	8:56:31	Unknown	NEADS: I heard it was a civilian aircraft.	1 (p. 267)	False report of civilian aircraft hitting the World Trade Center.
14	9:03:52	Unknown (possibly FAA)	NEADS: Sir, we got – we've got unconfirmed second hit from another aircraft…	1 (p. 268); 2 (p 23, cites "by 9:08" as time)	Realization of second impact.
c	9:21	FAA	Boston: I just had a report that American 11 is still in the air, and it's on its way towards – heading towards Washington.	2 (p. 26)	False report that American 11 is still flying.
20	9:34:01	FAA	FAA: We're – also lost American 77…	1 (p. 276)	First report of possible American 77 hijack or impact.
24	9:40:57	FAA	FAA: Delta 89, that's the hijack	1 (p. 281)	False report of Delta 1989 hijack.
27	10:07:16	FAA	FAA: We got a United 93 out here. Are you aware of that?	1 (p. 281)	First report of United 93 hijack or impact.

The three working hypotheses, indicated by clusters of transcripts, are depicted over time in Figure 1. Our rationale for each coding decision for each transcript is shown in Table 2.

Discussion

Members of organizations responsible for responding to critical events are typically well-trained in the application of protocols and routines when the detection of a known event is registered (Creed, Stout & Roberts 1993). Based on the details provided in the 9/11 Commission Report, it is evident that NEADS members were well-trained in the hijack protocol developed to coordinate operations between NORAD/NEADS and the FAA. This protocol included working with a designated FAA hijack coordinator, and assumed that pilots would 'squawk 7500' – the agreed-on universal code for hijack – on their transponders in order to facilitate NORAD's (and thus NEADS') ability to track the aircraft. Fighter jets would then linger five miles behind the hijacked aircraft in order to monitor the aircraft's flight path (*The 9/11 Commission Report* 2004: 17).

The members of NEADS clearly expected the scheduled training simulation, which would possibly involve practicing the hijack protocol, to take place on the morning of September 11. Their initial queries of others about the 'real-world' nature of the unfolding events that day, along with their subsequent speculation about the events being part of a simulation, is indicative of the initial training mindset. Alerted to a hijacking, NEADS members' initial sensemaking called for the immediate application of the hijack protocol for which they had been trained, but the abandonment of the training hypothesis took significantly more time. Thus, two hypotheses were simultaneously active – the hypothesis that this was an unusual, multi-aircraft hijacking simulation, and the hypothesis that the hijackings were real. The central assumption for both hypotheses was that the hijack protocol was the appropriate response.

Notification of the third hijacking triggered significant and mindful hypothesis updating at NEADS. At that point in time, the training hypothesis had been abandoned – NEADS members realized that the events of the day were real. NEADS members combined information about the World Trade Center impacts (including information from a false report that a small civilian aircraft had hit the first tower) and the third hijacking, and made sense of the situation with a new hypothesis: the area for which they were responsible was under coordinated attack. The normal hijack protocol was subsequently abandoned, as evident in the significant deviations from that protocol which subsequently occurred, in terms of requesting that fighter jets 'intercept' and 'divert' hijacked aircraft, rather than simply follow them. The hypothesis updating was somewhat tentative at first, and focused only on the defense of the New York City area; later efforts to move fighter jets to other locations indicated a broadening of the application of the attack hypothesis. The request for authority to shoot down the hijacked aircraft was the most significant and dramatic deviation from the hijack protocol during the time we investigated.

Connections to previous work

Our analysis indicates that the process of sensemaking under environmental turmoil is not a simple unitary process in which the understanding of the situation is constructed in a linear, cumulative manner. Instead, at least in terms of the NEADS members, sensemaking proceeded in a stepwise fashion, with three different working hypotheses consecutively surfacing as more information became available over time. The indication seems to be that an organization must first begin the process of discarding previous conceptions of the situation in order to fully embrace a new account that is better supported by emergent, accumulating evidence. This process of discarding outdated understandings and constructing new ones is a process characterized by transition periods in which evidence is interpreted in multiple ways and different possibilities are left open.

Our work is thus quite congruent with Kathleen Sutcliffe's conceptualization of sensemaking as a non-linear, iterative process in adaptive organizations (Sutcliffe 2001: 219). The analysis of collective sensemaking is also congruent with Isabella's (1990) conclusion that "determining what an event means appears to be a process of going through a series of interpretative stages" (Isabella 1990: 33) and Weick *et al.*'s (2005) conceptualization of sensemaking as a "continued redrafting of an emerging story" (2005: 415). However, elaborating on this redrafting process, we identify it here as a discontinuous process in which the development of 'the story' resembled an iterative practice of generating and rejecting working hypotheses.

Previous accounts of team behavior dubbed 'talking to the room' suggest that sharing (shouting) relevant incoming information to the room at large is an effective, economical method to facilitate collective sensemaking. That 'talking to the room' occurred is evident from the actual audio recordings. The pitch and intensity of vocalizations by NEADS members announcing, for example, "Okay, he said threat to the cockpit!" make clear that the information was intended for multiple people in the room – a point also noted by Bronner (2006: 266).

Future work

Our work describes a non-linear pattern of working hypothesis activation and updating, embedded within sensemaking and facilitated by talking to the room. It is important to note, however, that this scenario was most likely transpiring in multiple locations, simultaneously, on September 11, 2001. Boston Center FAA, NORAD, NEADS and Air Force bases constituted a network of inter-team connections, and teams in each organization activated and updated their own, unique versions of working hypotheses during sensemaking. While inter-organizational protocols were designed to smooth coordination across these teams and their organizations, it seems likely that the timing of activating and discarding or updating these protocols was different across teams and organizations. The difference in timing, coupled with possible differences in the content of working hypotheses, may have led to some of the confusion that transpired on that day. Future work should investigate the role of meta-sensemaking processes – making sense of multiple, simultaneous versions of the same events – and how networks of teams and organizations might benefit from such processes during extreme crises.

Within teams and organizations, future researchers should closely examine how and when working hypotheses emerge, and if and when these hypotheses help or hinder sensemaking efforts. As we discussed previously, some existing evidence suggests that having an incorrect hypothesis may be better than having no hypothesis at all; conversely, clinging to an incorrect hypothesis in the face of disconfirming information may prohibit an effective response under time pressured situations. Future work should investigate the characteristics of these working hypotheses, the times at which they emerge, and other pertinent dimensions to develop a more full understanding of the role of working hypotheses during crisis situations.

Similarly, a concentrated research effort should be focused on understanding more about the influence of disconfirming information on the motivation of teams and their organizations to update strongly-held working hypotheses. How much incongruent information is enough to reach a threshold of implausibility? How does the timing of receipt and other characteristics of incongruent information interact with characteristics of the working hypotheses to trigger a reconsideration of plausibility? Finally, how does training in the use of standard protocols facilitate or inhibit updating triggers? While researchers have investigated issues inducing individuals to switch from automatic to active cognitive processing (e.g., Louis & Sutton 1991), further work could be done in terms of developing a more complete understanding of collective hypothesis updating in ambiguous, complex crisis conditions.

One way to move toward such an understanding involves the overlaying of objective time upon the subjective sensemaking experiences of individuals, teams and organizations, as we have attempted to illustrate with our study. Time may seem to speed forward or to stand still for the participants embedded within an unfolding crisis, and combining their subjective temporal experiences with an objective temporal record of actions and communications may help to inform our understanding of subjective experiences of objective time – a notion that could prove critical in understanding more about what perceptions motivate people to drop initial hypotheses in favor of updated ones, and how they do so. For example, if subjective time moves more slowly than objective time for individuals experiencing a highly ambiguous and consequential situation, their perceptions regarding the amount of time remaining to gather more information or re-check existing assumptions may not be appropriate for the situation. The match or mismatch between subjective temporal experience and the unfolding of events in objective time, and the relationship to overall effectiveness, could prove to be a rich area for future investigation.

Limitations

As previously mentioned, our analysis here is limited by our access to data. We used the audio recordings and transcripts provided by two sources as our data, but it is possible that having access to the complete audio recordings made at NEADS on September 11, 2001 would add detail to our understanding of sensemaking processes employed that day. Additionally, in our analyses of the NEADS audio excerpts, we have assumed that the perceptions and interpretations we inferred from the excerpts were more or less shared by all NEADS personnel present. This may be a simplification of reality, as different members may have concurrently held distinct interpretations about the same event (Gephart 1997). However, the practice of 'talking to the room' seems to indicate at least basic agreement of the interpretation of events, since we did not encounter evidence of overt disagreement within the excerpts. Finally, while we took care in categorizing the transcripted communications at NEADS, our categorizing decisions may have been influenced by our own reading and interpretation of the sensemaking literature.

Conclusion

As others have noted, there is a certain tension between different schools of thought regarding how organizations should best prepare for crises. One school, referred to as High Reliability Theory (HRT), maintains that, through system redundancy and training, high-stakes organizations responsible for keeping complex systems in stasis can safely approach error-free performance. The other school, referred to as Normal Accident Theory (NAT), is based on Perrow's fundamental view that in complex, tightly-coupled systems, accidents and ensuing crises will eventually be unavoidable (Perrow 1984; see also Bain 1999). While it seems to us that the schools adopt either a short-term or a long-term view, respectively, of potential crisis occurrence, the events of September 11, 2001 certainly underscore the fact that even the best protocols and the most highly trained operators cannot possibly anticipate all possible permutations of crises they may face. We do not mean to suggest that training is therefore of no use. However, leaders and trainers of teams and organizations charged with responding to crises may do well to focus extended training effort on simulations that require the abandonment of normal protocols in order to successfully complete the mission. Content area experts may be well-versed in designing appropriate protocols and routines for the crises they can imagine or anticipate, but inviting designers outside the content area to 'blue sky' about potential crises (see Mitroff, Pearson, & Harrington 1996) may provide the new perspectives necessary in order to train 'out of the box' thinking, or 'mindfulness' in addition to successful protocol activation.

The day of September 11, 2001 began much as any other in the United States. For NEADS, it transformed what was to be just another training day into the 'real world' in a way that, for all but the most sequestered of strategic defense thinkers in the country, was unimaginable. Protocols were in place, but they did not fit the evolving pattern of events. By applying objective time to their emergent awareness, we can *see* the processes of sensemaking in action as the members of NEADS struggle to fit their accounts of themselves as defenders of their sector to the facts as they emerge. They shift their roles from observer to defender to pre-emptive attacker through the narrative patterning, through making sense of what seems, initially, to be inexplicable. In the space of minutes, and from chaos, they do what human beings are still uniquely capable of doing: they make sense.

Note

1) The portions of each of these excerpts that involve working hypotheses active at NEADS over time form the basis for our data. We listened to all of these excerpts and checked them against the transcripts published by Mr Bronner. We have no reason to believe that Mr Bronner's choice of the thirty audio excerpts biases our ability to ascertain the working hypotheses at NEADS over time. When possible, we verified the Bronner transcripts with information published in *The 9/11 Commission Report*. Additionally, we augmented the thirty Bronner transcripts with additional information from the 9/11 report, and in one instance added our own transcribed information from an audio recording to our data.

Chapter 6

A communication perspective on team situation awareness: A video-analysis study of emergency management command teams at the port of Rotterdam

Abstract

Crisis management teams are consisting of highly trained professionals often coming together for a short time to quickly respond to a situation characterized by high levels of complexity and dynamism. Previous research has indicated the importance for such teams to rapidly construct, share, and maintain an appropriate understanding of their task situation—in other words; they need to establish team situation awareness (Waller, Gupta, & Giambatista, 2004; Weick, Sutcliffe, & Obstfeld, 2005). In the present chapter we take a communication perspective to assessing team situation awareness communication (Keyton, Beck, & Asbury, 2010). In a study of 12 multidisciplinary crisis management teams performing a crisis management simulation, we investigate the structure, antecedents, and consequences of team situation awareness communication. Our findings indicate that the team communication process can be divided into two phases. An initial phase aimed at setting the structure of the meeting and sharing individually held information and a second decision making phase in which the teams focus on making decisions on actions to take. Our results indicate that, compared to average-performing teams, high performing teams spent more time on the initial phase and made decisions more rapidly in the decision making phase. Moreover, high-performing teams engaged in more collective interpretation processes during the decision making phase compared to average-performing teams and use of the whiteboard during the meetings influenced the extent to which teams engaged in collective interpretation processes.

Introduction

Teams are often responsible for managing complex dynamic systems, and especially when these systems deviate from their regular functioning, the team members face the vital task of diagnosing the state of the system in order to bring it back into stable operation (Weick et al., 2005; Waller et al., 2004). For example, crisis management teams must rapidly construct an understanding of an emergency situation in order to timely dispatch available resources—e.g. ambulances, fire engines, and emergency facilities—to the appropriate locations (Bigley & Roberts, 2001; Smart & Vertinsky, 1977; Smith & Dowell, 2000). Nuclear power plant control teams must gain a holistic understanding of the system and its deviations in order to coordinate their actions and bring it back into stasis (Hogg, Knut, Strand-Volden, & Torralba, 1995; Waller et al., 2004). Medical teams must rapidly form a diagnosis of the physical condition of a patient in order to effectively handle a medical emergency situation (Faraj & Xiao, 2006; Tschan, Semmer, Gautschi, Hunziker, Spychiger, & Marsch, 2006). And finally, management teams must continuously make sense of their environments in order to timely adapt their organizations to rapidly changing external circumstances (Bogner & Barr, 2000; Bourgeois, 1985; Eisenhardt, 1989; Nosek & McNeese, 1997; Suttclife, 1994; Thompson, 1967).

For such teams—operating in complex and dynamic environments, and facing ill-structured problems—making sense out of the flow of events constitutes an essential aspect of their task (Weick et al., 2005). While engaging in active task execution, team members must construct and continually update their understanding of the dynamic task situation as it unfolds over time. Moreover, in order for the team members to align their actions with one another and to function as an integrated entity, team members must share crucial aspects of their situation understanding (Endsley, 1995; Salas, Prince, Baker, & Shrestha,, 1995; Rico, Manzanares, Gil, & Gibson, 2008). A team's awareness and understanding of a complex and dynamic situation has been referred to in the literature as team situation awareness (TSA) and the process teams apply to gain TSA as team situation assessment (Cooke, Salas, Cannon-Bowers, & Stout, 2000; Endsley, 1995). In this paper we focus on a pivotal aspect of team situation assessment, namely the formation of team situation awareness through communication processes within the team. Although the importance of the formation of team level situation awareness has been widely acknowledged (Gutwin & Greenberg, 2004; Rico et al., 2008; Roth, Multer, & Raslear, 2006; Waller et al., 2004), little is known about the team processes underlying its development.

In addition, a number of calls have been made for the inclusion of temporal aspects in theories and studies of group and team processes, and scholars have posed numerous temporal characteristics of team communication behaviors (e.g. Ancona, Okhuysen, & Perlow, 2001; Arrow, Poole, Henry, Wheelan, & Moreland, 2004). However, Ballard, Tschan, & Waller (2008) noted that, despite these widely recognized calls "this variety of possible temporal patterns is not well reflected in group process research, even in studies where the group process is directly observed" (p.337). Therefore, in the present study we take a temporal approach to studying the team communication process. Notably, we investigate three temporal aspects of team processes that have been found to be important for understanding team functioning: the occurrence of phases in the team communication process (Gersick, 1988; Poole 1983), characteristics of team interaction patterns—reoccurring sequences of team members' communication actions—(Stachowski, Kaplan, & Waller, 2009; Waller, Zijlstra, & Philips, 2007), and the effect of the timing of specific types of team communication in the team communication process (Tschan et al., 2006; Waller, 1999).

We investigate the team communication process aimed at the formation of team situation awareness and team decision making of 12 multidisciplinary crisis management teams performing in an emergency management simulation. Building on the theory of situation awareness developed by Endsley (1995) in combination with a communication perspective on team cognition (Keyton et al., 2010; Waller, 1999; Tschan, et al., 2009), we investigate the structure, antecedents, and consequences of team situation awareness communication (TSA-C). The following section details the boundary conditions of the paper. Then, we review pertinent literature on TSA and provide a linkage between the cognitive notion of TSA and three levels of team communication. After this we present hypotheses and describe a study of 12 emergency system command teams. In our analyses we combine an exploratory approach—assessing the phase structure in the team communication process—with a hypothesis testing approach—testing the antecedents and consequences of TSA-C. Finally, we provide a discussion of the results and implications for future research and practice.

Theoretical background

Boundary conditions

Although the different types of teams enumerated in the introduction of this paper stem from rather disparate fields, there are some clear overlapping aspects in the characteristics of the teams as well as in the challenges they face. Therefore, we would like to point out five characteristics that serve as boundary conditions for the theory development and testing in the remainder of this paper.

A first point to note is that the teams we focus on in this study consist of experienced professionals. Whether they are medical teams, pilot teams, or crisis management teams, team members have received extensive training and hold an accumulated body of experience in functioning in comparable task situations. Research on expertise in problem solving indicates that experienced task performers are more effective in filtering information and more rapid in assessing underlying causes of problems than novice task performers (Larkin, McDermott, Simon, & Simon, 1980). Moreover, through extensive training team members are likely to develop efficient routines and operating procedures they can rapidly put to practice when the situation has been appropriately assessed (Klein, 1993; Rasmussen, 1990).

Second, the present study concerns temporal "swift starting" teams. McKinney, Barker, Davis, and Smith (2005) describe swift starting teams as consisting of well-trained professionals with no or limited knowledge of others on the team, that must perform immediately as they face high stakes from the beginning. In high-stakes environments—such as medical or crisis management environments—where teams have to form rapidly in response to an unexpected problem, teams are often composed of those organizational members that are available at the moment, and hence may have no or limited previous experience in working together (Tschan et al., 2006; Faraj & Xiao, 2006). Swift starting teams do not have time to go through typical team development processes and therefore have to rely on pre-existing structures and quickly establish interaction patterns in order to immediately engage in task performance upon the formation of the team. Waller and co-authors (2007) found in a study of aviation crews that these swift starting teams establish patterns of interaction very early in their work and that significant differences existed between interaction patterns of effective and ineffective teams.

Third, the specific challenges faced by these teams stem, to a large extent, from the high levels of complexity and dynamism of the environments in which they function. In highly complex environments, a large amount of variety and interrelatedness of elements encumbers the formation of an understanding of the situation and therefore necessitates that teams engage in extensive interpretive or diagnostic activity in order to be able to take effective action (Nosek & McNeese, 1997; Weick, 1995). Environmental dynamism implies that "the state of the world changes, both autonomously and as a consequence of the decision maker's actions" (Brehmer, 1992: 211). In dynamic environments, information is often uncertain or incomplete and crucial facts only become available as time progresses and the situation unfolds (Orasanu & Connelly, 1993). Moreover, team actions, task situations, and information availability are tightly interconnected; actions may change the task situation as well as allow for team members to obtain feedback and acquire additional data (Orasanu & Connelly, 1993; Weick, 1988). Since, under such circumstances, failures to make timely decisions and take appropriate actions may quickly result in adverse consequences, teams are under significant time pressure to rapidly form a practicable understanding of the situation (Rudolph, Morrison, & Carroll, 2009; Waller et al., 2004).

Fourth, as the previous two conditions already indicated a defining characteristic of the teams studied in this paper is their preoccupation with speed. Although an accurate and shared understanding of a crisis situation is important for effective performance, such high-reliability teams often do not have sufficient time to exchange and discuss all information. Given the rapidly changing dynamics of the task situation, actions must sometimes be taken without completely accurate and shared understanding. As Weick (1995) indicated, "(w)e might expect that speed, rather than a 'constant and close look,' would dominate whenever anyone has to adapt to complex cue patterns" (p. 58). Therefore, unlike other teams that work under less time-pressure—think for example of policy makers dealing with "global warming"—the fact that in these teams time is a very "scarce resources" is likely to have a profound impact on the particular dynamics of the communication within these teams.

Fifth, in the present study we focus on team processes that occur during transition periods. Marks, Mathieu, and Zaccaro (2001) argue that teams alternate between action and transition phases. Whereas during action phases teams engage in the actual execution of team goal attainment, during transition periods, teams engage in planning and preparations that facilitate the task execution during the action stages. The teams that are the subject of the present study should be distinguished from more generally studied work teams in that their purpose lies particularly in the optimization of these transition processes. The teams that are studied consist of high-level command teams of a multi-disciplinary multi-team system responsible for the management of large scale emergency operations. These command teams consist of the team leaders of the lower-level component teams. The goals of the team meetings are the sharing of information, the development of a shared understanding of the task situation, and the coordination of actions. Whereas these command teams are responsible for the execution of the emergency management operation, the actual action processes—the processes that are directly related to the combating of the incident—are executed by the lower-level field teams. So, during an actual crisis management operation, the command team members alternate between in-field periods and team meetings. During the in-field periods they gather information and provide commands and instructions to their own component team. During the team meetings, which are the focus of the present study, they engage in transition processes aimed at facilitating the action processes of the crisis management operation (Uitdewilligen & Waller, 2011).

Team situation assessment and team situation awareness

Despite the prevalence of teams functioning in such dynamic and complex environments, research on team cognition has mainly focused on relatively stable individual and team level knowledge structures, without explicitly articulating the cognitive processes in which team members individually and collectively engage (Salas & Fiore, 2004). Therefore, as a first step towards a dynamic account of team cognition, we make a distinction between the general long term knowledge that is embedded in individuals' cognitive structures—generally indicated as schemas, scripts or mental models—and the more specific and short term TSA that comprises the dynamic understanding of a specific situation (Bolman, 1980; Cooke et al., 2000; Orasanu, 1990; Salas et al., 1995; Stout, Cannon-Bowers, & Salas, 1996). Bolman argued that flight crews develop a 'theory of the situation'—a set of goals, beliefs, and behaviors that provide a coherent picture of what is happening and what action is appropriate" (1980: 32). Bolman explicitly distinguished these ephemeral 'theories of the situation' from the more stable and long-term 'theories of practice', which consist of cognitive patterns that enable individuals to construct a coherent understanding of a situation. Similarly, Cooke and colleagues (2000) refer to team situation models as the team's collective understanding, constructed from the team members' mental models but also incorporating specific information from the current situation. Since task situations change, new information becomes available, old information becomes superseded or forgotten, and understanding develops over time, TSA is subject to continuous change during a team's task performance episode (Nosek & McNeeese, 1997; Weick, 1995). Therefore, TSA can be characterized as what Marks, Mathieu, and Zaccaro (2001) called a team emergent state— a dynamic property of the team that varies as a function of team context, inputs, processes, and outcomes.

Scholars have suggested that team knowledge structures are particularly important for team coordination—the attunement of individual team members' actions toward goal directed performance (Cannon-Bowers, Salas, & Converse, 1993; Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000). Rico and colleagues (2008) argue that the dynamic knowledge structures a team develops while engaging in task performance constitute a more proximal antecedent for implicit coordination—coordination based on the tacit anticipation and adjustment to the actions and needs of other team members—than the more general team mental models. Agreeing upon a mutually understood label of the situation constitutes an important coordination mechanism for teams consisting of interdependent highly trained individuals (Bigley & Roberts, 2001; Rico et al., 2008). When team members have different roles and are trained to execute different functions within the team they are likely to develop distinct yet compatible procedural knowledge structures, allowing each of them to effectively execute their individual tasks while at the same time coordinating their activities with the other team members (Banks & Millwards, 2007; Marks, Sabella, Burke, & Zaccaro, 2002).

The link between TSA and team coordination proposed by Rico and colleagues (2008) can be explained by combining the notions of script theory and coordination. According to script theory, different situational labels—so called script headers—are likely to trigger different action repertoires from procedural memory (Bowers, Black, & Turner, 1979; Schank & Abelson, 1977). Similarly, in an organization in which behaviors are strongly guided by pre-established procedures, situation labels will be associated with specific procedures and procedures of individual members or entities are developed in such a way that they are compatible with each other. Therefore, the collective attachment of a specific label to the situation ensures that in each team member those unique procedural knowledge structures will be triggered that will lead to the interlocking coordinated actions the team requires to execute its task as an integrated entity (Poole, Gray, & Gioia, 1990; Zohar & Luria, 2003). For example, when a crisis management team categorizes an emergency situation as 'class A', fire fighters will extinguish the fire from a distance and medical personnel will stay put until they get the opportunity to take care of casualties, while if the situation is classified as 'class B' the fire fighters will fight the fire at close quarters and medical personnel will take immediate care of the wounded. Although the exact meaning attached to the labels may differ among the team members, collective acceptance of the label and compatibility in their procedural knowledge structures enables the team members to effectively coordinate their activities (Cannon-Bowers et al., 1993; Klimoski & Mohammed, 1994).

However, apart from this implicit form of coordination based on relatively automatic script based processing, teams may be faced with situations that cannot be directly categorized under predefined labels. In such situations, teams must engage in active TSA-C through which they share information about the situation, influence each others' understanding, and co-construct their situation awareness (Stout et al., 1996; Weick, 1995). This form of active TSA-C is closely related to team sensemaking "the process by which a team manages and coordinates its efforts to explain the current situation and to anticipate future situations" (Klein, Wiggins, & Dominguez, 2010, p. 304). In the next sections we discuss more thoroughly the nature and the communication practices that may lead to high quality TSA.

Three levels of TSA-C: facts, interpretations, and anticipations

The existing literature has indicated two facets of TSA that are important for team functioning: TSA similarity and accuracy (Salas et al, 1995). Similarity refers to the extent to which TSA is shared (similar) among the team members. TSA accuracy refers to the extent to which the awareness of the situation matches the actual state of that situation (Endsley, 1995; Mosier and Chidester, 1991). However, whereas accuracy may be important in relatively simple and straightforward situations, in more complex and ambiguous situations it is often not possible to objectively know what the situation is and to compare team members' understanding of the situation with a 'true' accurate view of it. Situation assessment in such situations more closely resembles the notion of sensemaking, which emphasizes the idiosyncratic and subjective nature of the processes of giving meaning to and constructing an understanding of the situation (Weick, 1995). Literature on sensemaking seems to suggest that it is not as much TSA accuracy but rather, a rich understanding of the situation that enables teams and organizations to be prepared for a wide variety of possible situations (Starbuck & Milliken, 1988; Weick et al., 2005).

In the theory of situation awareness, this richness of the situation understanding is implicitly addressed in Endsley's (1995) distinction between three levels of situation awareness. Endsley argued that situation awareness can be distinguished into three hierarchically ordered levels: the first level pertains to the perception of the individual elements in the environment, the second level to the integration or interpretation of the elements into a comprehension of the current situation, and the third level refers to the projection and anticipation of future states. In the next section we will first introduce a communication perspective on team cognition, then we will link the three levels of TSA posed by Endsley to teams' knowledge sharing and collective interpretation processes and we will build hypotheses that link these processes to team performance.

TSA and team communication

Whereas in the previous sections we have provided a dynamic depiction of the product of team situation awareness, we now will turn to a discussion of the process of TSA-C—how team situation awareness is created, maintained, and adjusted over time through team communication. Keyton and co-authors (2010) propose a communication perspective on team cognition that recognizes communication as a macro-cognitive process (Letsky, Warner, Fiore, & Smith, 2008) and emphasizes that meaning is developed in interaction. They propose a research methodology that takes team communication as a reflection of team cognition. Although team cognition may entail team members' individual knowledge structures and cognitive processes, collective meaning is created in group dialogue and hence communication can be seen as a window into group cognition. Cooke, Gorman, and Kiekel (2008) make a distinction between 'in the head' and 'between the head' approaches to assessing team cognition. Whereas an 'in the head' approach to team cognition focuses on the characteristics of team members knowledge structures as input to team processes, a 'between the head' approach locates team cognition in the interaction processes occurring among the team members. They conclude that "we . . . propose that communication is not just a window into team cognition, but that communication is cognitive processing at the team or group level" (p.54, 2008).

Integrating a communication perspective on team cognition with situation awareness theory of Endsley (1995), in the next section we will build a number of hypotheses linking specific TSA-C processes to team performance. First, individual team members' communication behaviors can be categorized as falling under one of the three levels of TSA information and the extent to which team members engage in these types of communication is likely to have an impact on team functioning. Second, we argue that not only the amount of TSA information a team exchanges but also the extent to which teams engage in collective versus individual interpretation processes is likely to have an impact on team performance. Furthermore, we identify antecedents that may influence the extent to which a team engages in collective interpretation processes.

Hypotheses

Team information sharing is the introduction of members' individually held knowledge into the team's public space. It refers to the simple exchange of privately held information about the task situation with the other members of the team. By exchanging information about the situation, teams may not yet create a shared understanding of the task situation but a shared body of information may constitute the input for higher level situation awareness formation. Studies on cooperative work teams have observed the practice of 'talking to the room', in which team members express out loud new information not directed at a specific individual but instead to the room at large (Artman & Waern, 1999; Heath & Luff, 1992; Waller & Uitdewilligen, 2008). By expressing information aloud in this manner, teams create common ground—a shared knowledge base combined with the awareness that the knowledge is shared—that can serve as an input for collective sensemaking (Clark & Brennan, 1991; Krauss & Fussell, 1991).

A wide variety of studies indicates that information sharing is a pivotal team process with a substantial impact on team performance. In a recent meta-analysis, including a wide variety of teams and tasks, Mesmer-Magnus and DeChurch (2009) found a consistent positive relationship between team information sharing and team performance. However, existing research has not taken into account that different types of information can be shared among team members. Therefore, based on the situation awareness theory of Endsley (1995) we pose that individual team members' information sharing behaviors can be categorized as falling under one of the three levels of TSA information.

Level one TSA information refers to basic factual information about individual elements of the situation. When team members communicate level one TSA information, they forward simple factual information they received about the task situation. Level two TSA information, on the other hand, refers to semantically enriched information that is the result of the integration of information elements into a comprehension of the current situation. Level two TSA information can be distinguished from level one information by the interpretation processes that have taken place on the information. Interpretation is about giving meaning to stimuli; it is the process whereby disjointed information elements are synthesized into a holistic understanding of the situation (Endsley, 1995), or informational elements are linked to existing knowledge structures (Durso & Gronlund, 1999; Starbuck & Milliken, 1988; Weick, 1995). Accordingly some scholars have referred to this process as 'running' mental models, by which they mean that information gleaned from the environment is inserted into individuals' mental models and inferences are derived by reasoning according to the internal logic of the model (e.g. Banks & Millward, 2000; De Kleer & Brown, 1983; Klein, 1993). So, when team members communicate level two TSA information, they share information that results from a combination of level one information and their previous knowledge. The third level of TSA information pertains to projections and anticipations of future states. This level of situation awareness extends interpretations of the situation with projections of how the situation will develop in the near future (Endsley, 1995).

Combining research on team information sharing and TSA, we expect that sharing information on the three levels of TSA is likely to contribute to the development of shared and high quality TSA, which will have a positive effect on team performance. Therefore, we propose that:

H1: The amount of level one, level two, and level three TSA information that is shared within the team during a time interval will be positively related to team performance during that interval.

The information sharing behaviors described above represent individual level constructs—they are acts of communication performed by individual team members. Simply looking at single communication behaviors ignores the temporal context in which these behaviors occur (Weingart, 1997). Although frequencies of the occurrence of these behaviors during a specific period may provide us with an estimation of the amount and type of information that is shared, it provides no information about how the team processes this information over time. Therefore, the exact meaning of a communication behavior should be considered in context of the behaviors that precede and follow it in time (Ballard et al., 2008; Weingart, 1997). For example, level one TSA information provided in response to a question may indicate a different type of team communication than the same information provided without a specific request (e.g. Rico et al., 2008; Stachowski et al., 2009). Therefore, we argue that in addition to the extent in which teams engage in information sharing, the specific form of this information sharing process also matters. More specifically we expect that the extent to which the teams engage in collective interpretation processing will be important for team performance.

The information processing model of groups poses that just like individuals, teams collectively process information by encoding, remembering, processing, and responding to information (Hinsz, Tindale, & Vollrath, 1997). Much empirical research on information processing has focused on the role of sharing information; how group characteristics and the distribution of information among the group members influence what information is shared among group members during group discussions (Stasser & Titus, 1985). Studies investigating information sharing with a so-called "hidden profile" paradigm often focus on the exchange of level one TSA information. In hidden profile studies information is distributed among team members in such a way that only by incorporating the unique knowledge of each member the team can realize the optimal decision (Stasser & Titus, 1985). Whereas these studies explore the conditions under which group members effectively share privately held information (e.g. Larson, Christensen, Franz, & Abbott, 1998), they do not answer questions about the extent and form of interpretation team members conduct on information before and during their communication with other members. As the information processing model indicates, apart from sharing information, teams also collectively process information by combining and integrating pieces of knowledge into higher order conceptions (Hinsz et al., 1997; Wegner, 1995). For example, research on collective induction shows that groups can derive general principles from a collection of concrete examples (Laughlin & Futoran, 1985).

Team members can individually process lower level information into higher level understandings but they can also do this collectively in an interaction process taking place among the team members. In an experimental study, Fraidin (2004) showed that teams benefited when specialized team members could connect individual information elements before sharing them with the other team members. It can thus be efficient if team members individually interpret information before they share it with the other members; particularly if these team members are more experienced with processing this particular kind of information (Wegner, 1991). However, there also is a risk involved in individual processing. Because the other members will not have access to the raw information material, they may not always be able to check the interpretations (Hutchins, 1995). They will not be able to come to different conclusions and disagree on the interpretations of the data. Therefore, apart from individually forming interpretations, team members may also explicitly process information—by speaking out loud—during interaction, thereby enabling each other to adjust, correct, refine and co-create higher order information from lower order information elements (van den Bossche, Gijsleaers, Segers, & Kirschner, 2006). Because team members have different background knowledge (e.g. mental models) they may apply to the information, they may process similar pieces of information differently and consequently come to differing interpretations. By asking questions and publicly making inferences, group members impact not only their own but also other members' interpretation of that information, thereby engaging in deeper levels of information processing.

A number of concepts have been posed in the literature, that tap into the notion that teams differ in the extent to which they engage in thorough information processing. De Dreu, Nijstad, and Van Knippenberg's (2008) posed the idea of motivated information processing in groups. This theory poses that the extent to which group information processing is deliberate and systematic—versus shallow and heuristic—depends on the extent to which group members are motivated to achieve a rich understanding of the situation. Van Knippenberg, De Dreu, and Homan use the concept of information elaboration, which they define as "the exchange of information and perspectives, individual-level processing of the information and perspectives, the process of feeding back the results of this individual-level processing into the group, and discussion and integration of its implications" (2004, p. 1011).

Several studies have indicated a positive relationship between information elaboration and performance (e.g. Homan, van Knippenberg, Van Kleef, & De Dreu, 2007; van Ginkel, Tindale, & van Knippenberg, 2009). Schulz-Hardt and colleagues (2006) found that discussion intensity—coded as the average proportion of information mentioned, the average repetition rate of information, and the discussion time—was the primary mediator between the effects of dissent on group decision quality.

In sum, in complex and ambiguous environments team information processing cannot be represented merely by the amount of information shared within the group but is strongly dependent on the extent to which a team collectively engages in higher level processing of the available information. We expect that in particular, team processes, in which team members engage in an exchange of their interpretations about the situation, will lead to shared and high quality TSA. Therefore, we propose that:

H2: The extent to which the team engages in collective interpretations during a time interval will be positively related to team performance during that time interval.

Team phases and the timing of TSA-C

Previous studies on team processes over time suggest that particular clusters of team activities often occur during specific periods in the team process, suggesting the occurrence of segments or phases in the team process (e.g. Gersick, 1988; Poole, 1983, Tuckman, 1965). Poole and Holmes (1995) define a phase as “a coherent period of group interaction and activity that serves an identifiable function, such as a period of problem definition” (p.102). An often cited example of a phase structure in the team process is Gersick’s observation that team’s shift the nature of their activities when half of the time they have been allotted has been surpassed.

Ballard and colleagues (2008) noted that although group processes are often clearly segmented, because the segments are not regularly distributed over time, they may not be identifiable by simply dividing the task in evenly distributed time intervals. Therefore, we expect that the global structure of the team communication process will manifest the occurrence of changes in the concentration of specific types of team communication over the complete team task episode. If similar shifts in the concentration of activities occur in most of the teams this suggests the existence of a phase structure in the teams’ communication: the existence of specific periods in which the teams engage in activities that are qualitatively different from the activities in the adjacent periods (Poole, 1983). Note that these shifts in the communication structure do not necessarily occur at the same time in all teams; teams may differ in the amount of time they spend in each phase and therefore also in the moment in time they shift from one phase to another. Previous studies on team communication suggest that it is not the total frequency of specific behaviors per se, but the timing of team behaviors that is important for successful team performance (Waller, 1999; Tschan et al., 2006). Therefore we expect that *teams will manifest an identifiable phase structure in the team communication process and the timing of team communication behaviors within the team phases will be important for team performance.* Because we cannot a priori establish the phase structure in the team communication processes, we do not propose a formal hypothesis; instead, we will explore the teams' phase structure to specify more precisely when in the teams' communication process, specific behaviors and processes are most beneficial for team performance.

Communication structuring practices and TSA

One of the biggest challenges to crisis management teams is the balancing of sometimes conflicting needs for comprehensive information processing and the need to return to the field as rapidly as possible. In order to comply with these dual purposes, teams should optimize the efficiency of their transition processes in such a way that they can maximize the amount and quality of information processing in the minimum amount of time. Important factors therefore in explaining team performance are the practices and behaviors a team uses to structure its communication process (Hanssen, van de Wiel, Zijlstra, Bauhus, & Koopmans, 2010). From the existing literature we identified three practices teams can use to structure their communication processes: structuring behaviors, external objects, and standardized interaction patterns. Below we will provide reasoning for the relationship between each type of structure and TSA communication.

Structuring behaviors. Maier (1967) argued that in order for a group to optimize its decision making quality, group leaders should manage the group discussion process by managing the topics and information that are entered into the group discussion, by encouraging members to speak, by dividing speaking turns, and by managing the time. In other words, active structuring of the group communication process is required in order to ensure efficient information sharing and the integration of various viewpoints. Studies that have looked at the role of structuring during team discussion seem to provide support for this notion. Peterson (1997) found that process directiveness—the extent to which the leader regulates the process by which the group reaches its decision was consistently positively related to the quality of group processes and outcomes. In an experimental study, Stasser, Taylor, and Hanna (1988) found that providing a structure for group meetings increased the amount of information shared in decision making groups; however, this increase was due mainly to an increase in sharing of information that was already held by more than one team member. From a study that did an in depth analysis of patient review meetings, Hanssen and colleagues (2010) concluded that given the limited amount of time medical personnel can spare for meetings and given the high requirements for information sharing, meetings should be highly structured and efficiently organized.

It could be argued that although high amounts of structuring behaviors may be related to speed and efficiency, it may also have downsides in terms of reduced openness to new information, flexibility and creativity. If a team leader strictly guards the meeting agenda and speaking turns, team members may be withheld from sharing thoughts or information and from making cross linkages among topics. Whereas when team leaders take a more yielding approach to the communication structure in the group, team members may voice a wider network of associations, information, and ideas. However, it should be noted that whereas structuring the team communication process is often considered an important component of the team leader role (e.g. Maier, 1967) structuring behaviors may be performed by other team members as well. Moreover, with structuring behaviors we do not refer to a strict adherence to fixed regulations and procedures; instead they constitute a set of behaviors that can be applied by the team leader and other members to control and actively guide the interaction patterns within the team. For example, structuring can be used to terminate a discussion on a low priority issue but also to probe members to more thoroughly assess a crucial issue. Instead of fixed and pre-established behavior patterns, structuring actually constitutes adaptive behavior that can be used to actively guide the communication process. Therefore, we expect that, given the emphasis on speed and efficiency, structuring behaviors will be positively related to the extent to which a team engages in collective interpretation processes.

H3a: The amount of structuring behaviors will be positively related to the extent to which a team engages in collective interpretation processes.

Knowledge tool (whiteboard). Apart from structuring behaviors, teams may use knowledge tools, such as schema's and whiteboards to structure the team situation assessment process. In particular work on distributed cognition emphasizes the role of artifacts in the formation of TSA (Hutchins, 1995; Heath & Luff, 1992). For example, from an in depth anthropological study of a rescue command system, Artman and Garbis (1998), concluded that artifacts (a diary, schedule, and a whiteboard with map) played an important role in the formation of teams' situation awareness as they "contain the necessary but not sufficient information" and therefore "team members must in addition interpret the information and make sense of it" (p.6).

Use of knowledge tools seems to be beneficial not only because they structure the communication behaviors—such as speaking terms and sequence of topics that are discussed—but more particularly because they can provide team members with a cognitive structure that may help them to keep an overview of and efficiently remember the information that is presented in the group (Fiore, Cuevas, & Oser, 2003; Suthers & Hundhausen, 2003). This role of a whiteboard as a cognitive structuring device gains support from an experimental study of Rentsch, Delise, Salas, and Letsky (2010), in which they trained half of their teams to exchange information on an information board using schema enriched communication. They found that, teams in the training condition made significantly more use of the information board and consequently had higher quality knowledge and more cognitive congruence than teams in a control condition. Maier (1967) suggested that groups like individuals can be considered to have working memory in which they keep active the information that is relevant for the task. An external knowledge tool, such as a whiteboard, can help a team to structure its knowledge and offload the limited working memory capacity of the team members (Scaife & Rogers, 1996). Therefore, we suggest that:

H3b: The use of a knowledge tool, such as a whiteboard, will be positively related to the extent to which a team engages in collective interpretation processes.

Standardized interaction patterns. A third structuring practice that has been investigated in the literature refers to the repeated use of standardized interaction patterns among the team members (Gersick & Hackman, 1990; Kozlowski, Gully, Nason, & Smith, 1999). Interaction patterns are defined as "regular sets of verbalizations and nonverbal actions intended for collective action and coordination" (Stachowski et al., 2009, p. 1537). Interaction patterns provide structure to the team communication process by creating shared expectations among the members about the sequence of speaking turns and communication actions. For example, if a team leader has consistently followed up all explanations of a fire officer with a short summary, team members will expect this behavioral sequence to prevail and are likely to adjust their own behaviors to it.

Empirical results on the effects of standardized interaction patterns on team performance are mixed. On the one hand, in their research on cockpit crew teams, Kanki and colleagues found that higher performing teams used more standardized interaction patterns (Kanki & Foushee, 1989; Kanki, Folk, & Irwin, 1991). They explain these results by speculating that closely following standardized operating procedures leads to predictable patterns that facilitate coordination because they allow team members to accurately predict each others' behaviors. On the other hand, Stachowski and colleagues (2009), in a study on nuclear power plant control teams responding to a simulated crisis, found that better performing teams exhibited fewer, shorter, and less complex interaction patterns. They argue that, although routinized interaction patterns may be beneficial under normal routine circumstance, crisis situations require teams to flexibly adjust their role structures and interaction patterns. Particularly in situations requiring extensive sensemaking of ambiguous information and consisting of novel circumstances, adherence to standardized behavior may be detrimental because it may set teams in an automatic—versus a deliberate—processing mode (Louis & Sutton, 1991; Schiffrin & Schneider, 1977). Therefore it is likely to promote the acceptance of existing off-the-shelve interpretations and limit a teams' pursuit of a wider possibility of interpretations that may lead to a deeper more nuanced understanding of the situation (De Dreu, et al., 2008). Therefore, we expect that:

H3c: The use of standardized interaction patterns will be negatively related to the extent to which a team engages in collective interpretation processes.

Methods

Sample

We collected data on 12 multidisciplinary crisis management teams consisting of 9 members per team operating in a single inter-organizational emergency management network in the Port of Rotterdam region. Each team is headed by an officer of the fire brigade and in addition is comprised of another officer of the fire brigade, an officer of the police force, an officer of the port authority, a chemical specialist from the medical protection service, a representative of the medical emergency service, a representative of the municipality, an information manager, and a public relations official of the police department. All participants in the simulation were active members of their respective emergency organization. The participants participated for training purposes and the assignment to teams was based on scheduling conveniences. The average age of respondents was 43.98 years (SD = 9.43), their average tenure was 16.20 years (SD = 12.52), and they had been member of emergency management teams on average for 6.82 years (SD = 6.64). All teams consisted of Dutch members.

Training exercise

We studied the teams as they performed in a training exercise consisting of a simulated scenario of an incident comparable to the type of incidents they would encounter in their role as command team members during multi-team system crisis management operations in the Port of Rotterdam. The scenario has been developed by a group of experts with representatives from the various emergency services involved. Information about the scenario was presented to team members at pre-specified times via their individual computer screens or collectively via an overhead projector placed in the middle of the room. Team members were seated at individual work-stations containing two computers. On the first computer, they received role specific information and they could input commands, send messages to each other, and ask questions to the simulation leaders. They could use the second computer for accessing the internet or their own databases to collect additional information. At regular intervals, team members came together in the corner of the room at a rectangular table in Command Place Incident (CoPI) meetings to share information, construct a shared understanding of the situation, and collectively make decisions. These sessions were videotaped using two cameras and three microphones connected to the ceiling of the room. Due to variations across team processes, the number of collective meetings teams engaged in varied per team. Nine teams engaged in three collective meetings and three teams engaged in two collective meetings.

Procedure

Team members were invited to attend one of twelve—six morning and six afternoon —crisis management simulation sessions taking place in one year. A schematic depiction of the room were the exercise took place can be found in Figure 1. At the start of each session team members were provided with a presentation instructing them on the purpose and goal of the simulation, the simulation procedures, and the use of the simulation interface. In order to familiarize the participants with the procedures and simulation interface they started with a short practice scenario. After the practice scenario team members were asked to seat themselves at their individual work station and the main scenario was started. During the scenario, participants received information about the emergency incident at pre-established times. Participants of the emergency services received information that corresponded with their role in the simulation and that was comparable to the information they would encounter in the field during actual emergency operations. During the simulation participants could send short messages to each other and contact the simulation leaders to gather additional information. Apart from information presented via their computers, participants received scripted information from simulation leaders who played the role of field officers and representatives of the companies involved. Information provided to the participants was scripted; however, the amount and type of additional information team members could gather depended upon the questions they asked to the simulation leaders. The main scenario lasted approximately three hours and contained two or three CoPi meetings. The team leader was responsible for initiating and deciding upon the duration of the CoPI meetings. After the simulation team members filled in a short questionnaire regarding their background and experience during the simulation.

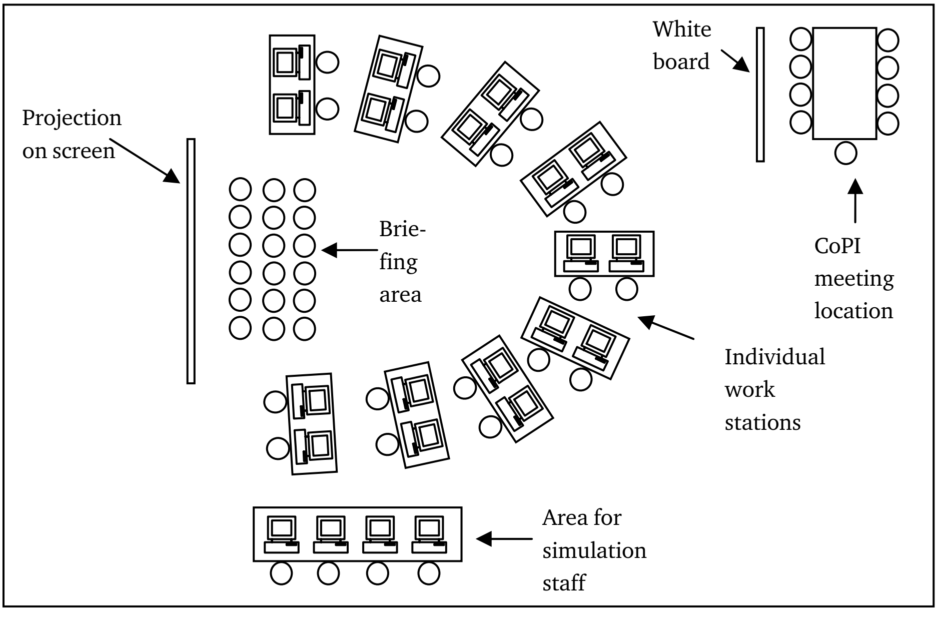


Figure 1. Schematic map of the simulation room

Scenario

The scenario consisted of a large scale traffic incident on a busy traffic intersection, involving multiple trucks and vehicles, chemicals (formic acid and styrene) leaking from a higher to a lower roadway, and multiple casualties. The scenario was developed so that each emergency service organization (each team member role) would be involved in the incident. The chemical advisor supervised the measurement of substances and informed the other services on the effects and dangers associated with them. The fire brigade was responsible for rescuing casualties and executing all activities that took place directly at the incident location.

The Port Authority provided back up of fire extinguishing powers to the fire brigade and, given that the location of the incidents was close to the harbor premises, they provided blueprints of pipelines and chemical storage facilities that could be affected by the incident. The medical service was responsible for treating and transporting casualties. The police force was responsible for clearing of the incident location, securing access routes towards the incident, leading civilian traffic flows away from the incident, and assessing the liability for the accidents. The representative of the municipality was responsible for sheltering civilians that had been affected by the incident and the public relations official controlled the release of information towards the public and press.

The emergency services were highly interdependent in the execution of their tasks. For example, whereas, the medical services are in charge of treating and transporting casualties, they were not allowed to enter the incident area itself and therefore depended upon the fire brigade to rescue the wounded from the vehicles and supply initial medical care. Because of the complexity of the scenario and the fragmented distribution of information, it was crucial for the team members to share information and collectively construct a representation of the incident situation during the CoPI meetings.

Not all information about the scenario became available to the team members immediately but instead information was released over time as the events in the scenario unfolded. The scenario was interactive to a limited extent; contingent on decisions of the team members, the scenario could take separate directions (e.g. traffic jams could be limited to the extent that teams chose to divert traffic streams early on in the scenario). However, the overarching logic of the scenario and the main information elements remained similar independent of the decisions taken by the teams.

Data Coding

Our measures of TSA-C and team interaction patterns are based on behavioral observation of the videotapes of the CoPI meetings. One independent coder, blind to the hypotheses, recorded CoPI members' communication behaviors on activity logs while watching the videotapes. A second coder (the first author of this paper) coded one of the twelve simulation sessions, in order to establish inter-rater reliability measures. Inter-rater reliability, calculated by Cohen's Kappa's ranged from .64 to .79 with an average of .71, indicating acceptable inter-rater reliabilities (Fleiss, 1981). Thus, we used the first coder's activity logs for the analysis of the communication. The activity logs contained information about the start time of a communication behavior, the role of the team member, and the type of communication behavior. The coders recoded the occurrence of the three individual level TSA-C behaviors (level one, two, and three) and seven other communication behaviors—structuring, questions, affirmations, commands, proposals, decisions, and non-task related communication. Details regarding each coded aspect of communication appear below.

We coded TSA-C as information that was shared with all members during the CoPI meetings. Although, individual cognitive processes occur in and among the minds of the individual team members and therefore can only be effectively studied with knowledge elicitation techniques (Cooke et al., 2000) team cognition processes occur among the minds of team members and can therefore be accessed through analyses of team communication structure and content (Kennedy & McComb, 2010). When team members publicly communicate information in the CoPI meetings it can be reasonably assumed that all team members will perceive this information and consequently it will become collective knowledge (Uitdewilligen & Waller, 2008; Artman & Waern, 1999).

As indicated before, we distinguished between the three levels of team situation awareness that were identified by Endsley (1995). We coded level one TSA-C as occurring each time a team member reported a simple fact. With simple facts we refer to information the team members have received almost literally through the simulation and simply forward to other members. For example, "The driver of the first truck is heavily wounded." In addition this category includes simple information about what actions team members have taken as well as informative confirming or disconfirming answers to questions. For example, in case a team member would ask whether the chemical substance styrene was involved in the incident and another member would answers with "yes" we would code this answer as level one TSA-C. We coded level two TSA-C as utterances referring to interpretations of the situation. With interpretations we refer to an integration of simple information elements or a combination of simple information and a team member's background knowledge (Endsley, 1995). Examples include, "Given that traffic from these two roads will come together here, this traffic route will be heavily overcrowded" and "these chemicals make this situation here very explosive." We coded level three TSA-C as communications behaviors that include an anticipation of a future situation or the development of possible scenarios on how the incident could develop in the near future. Examples of this category include "If that tanker remains at that location, it can also catch fire" and "If these people will be in this traffic jam for much longer we will have to supply them with food and water."

Structure was coded in three ways. First, it was coded every time a behavioral action occurred, in which a team member created structure in the team process. More specifically, this category included statements specifying the agenda of the meeting, asking/allowing someone to talk, urging members to hurry, and inquiring whether the information is clear for all members. Example statements are "I propose to make a round.", "We will come back to that later!", and "Anymore questions?" So, structuring behaviors could occur by the leader as well as by the other members of the team.

Second we measured structure based on whether the team made use of the whiteboard in order to structure their communication. We coded this form of structuring as present if team members actively noted down information on the whiteboard during their discussion. We coded whiteboard structuring as absent if team members did not write anything on the whiteboard, only wrote on the whiteboard before the session but not during the session, or only drew a sketch of the situation on the whiteboard. Seven teams actively used the whiteboard while five teams did not make active use of it during their meetings. Active use of the whiteboard implies that the teams used the whiteboard not only before the CoPI meetings to write down basic information but that members' also wrote down information and referred to this information during the meeting.

Third, we coded *structure* as the extent to which a team's communication occurred in a routinized manner, indicated by their interaction pattern complexity (Stachowski et al., 2009). In order to *assess team interaction patterns,* we used THEME, a pattern recognition software algorithm (Magnussen, 1996; Ballard et al., 2008). THEME software searches for patterns in temporally ordered event data by first searching for simple co-occurrences of events and then combining these into more complex hierarchically ordered patterns. As an input for pattern recognition we ordered the communication in a temporally ordered string of events containing information on the specific communication behaviors and the team member role associated with that communication. Consistent with previous studies using THEME software to derive team interaction patterns (Stachowski et al., 2009) we set the confidence interval to derive patterns at 0.05, indicating that patterns were only retained if they occurred at a less than 5 % probability level. We only retained patterns if they occurred at least 3 times.

Because meeting times as well as the rate of communication to meeting time differed between teams, this may have an impact on the pattern statistics derived by a THEME analysis. As THEME retains patterns that occur at least 3 times, the program is likely to find more patterns in a team with more communication utterances. For example, if a team with 200 communication utterances uses a questions-answer-question sequences two times, it will not be picked up by the program; whereas, if a team with 300 communication utterances uses the same sequences two times in the first 200 utterances and one time in the last 100 utterances it will be picked up. Because we are interested in the structure of the communication, independent of the total amount of communication, we first assessed the total amount of communication that was used by the team with the least communication utterances. Subsequently, for the interaction pattern analyses, we used from each team only the amount of communication similar to that of the team with the least communication utterances (205 utterances). We derived indicators for the total number of different patterns, the number of occurrences of patterns, the average length of patterns, the average hierarchy of patterns, the average number of actors involved in a pattern, and the average number of switches between actors. A factor analysis on these measures indicated that one common factor accounted for 88.91 % of the variance. So, we calculated one pattern complexity factor consisting of the average of the z-score of these six indicators.

Decisions were coded as a decision that closes a raised topic or problem. Thus, a decision always concluded a topic that had been raised and discussed beforehand. Examples, include “So, we’ll scale up the incident to level two” or “Ok, then we’ll place two contamination units, one here and one here.” Questions were coded as occurring when a team member requested information, including clarifications. Examples are “What kind of chemicals are involved in the incident?” and “What does that mean?” Affirmations were coded as occurring when a person agreed to take a specific action. For example “Yes, I will do that.” Commands were coded as occurring when a team member told other team members what actions they should take or what information they should gather. Examples include “So if you will inquire what will happen on the water then!” and “Could you draw that in here please?” Proposals were defined as opinions or suggestions regarding how the incident should be dealt with. For example, “Maybe we should call in another CoPI team” and “We can ask the company manager to join the meeting.” Finally, non-task related communication was coded as all communication behaviors that did not seem to have a direct relationship to the simulation task. This would include communication about general aspects of the job or about colleagues, as well as jokes and laughter.

Sequences

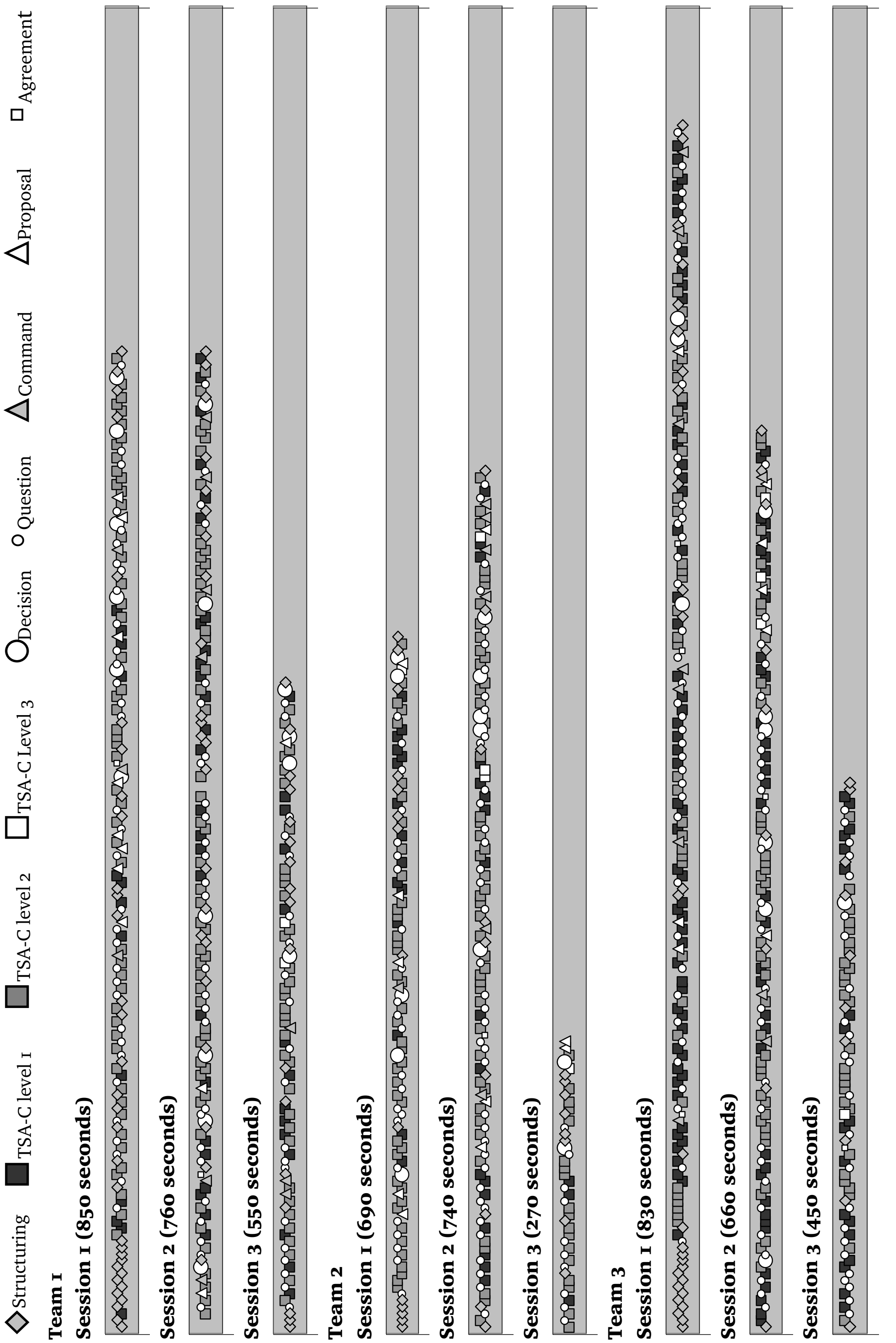
The coded communication acts described above represent individual level constructs—they are acts of communication performed by individual team members. Aggregation of single communication behaviors ignores the temporal context in which these behaviors occur (Weingart, 1997). Therefore, the exact meaning of a communication behavior should be considered in context of the behaviors that preceded it in time. For example, higher level TSA-C information provided in response to a question may indicate a different type of team communication than information provided without a specific request. Since in teams, communication behaviors often occur in reaction to behaviors of other team members, we measure team level communication behavior as sequences of contiguous communication behaviors. Figure 2 displays the sequences of teams' communication behaviors for all sessions of the twelve teams. Sequences are ordered from left to right according to their temporal order and each sign represents a specific communication act. If successive communication acts are located on the same height, this suggests that they are uttered by the same person; if communication acts are alternately located low and high, they are uttered by different team members. The most basic behavioral patterns are sequences consisting of two subsequent communication behaviors and most communication of the CoPI teams can be summarized by five main two-behavior sequences: Question followed by TSA-C level 1, Question followed by TSA-C level 2, TSA-C level 1 and level 2 alterations, TSA-C level 2 alterations, and Mono-actor patterns,. Together these sequences cover 65 % of all communication acts in the teams.

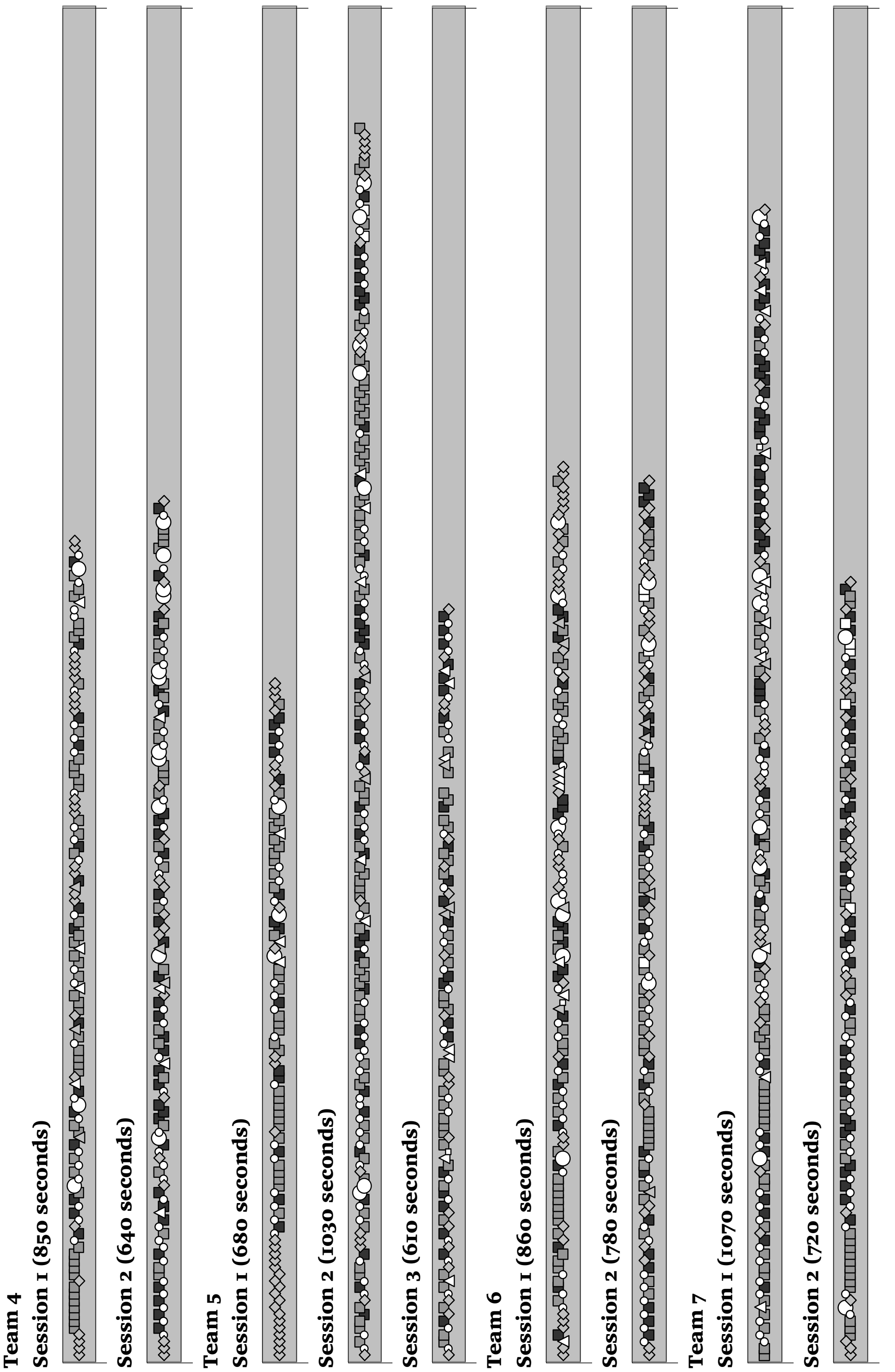
Question-TSA-C sequences make up large part of the teams' communication, occurring on average 66 times per team. 41 times (SD = 20.82) question- level one TSA-C and 25 times (SD = 8.46) question – level two TSA-C combination. The high occurrence of these sequences in the data suggests that in the CoPI teams, members actively probe each other for additional information about the incident situation. It should be noted that the here presumed order of first a question and then an information communication is based on common sense logic as it cannot be derived unambiguously from the data whether the question triggers the TSA-C or whether a previous TSA-C triggers a question. As can be seen in Figure 2 often strings of repeated question-TSA-C occur suggesting the occurrence of small segments of active question driven information sharing.

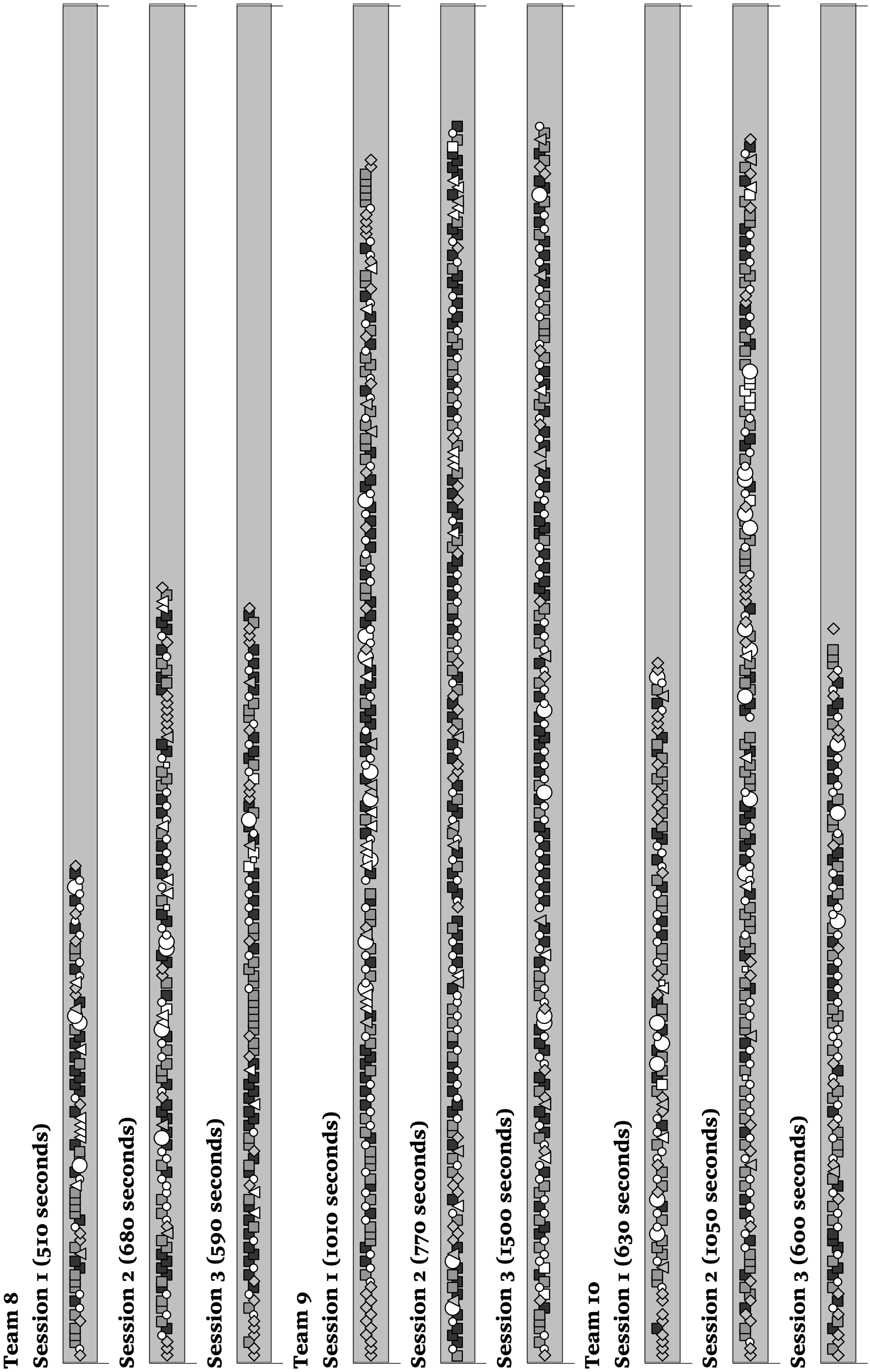
TSA-C following TSA-C by another team member occurs on average 47.22 times (SD = 19.92) in the teams. These combinations suggest that team members are pooling information on a specific topic, for example, as one member provides initial information and another member adds an interpretation. For 32.78 occurrences this constitutes combinations of level one and level two TSA-C. In 14.44 (SD = 7.91) cases this constitutes combinations in which level two TSA-C of one team member is followed by level two TSA-C of another team member. These higher level TSA-C sequences indicate that teams engage in *collective interpretation processing*, whereby team members build on, correct or add to interpretations made by other team members. As can be seen in Figure 2 strings of repeated combinations of higher level TSA-C occur suggesting that teams engage in specific periods in which they combine their interpretations, thereby engaging in team sensemaking activities (Klein et al., 2010).

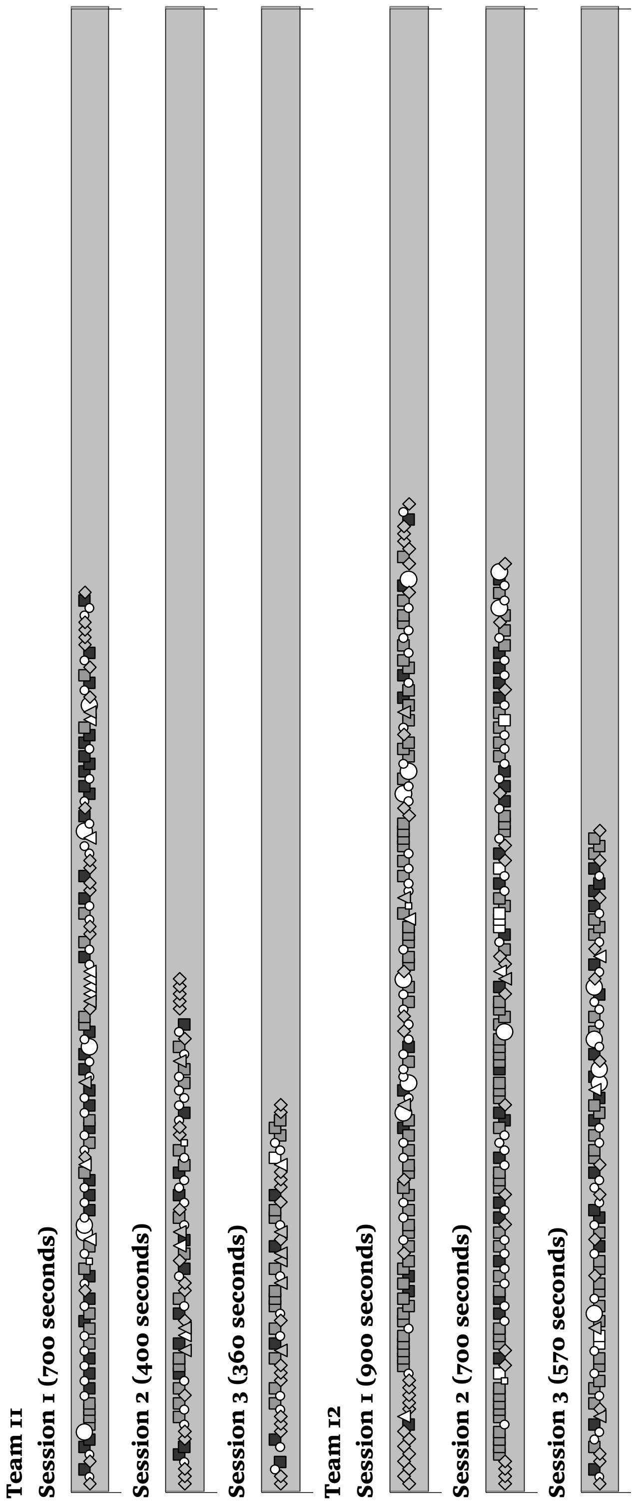
A fifth pattern, consisting of sequences of actions cannot really be considered an interaction pattern as it relates to sequences of behaviors from one single team member. These mono-actor patterns, often consisting of level two TSA-C followed by another level two TSA-C of the same team member occur on average 24.9 times (SD = 10.65) per team. The occurrence of this sequence suggests that one team member is providing explanations to the other members about a specific topic.

Figure 2. Sequences of team communication behaviors




Team 4
Session 1 (850 seconds)
Session 2 (640 seconds)
Team 5
Session 1 (680 seconds)
Session 2 (1030 seconds)
Session 3 (610 seconds)
Team 6
Session 1 (860 seconds)
Session 2 (780 seconds)
Team 7
Session 1 (1070 seconds)
Session 2 (720 seconds)


Team 8
Session 1 (510 seconds)
Session 2 (680 seconds)
Session 3 (590 seconds)
Team 9
Session 1 (1010 seconds)
Session 2 (770 seconds)
Session 3 (1500 seconds)
Team 10
Session 1 (630 seconds)
Session 2 (1050 seconds)
Session 3 (600 seconds)



Team 11
Session 1 (700 seconds)
Session 2 (400 seconds)
Session 3 (360 seconds)
Team 12
Session 1 (900 seconds)
Session 2 (700 seconds)
Session 3 (570 seconds)

Team performance. We measured team performance with a short questionnaire that was filled in by the simulation instructors after the team simulation exercise. Team functioning was judged by two instructors for six teams and by three instructors for the other six teams. Team performance was measured with four questions including questions about the general perceptions of team performance—e.g. "Can you indicate how good you think the performance of this team was during the crisis management simulation?"—, as well as indications of shared understanding of the situation— e.g. "Can you indicate to what extent you perceived there to be a shared understanding of the situation by the members of the team?" Answers were given on 7 point Likert scales. Cronbach's Alpha over the 4 items was .97. $R_{wg}P(j)$s calculated with a moderately skewed null distribution—given a tendency of the raters to give ratings on the high end of the scale—ranged from .78 to .98, with an average of .94, indicating acceptable agreement among the raters (LeBreton & Senter, 2008). Previous research in this area suggests that the distribution of performance is likely to be bimodal (Tschan, 1995; Waller, 1999; Waller et al., 2004). In addition, although the deviation from normality is not significant our performance distribution also shows a bimodal shape. Therefore in line with previous research, teams were categorized as average or high performing on the basis of a median split on the performance score (Raes, Heijltjes, & Glunk, 2009; Tschan, 1995; Waller, 1999).

Results

Table 1 displays the relationship between demographic variables, use of standardized interaction patterns, whiteboard use, total time used by the teams, and team performance. Notably, teams with higher average tenure tend to use more time in total for the scenario. None of the variables was significantly related to performance.

Table 1. Descriptive Statistics and Intercorrelations Between Demographics and Team Performance

		Mean	*SD*	*1.*	*2.*	*3.*	*4.*	*5.*
1.	Average age	43.40	3.33					
2.	Average tenure	15.07	4.40	.79**				
3.	Interaction patterns	0.00	0.94	-.41	-.38			
4.	Whiteboard use	0.58	0.51	.00	-.16	.00		
5.	Total Time	2000.83	499.19	.37	.58*	-.38	-.15	
6.	Performance	5.64	0.97	.34	.34	.21	.46	-.24

Note. N = 12, †p < .10. * p < .05. ** p < .01.

Phase structure of the team communication process

Before our analyses of the antecedents and consequences of TSA-C we conducted an exploratory analysis to determine the phase structure of the team communication processes. An initial starting point for the identification of a phase structure is the division of the team communication process into the clearly demarcated sessions. The temporal structure of a crisis management operation makes it more likely that different types of TSA-C will be more prevalent during different moments in the crisis management operation (Uitdewilligen & Waller, 2011). When teams are faced with unexpected deviations from routine operations, during the initial team meetings, time is likely to be an extremely scarce resource and team members will be bombarded with information. Therefore, we expected that the first team meetings will be dedicated mainly to level one information sharing as there is little room for more advanced TSA-C. In the second team meeting, as the tempo dictated by the immediate demands of the situation slows down, and the amount of new information team members face decreases, team members may have more time for higher level information processing. Finally, in the last meetings of the incident operation, level three TSA is likely to increase as the immediate threat of the incident is under control and teams have constructed initial shared understandings of the situation, the focus shifts towards long-term effects and the finalization of the crisis management operation. Therefore, as a starting point to analyze the phase structure in the team communication process we assess whether the relative occurrence of the different types of team situation awareness differs over the three team sessions.

We used paired sample t-tests to assess whether the relative amount of communication behaviors differed within the teams over the three sessions. Note that because three teams, only had two sessions, t-tests comparing the second and third session are based on a sample of nine teams. As can be seen from Table 2, TSA-C level three significantly increased from the first to the second session, structuring was used significantly less in the third session than in the second session, and the use of proposals decreased from the first to the second session. Altogether, these results indicate that some minor differences exist; however, the use of most of the communication behaviors remains stable over the three sessions.

Table 2. Time and Percentages of Behaviors, and T Tests per Session

	Session 1	*Session 2*	*p**	*Session 3*	*p***
Time (in seconds)	798	744	.47	611	.27
Agreement	0.6	0.7	.67	0.4	.10
Command	2.7	3.3	.64	2.7	.49
TSA-C level 1	21.1	23.9	.19	21.9	.31
TSA-C level 2	25.5	25.4	.96	25.5	.25
TSA-C level 3	0.2	1.8	.00	1.6	.88
Question	25.7	26.1	.32	26.7	.61
Structure	15.3	12.6	.12	14.7	.05
Proposal	4.4	2.6	.02	2.3	.49
Decision	4.9	3.5	.11	2.8	.27
Nontask	0.4	0.6	.31	1.4	.17

* Significance of difference between session 1 and session 2 based on 12 teams

** Significance of difference between session 2 and session 3 based on 9 teams

However, as Ballard and colleagues (2008, p. 338) indicated "phases typically are not regularly distributed over time." Whereas, sessions may indicate one form of phase structure within the teams, additional phases may exist within specific sessions and extend over multiple sessions. A direct examination of the team processes may facilitate the development of well-informed temporal theories, for example, as it may inform us on phases in team interaction, which could not have been identified with simple summary measures of team member behaviors (e.g. Gersick, 1988). Our coding method allowed us to analyze such temporal patterns in the team communication data. As a first step, we created graphical representations of the team communication sequences. As Langley (1999, p. 700) noted "Visual graphical representations are particularly attractive for the analysis of process data because they allow the simultaneous representation of a large number of dimensions, and they can easily be used to show precedence, parallel processes, and the passage of time." She notes that visual depictions themselves are not theories but may provide intermediary steps that facilitate the translation from the raw data to more abstract conceptualization. We first analyzed the team communication data for indications of global patterns—phases—of team communication occurring in all teams. We alternated between investigation of the graphical representations of the team processes represented in Figure 2 and viewing of the actual videos for identification of phases in the communication data.

Global phase patterns

Our analyses of the video data and the communication sequences displayed in Figure 2 suggest that specific segments can be identified in almost all teams, providing a replication of the observed phase structure. Most teams only start making decisions after an initial period of providing structure and sharing information. However, the length of this initial phase differs among the teams, as for example team one engages in a relatively long initial phase whereas team nine immediately engages in decision making actions. As soon as a first decision has been made, additional decisions follow more rapidly. This suggests that a distinction can be made between an initial phase and a subsequent decision making phase.

The initial phase commences in all but one team with a number of structuring actions, typically clarifying team members' roles and laying out ground rules about the process of the meeting. Generally, the leader initiates this structuring but other team members contribute structuring communication as well. After this initial structuring, team members share the information they have gathered and provide explanations about this information to the other team members without explicitly formulating implications for actions. Often team members make a round in which all team members successively share their information with the other members. Team members share information as they are given speaking turns by the team leader, in response to questions from other team members, or as they add details or explanations to information shared by another team member. This initial phase resembles laboratory information sharing tasks in which team members have to pool information that is distributed to the individual members. The goals of this phase is to create a shared understanding of the incident, including aspects such as a spatial understanding of the incident location, knowledge of the chemical substances involved, and an overview of the amount and severity of casualties caused by the incident.

The second, decision making, phase is initiated when team communication shifts from general information sharing about the incident to communication regarding specific decision topics. Whereas, the initial phase is aimed at providing a general structure for the sessions and pooling all important information that is held by the team members, the second phase is aimed at making decisions that are functional for the teams' actions and coordination among the teams. Unlike many laboratory decision making tasks, in which teams only have to make one single decision, CoPI teams need to make decisions on a variety of subjects, ranging from determining the optimal location of medical and decontamination units, to establishing a strategy for containing spilled chemicals and deciding whether the incident should be scaled up to a higher emergency level. Whereas, in the initial phase information is shared per person as each team member shares all knowledge they consider relevant for the other members' understanding of the incident situation, in the second phase the team members contribute and explicitly interpret information in relation to a specific decision topic.

In the initial phase team members set out the ground rules and outline of the meetings and pool their individually held information without restricting information sharing to specific topics. This phase can be identified in the data by the absence of decision making—the initial period before decisions start to follow upon each other in a rapid succession. In the decision making phase team communication is concentrated around specific decision topics and often culminates in the team closing of the topic with a decision. This phase can be identified in the data by a regular punctuation of the communication with proposals and decisions. Although this broad structure seems to occur in all teams, the time each team spends on each phase and the specific activities they engage in within the phases differ per team.

We used paired sample t-tests to assess whether the relative amount of communication behaviors differed within the teams among the two phases. As can be seen from Table 3, the percentages of all communication behaviors except commands ($p = 0.09$) and proposals differed between the phases. The relative amount of Agreements, Questions, and TSA-C level one is higher in the decision making phase, whereas, the relative amount of Structuring and TSA-C level two is higher in the initial phase. TSA-C level three, Decisions, and Nontask related communication do not occur in the initial phase. Altogether, these results provide support for the proposed two-phase structure. Therefore, in the subsequent tests of our hypotheses we will divide the communication processes not only along the three sessions but also along the two phases.

Table 3. Time and Percentages of Behaviors and T Tests per Phase

	Initial phase	*Decision making phase*	*p*
Time (in seconds)	346	1655	.00
Agreement	0.1	0.7	.00
Command	1.5	2.9	.09
TSA-C level 1	16.4	23.7	.05
TSA-C level 2	34.7	23.9	.04
TSA-C level 3	0	1.3	
Question	20.2	26.9	.00
Structure	24.2	12.1	.00
Proposal	3.1	3.2	.85
Decision	0	4.3	
Nontask	0	0.7	

Test of hypotheses

Our first hypothesis suggested a positive relationship between the amount of level one, two, and three TSA-C communication and team performance. Table 4 depicts t-tests comparing the amount of all coded behaviors between the average- and the high-performing teams per session and Table 5 depicts t-tests comparing the amount of all coded behaviors between the average- and the high-performing teams per phase. As can be seen from these tables, none of the behaviors significantly predicted team performance, thereby providing no support for hypothesis 1.

Table 4. Mean Frequency, Standard Deviations, and T Tests of Coded Behaviors per Session for Average- and High-Performing Teams

	Session 1				Session 2				Session 3			
	M	*SD*	*t*	*p*	*M*	*SD*	*t*	*p*	*M*	*SD*	*t*	*p*
Total Time												
Av. Perf. Teams	803	224	0.10	.92	720	208	-0.47	.65	724	445	1.08	.32
High Perf. Teams	793	85			768	140			470	149		
Agreement												
Av. Perf. Teams	0.67	0.52	-0.32	.76	1.00	0.89	1.17	.27	0.20	0.45	-0.88	.41
High Perf. Teams	0.83	1.17			0.50	0.55			0.50	0.58		
Command												
Av. Perf. Teams	3.17	2.04	0.13	.90	3.33	3.14	-0.34	.74	3.40	2.79	1.18	.28
High Perf. Teams	3.00	2.45			3.83	1.83			1.50	1.73		
TSA-C level 1												
Av. Perf. Teams	26.17	12.97	0.44	.67	32.83	19.16	0.60	.56	35.20	36.15	1.12	.30
High Perf. Teams	22.33	17.24			27.83	7.41			14.25	8.18		
TSA-C level 2												
Av. Perf. Teams	23.83	10.65	-1.49	.17	25.83	12.91	-1.77	.11	23.60	13.13	0.21	.84
High Perf. Teams	32.50	9.44			39.33	13.57			22.00	8.12		
TSA-C level 3												
Av. Perf. Teams	0.17	0.41	0.00	1.00	2.50	2.07	0.62	.55	1.80	1.64	0.88	.41
High Perf. Teams	0.17	0.41			1.83	1.60			1.00	0.82		
Question												
Av. Perf. Teams	30.33	12.53	0.56	.59	31.33	10.71	-0.31	.76	34.60	31.95	0.95	.37
High Perf. Teams	27.00	7.62			33.00	7.35			19.00	6.38		
Structure												
Av. Perf. Teams	15.83	5.00	-0.67	.52	14.50	5.43	-0.48	.64	13.00	3.08	0.46	.66
High Perf. Teams	18.33	7.58			16.17	6.59			11.75	5.12		
Proposal												
Av. Perf. Teams	5.50	3.73	0.59	.57	3.50	3.27	0.21	.83	2.40	2.07	0.25	.81
High Perf. Teams	4.50	1.87			3.17	1.94			2.00	2.71		
Decision												
Av. Perf. Teams	6.00	1.41	1.63	.13	3.17	3.06	-1.96	.08	3.60	3.58	0.94	.38
High Perf. Teams	4.50	1.76			6.00	1.79			1.75	1.71		
Non-task												
Av. Perf. Teams	0.50	0.55	0.42	.69	0.83	0.75	0.29	.78	1.00	1.00	-0.83	.43
High Perf. Teams	0.33	0.82			0.67	1.21			1.75	1.71		

Note, N= 12 teams for session 1 and 2, N = 9 teams for session 3.

Table 5. Mean Frequency, Standard Deviations, and T Tests of Coded Behaviors per Phase for Average- and High-Performing Teams

	Initial phase				Decision making phase			
	M	*SD*	*t*	*p*	*M*	*SD*	*t*	*p*
Total Time								
Av. Perf. Teams	281.67	68.53	-3.05	.01	1845.00	594.33	1.40	.19
High Perf. Teams	410.00	76.94			1465.00	300.58		
Agreement								
Av. Perf. Teams	0.00	0.00	-1.00	.34	1.83	1.17	0.45	.66
High Perf. Teams	0.17	0.41			1.50	1.38		
Command								
Av. Perf. Teams	0.50	0.55	-0.70	.50	8.83	7.63	0.62	.66
High Perf. Teams	1.00	1.67			6.83	1.94		
TSA-C level 1								
Av. Perf. Teams	4.83	3.76	-0.90	.39	83.50	56.50	1.43	.18
High Perf. Teams	10.17	14.03			49.50	14.90		
TSA-C level 2								
Av. Perf. Teams	10.83	7.60	-1.60	.14	58.50	27.80	-0.73	.48
High Perf. Teams	16.83	5.19			69.67	25.08		
TSA-C level 3								
Av. Perf. Teams	0.00	0.00			4.17	1.72	1.55	.15
High Perf. Teams	0.00	0.00			2.67	1.63		
Question								
Av. Perf. Teams	6.50	4.42	-1.09	.30	84.00	42.03	1.25	.24
High Perf. Teams	10.67	8.26			62.00	10.00		
Structure								
Av. Perf. Teams	6.83	5.42	-1.47	.17	34.33	8.52	1.21	.25
High Perf. Teams	13.67	10.05			28.50	8.12		
Proposal								
Av. Perf. Teams	1.00	1.10	-1.00	.34	10.00	5.66	1.06	.31
High Perf. Teams	1.83	1.72			7.17	3.31		
Decision								
Av. Perf. Teams	0.00	0.00			12.17	5.71	0.19	.85
High Perf. Teams	0.00	0.00			11.67	2.73		
Non-task								
Av. Perf. Teams	0.00	0.00			2.17	1.94	0.00	1.00
High Perf. Teams	0.00	0.00			2.17	2.14		

Note, N= 12 teams

Hypothesis 2 states that the extent to which a team engages in collective interpretation will be positively related to team performance. In order to test this hypothesis we investigated the occurrences of the different sequences of communication per phase and per session. We specifically considered the frequency of sequences in which one member's voicing of level two TSA was followed by level two TSA from another team member, as an indication of collective interpretation. As can be seen from table 6 and 7, whereas the average- and high-performing teams do not significantly differ in terms of the four other sequences, in the first session high-performing teams use significantly ($p < .05$) more collective interpretation sequences ($M = 6.17$) than average-performing teams ($M = 2.67$). In the second session a substantial difference exists between the occurrence of collective interpretation in the average- ($M = 3.17$) and high performing teams ($M = 8.17$), but the effect is not significant anymore ($p = .15$). In addition, a comparison of the use of the collective interpretation sequences per phase suggests that whereas there is no significant difference between the average- and high-performing teams in the initial phase the difference in the use of collective interpretation sequences in the decision making phase is marginally significant ($p = .07$). Altogether this provides support for hypothesis 2. In addition, these results suggest that the effect of the use of collective interpretation processes depends on the timing of these processes in these specific sessions and phases.

Finally, to assess the extent to which each of these five communication sequences distinguished between average- and high-performing teams, we conducted discriminant function analysis, predicting team performance on the basis of the total occurrence of the sequences. In combination, the five characteristics do not significantly differentiated the average- from high performing teams (Wilk's $\lambda = .243$, $\chi^2(5, N = 12) = 6.26$, $p = .28$). However, using the stepwise selection method we find that the TSA-C level 2 alterations (discriminant function coefficient = .71) and the Question-TSA-C level 2 sequences (discriminant function coefficient = .47), significantly differentiated the average- from high-performing teams (Wilk's $\lambda = .47$, $\chi^2(2, N = 12) = 6.26$, $p = .03$). Using these two variables, we were able to correctly predict all of the teams as being average- or high-performing.

Table 6. Mean Frequency, Standard Deviations, and T Tests of Behavior Sequences (and Time per Decision) per Session for Average- and High-Performing Teams

	Session 1				Session 2				Session 3			
	M	*SD*	*t*	*p*	*M*	*SD*	*t*	*p*	*M*	*SD*	*t*	*p*
TSA-C level 2 – TSA level 2 alterations												
Av. Perf. Teams	2.67	2.66	-2.20	.05	3.17	3.82	-1.54	.15	3.20	1.64	-0.04	.97
High Perf. Teams	6.17	2.86			8.17	6.97			3.25	2.22		
Question - TSA-C level 1												
Av. Perf. Teams	14.33	9.44	0.81	.44	15.50	9.99	0.00	1.00	13.67	11.11	0.65	.54
High Perf. Teams	10.50	6.83			15.50	2.88			9.75	5.38		
Question - TSA-C level 2												
Av. Perf. Teams	10.33	6.35	0.17	.87	8.50	2.88	-0.49	.63	8.50	2.88	0.19	.85
High Perf. Teams	9.67	7.45			10.00	6.84			10.00	6.84		
TSA-C level 1 – TSA-C level 2 alterations												
Av. Perf. Teams	13.83	2.32	-1.14	.28	15.33	11.29	-0.84	.42	13.00	9.11	0.75	.48
High Perf. Teams	17.50	7.50			20.83	11.51			9.00	5.94		
Mono-actor sequence												
Av. Perf. Teams	10.00	4.94	-0.12	.91	9.83	8.61	0.60	.56	6.17	2.86	-0.22	.83
High Perf. Teams	10.33	4.84			7.50	3.99			6.50	1.00		
Time per Decision												
Av. Perf. Teams	133.6	17.83	-2.10	.08	286.9	112.4	2.75	.03	286.13	193.08	-0.33	.75
High Perf. Teams	198.2	73.09			142.2	63.20			333.13	236.53		

Note, N= 12 teams for session 1 and 2, N = 9 teams for session 3.

Table 7. Mean Frequency, Standard Deviations, and T Tests of Behavior Sequences (and Time per Decision) per Phase for Average- and High-Performing Teams

	Initial Phase				Decision making phase			
	M	*SD*	*t*	*p*	*M*	*SD*	*t*	*p*
TSA-C level 2 – TSA level 2 alterations								
Av. Perf. Teams	1.00	1.67	0.00	1.00	8.50	5.89	-2.03	.07
High Perf. Teams	1.00	1.10			16.50	7.64		
Question - TSA-C level 1								
Av. Perf. Teams	2.83	2.99	-0.76	1.00	42.17	25.45	0.82	.43
High Perf. Teams	4.83	5.71			32.50	13.32		
Question - TSA-C level 2								
Av. Perf. Teams	3.33	2.73	0.50	.63	26.33	9.44	0.29	.78
High Perf. Teams	2.67	1.75			24.67	10.65		
TSA-C level 1 – TSA-C level 2 alterations								
Av. Perf. Teams	4.33	3.61	-0.33	.17	40.00	20.24	-0.37	.72
High Perf. Teams	5.33	6.44			44.33	20.05		
Mono-actor sequence								
Av. Perf. Teams	3.67	2.94	-1.48	.75	24.67	11.06	0.46	.65
High Perf. Teams	6.83	4.36			22.17	7.33		
Time per Decision								
Av. Perf. Teams					168.27	50.90	1.57	.15
High Perf. Teams					129.14	34.04		

Note, N= 12 teams

Hypotheses 3a - 3c relate to the effects of structure on collective interpretation processes. We expected that the amount of structuring behaviors and the active use of the whiteboard will be positively and the use of standardized interaction patterns will be negatively related to the extent a team engages in collective interpretation processes. In order to test the effects of structuring behaviors, we added the three types of structuring to the equations predicting collective interpretation processes. Because of the relatively small sample size we consider significance levels of smaller than ten percent as significant. As can be seen from Table 8, structuring behaviors and the use of standardized interaction patterns are not significantly related to the use of collective interpretation processes, whereas structured use of the whiteboard is positively related to the use of collective interpretation processes. Therefore, only hypothesis 3b is supported.

Table 8. Results of Structuring Predicting Collective Interpretation Processes

	Control		Model 1		Model 2		Model 3	
	Beta	*SD*	*Beta*	*SD*	*Beta*	*SD*	*Beta*	*SD*
Intercept	7.69	6.80	1.37	7.32	1.33	6.83	7.57	7.55
Total Communication	0.02	0.02	-0.02	0.03	0.02	0.02	0.02	0.02
Structuring behaviors			0.39	0.24				
Whiteboard use					8.06†	4.12		
Standardized Interaction patterns							0.15	2.82
Total R^2	0.05		0.28		0.34		0.05	
R^2 Change			0.22		0.28†		0.00	

Note. N = 12, †p < .10. * p < .05.

Additional analyses

In addition to the analyses related to our hypotheses we conducted analyses into whether differences exist in the phase structures of the average- and high-performing teams. We were interested in whether the extent to which the teams adopted the specific generic two phase communication structure was positively associated with team performance. Therefore, we assessed the amount of time teams spent on the initial phase and the average time they spent per decision in the decision making phase.

As can be seen from Table 5, the total time teams spent in the initial phase significantly differed ($p < .05$) between the average- (Mean = 281.67 seconds) and high-performing teams (Mean = 410 seconds), suggesting that if teams invested more time in the initial phase this had a positive effect on team performance. However, despite the overall positive effect of time spent in the initial phase our analyses show no significant effects for the use of any of the specific coded communication behaviors in the initial phase on team performance. So, the beneficial effects of investing time in the initial phase cannot be attributed to the use of a single communication behavior type.

Finally, whereas there were no significant differences between average- and high-performing teams in the total amount of decisions per meeting or per phase, the data suggests differences in the amount of time teams spent per decision in the decision making phase. As can be seen in Table 7, although the average time per decision in the decision making phase is substantially higher for the average-performing teams (M = 168.27) than for the high-performing teams (M = 129.14), this difference is not significant ($p = .15$). However, as can be seen from Table 6, whereas the time per decision is significantly higher for high-performing teams than for average-performing teams in the first session ($p = .08$), it is significantly lower for high-performing teams in the second session ($p = .03$), and there is no significant difference between the teams in the third session ($p = .75$). Because the greater amount of time spent in the initial phase is likely to account for the effect that higher performing teams spent more time per decision in the first session, this suggests that teams benefit from minimizing the time they spent per decision, particularly in the second session.

Discussion

The general purpose of this study was to assess the structure, antecedents, and consequences of TSA-C in complex and dynamic circumstances. Our analysis of the phase structure of the teams' communication processes indicates that the team communication process can be divided into two separate phases. An initial introduction phase in which teams set the structure for the meeting and share individually held information and a second decision making phase in which the teams focus on making decisions on actions to take. Additional analyses indicated that, compared to average-performing teams, high-performing teams spent more time in the initial phase and made decisions more rapidly particularly during the second session in the decision making phase. Furthermore our findings indicate that; although, the frequency of single TSA-C behaviors were not directly related to team performance, high-performing teams engaged in significantly more collective interpretation processes—sequences in which one member voices level two TSA, which is followed by level two TSA from another team member—than average-performing teams during the decision making phase. Moreover, schematic use of the whiteboard influenced the extent to which teams engaged in collective interpretation processes. We will now turn to a discussion of these findings.

Two phase structure in team communication process

Previous studies have indicated that often phase structures can be identified in team communication processes (Poole, 1983). In addition to these previous studies the findings of this study suggest that differences in the phase structure among the groups are associated with differences in team performance. Compared to average-performing teams, high-performing teams had a clear phase structure characterized by a relatively long initial phase and a decision making phase in which decisions followed each other rapidly. Findings in the literature indicate that team processes occurring early on in teams' life span have long-lasting effects on team performance (Ericksen & Dyer, 2004; Gersick, 1988; Mathieu & Rapp, 2009). In particular initial planning activities have been related to team performance in later phases (e.g. Marks et al., 2001; Mathieu & Rapp, 2009). However, these studies have often looked at teams with much longer lifespans than the short-term crisis management teams that are the topic of this study.

A number of explanations can be proposed for the positive relation between the total duration of the initial phase and team performance. Whereas, in this phase team members are free to contribute all information they consider relevant for the other team members, during the subsequent decision making phase, team communication is focused on specific decision topics and members may be withheld from sharing information that is not immediately relevant to the topic at hand. As some information may not fit to any of the topics a team may discuss, it is important that all team members are provided the opportunity to contribute to the group information that may be relevant for the functioning of the team. Moreover, because the decision topics that will be discussed in the decision making phase are not a priori determined, in the initial phase team members may present decision topics they consider relevant to be discussed in the subsequent decision making phase. If teams, in the initial phase, spend time on establishing a well-considered agenda of decision topics, this may lead to more structured communication and more complete coverage of the decision topics during the decision phase. However, as we did not find significant differences between the average- and high-performing teams on specific behaviors, such as the amount of information that was communicated or the amount of structuring behaviors in the initial phase, the effect cannot be ascribed to a single type of behaviors.

In addition to the longer initial phase, the high-performing teams made decisions more rapidly particularly during the second session in the decision making phase. Although in the initial information sharing phase it is important that all team members get the opportunity to share their individually held information, in the decision making phase too much information sharing may become detrimental to performance. Because teams are under high pressure to make their decisions rapidly, it is important that they engage in a focused discussion of the decision topics and do not spend precious time on sharing information that is not directly relevant for the teams' decisions. As Weick (1995) indicated, it is often not accuracy but an acceptable shared understanding of the situation that is important for successful team performance in high-paced dynamic situations. Therefore, during this phase, it is important that team communication is aimed at formulating decisions that enable actions and facilitate coordination. Teams that do not take this pragmatic approach to TSA-C run the risk of rambling on about an issue without reaching a pragmatic decision. For example, Team 9 in the second session, apart from making two initial decisions, this team engaged in a long stretch of information exchange—filling almost the complete session—in which no decisions were made. Analysis of the video suggests that during this period the team engaged in an unstructured widely diverging discussion in which a variety of related issues are discussed but no clear decisions are made about any of these subjects.

Collective interpretation processes

Although, the frequencies of single TSA-C behaviors were not directly related to team performance, high-performing teams engaged in significantly more collective interpretation processes than average-performing teams during the decision making phase. This finding is in line with Information Elaboration theory, which poses that team decision making benefits if team members engage in higher level information processing before making collective decisions (Van Knippenberg et al., 2004). It also concurs with a study of Van den Bossche and colleagues (2006), who found that co-construction of meaning in teams—collectively developing an understanding of the situation by refining, building, or modifying publicly voiced interpretations—leads to high levels of shared understanding and consequently to effective performance.

Collective information processing stands in contrast with individual information processing, where team members individually process information without explicitly discussing their interpretations with the other team members. Collective interpretation processes may preclude team members from running into misunderstandings, which may occur when interpretations are privately reached. When interpretations are communicated within the meetings, other team members have the ability to compare the voiced interpretations with their own understanding and if needed correct or add to this interpretation, thereby reducing 'representational gaps.' Therefore, collective processing is likely to lead not only to more refined but also to more similar TSA. Particularly when team members have varying backgrounds, they may reach diverging interpretations based on similar information (Rico et al., 2009). Diverging interpretations of an issue are likely to result in conflict and decreased team performance (Cronin & Weingart, 2007).

Communication structuring practices

Finally, whereas some teams did not or only marginally made use of the whiteboard, other teams made use of the whiteboard in a highly structured fashion, using it to sketch the details of the situation, and structurally depict information from various sources. Highly structured use of the whiteboard may benefit teams for three reasons. First, it can be an efficient method for communicating the main facts of the situation. For instance, in some teams, the officer of the fire brigade—who held most general information about the particulars of the incident—already started writing down information before all members had arrived at the meeting, thereby economizing on valuable meeting time. Second, use of the whiteboard helps teams to structure their communication process and keep an overview of the topics that need to be discussed (Artman & Garbis, 1998; Renstch et al., 2010). Third, apart from affecting the structure of the team communication process, use of the whiteboard may promote cognitive similarity by facilitating the adoption of information in members' individual mental models.

Limitations

An important limitation refers to our communication measure of TSA. We used coded communication utterances to measure the different levels of TSA and we did not have at our disposal a quality measure for the statements. However, the complexity and ambiguity of field situations often makes it impossible to derive indications of the correctness of interpretations about those situations. And as Weick and colleagues indicate "Sensemaking is not about truth and getting it right. Instead, it is about continued redrafting of an emerging story so that it becomes more comprehensive, incorporates more of the observed data, and is more resilient in the face of criticism" (2005, p. 425). Our findings seem to be consistent with this theoretical assertion that collective information processing will lead to a richer understanding of the situation.

In addition, by measuring TSA from communication data we cannot infer if and how the content of this communication will actually be incorporated in team members' knowledge structures. We cannot be sure whether communication that is voiced within the group will actually become part of team members' cognitive representations—e.g. team members may not understand or simply not pay attention to all information that is communicated. Moreover, we do not take into account the part of TSA team members have privately formed without explicitly communicating it in the team. However, as Cooke and colleagues (2001) noted, team knowledge is a product of team members' individual knowledge plus communication processes. Through the communication process, groups make their knowledge explicit, and it is this expressed knowledge that finds its way into team decisions. So, although measuring team cognition from communication gives us an indication of the knowledge that is used in collective decision making, we cannot draw definite conclusions about whether and how this communication precipitates into team members understanding of the situation. Therefore, future studies could assess both TSA communication and the TSA knowledge structures in order to find out how collective team information processing is shaped by and shapes individual and team level knowledge structures.

Limitations also arise from the small sample size of the study. First, the small sample size limits the possibility to find small and medium sized effects. Given the semi-exploratory nature of the study we therefore opted not to adopt a strict criteria using Bonferroni corrections—controlling for the increased probability of finding significant results when testing multiple hypotheses—in testing differences between average-and high-performing teams (Shaffer, 1995). Therefore, the findings from the present study should be considered as initial indications and additional research with larger sample sizes is needed to test the robustness of these effects. Second, the small sample size limits the possibility of identifying heterogeneity in the phase structure among the teams. Although the basic two phase structure could be identified in almost all teams, the existence of variation among the teams in the length of the phases and the type of activities within the phases suggests that there may exist additional heterogeneity in the global communication structures, which has not been fully captured by the two phase structure. For example, the longer time periods between the decisions during the decision making phase may indicate that some teams actually reverted back to the initial phase after making their first decisions. Larger samples of teams are required to identify such, more fine-grained aspects of heterogeneity in teams' phase structures.

Finally, a limitation related to the specific sample of this study concerns the fact that the teams did not spent an equal of amount of time for the sessions. This divergence in the use of time may have had an impact on the team processes. However, we did not find significant effects of the amount of time used on team performance.

Conclusion

Weingart (1997) distinguished between analyses of what groups do—relating to the frequencies of specific behaviors—and analyses of how groups do it—focusing on the sequential nature of team member interaction. Whereas an increasing number of studies investigate group processes over time, these studies still often use perception based summary measures or frequencies of behaviors summarized over a period of time (e.g. Jehn & Mannix, 2001; van der Kleij, Schraagen, Werkhoven, & De Dreu, 2009). Although these studies provide information on the dynamics of team processes over time they do not give us insight into how teams actually execute their task; they do not provide information on the actual sequences of behavior that make up the team process. In order to gain more insight in the 'how' of team processes, Ballard and colleagues (2008) made a call to more explicitly incorporate time in the analyses of team communication data. With this study we answered this call in four ways. First, we analyzed the team communication data for indications of a global structure—phases—of team communication occurring in all teams. Second, apart from looking at frequencies of behaviors, we identified local patterns—sequences—of contiguous communication acts that indicated collective interpretation processes. Third, we compared average- and high-performing teams on their use of both frequencies and sequences in the different sessions and phases of the group communication process. Fourth, we assessed the extent to which teams communicated using standardized interaction patterns and related this to team collective interpretation processes. The results of these analyses clearly indicate the added benefit of adopting a temporal approach to analyzing team communication.

Chapter 7

Conclusion

Introduction

Due to a collection of convergent factors—e.g. global competition, technological developments, market deregulations—many organizations nowadays are faced with environments that are turbulent and complex to a degree that was hitherto unimaginable (Waller & Roberts, 2003). For these organizations change has become the norm instead of an exception in their everyday reality and many have reverted to teams to deal with such challenging circumstances (Burke, Stagle, Salas, Pierce, Kendall, 2006; Ilgen, Hollenbeck, Johnson, & Jundt, 2005). Given the pivotal role of teams for the functioning and survival of organizations, this challenges teams to sense changes in the wider environment and be able to rapidly adapt to a variety of expected and unexpected circumstances. In this dissertation I argued that adaptation has an important cognitive component; perceiving, interpreting, and planning for environmental changes are cognitive processes that are shaped and influenced by team member knowledge structures.

However, despite of its pivotal role, research on the cognitive aspects of team adaptation is still scarce. Therefore, the main questions that guided this dissertation related to the role of team cognition in team adaptation. This dissertation had three aims. First, to unravel the relationship between characteristics of the described cognitive structures and team adaptation and to investigate how team cognitive structures interact with team processes in predicting team adaptive performance. Second, to investigate the nature, antecedents, and consequences of change and development of cognitive structures. Third, to investigate the nature of teams' cognitive adaptation processes and their effect on team adaptation to novel circumstances.

In this concluding chapter, I will first give an overview of the main findings of this dissertation with respect to these questions. Second, I will discuss implications for theory, methods, and practice. Third, I discuss limitations of the present research and provide directions for further research.

Main findings

Chapter 2, contains an extensive review of the three main team cognition constructs of shared mental models, transactive memory systems, and team situation awareness. A conclusion from this review is that although these cognitive structures are often considered beneficial, they may not always facilitate team adaptation. In addition, it was concluded that research regarding the most investigated team cognition concept of shared mental models should go beyond similarity and accuracy and take into account characteristics of team mental models that may be more closely related to team adaptation, such as complexity and flexibility.

Chapter 3 and chapter 4 concerns research that is set out to investigate this assertion by measuring these aspects of team cognition and investigate their relationship with adaptive team performance. In chapter 3, a study is presented that explores the role of mental model updating on team adaptive performance using the task change paradigm. Findings of the study indicate that whereas team mental model change per se did not have a significant effect, system mental model updating—mental model change in line with changes in the task environment—is an important precursor to team adaptation. Moreover, this relationship was partially mediated by team interaction patterns.

In chapter 4, a model is presented and tested that delineates the effects of team internal and external cognitive alignment on task performance over time. Findings of the study indicate that both internal and external cognitive alignment are crucial for team performance trajectories. Although team mental model complexity predicts team information search trajectories and team information search predicts team performance trajectories, no conclusive evidence was found for a mediation effect of team information search. Finally, evidence was found for a moderation effect of team mental model complexity on the effect of team information search on team performance trajectories.

Whereas chapter 3 and 4 focus mainly on cognitive structural aspects, the focus in chapter 5 and 6 is on team cognitive processes in team adaptation. Chapter 5 presents analyses of the sensemaking process of a team faced with an unexpected ambiguous high-impact crisis situation. It was found that the team made sense of the situation by formulating working hypothesis of the situation, which they revised in an iterative fashion.

Chapter 6, zooms in on the cognitive team processes of the command teams of an emergency management system. In this chapter the communication data of the multidisciplinary command teams performing in a crisis management simulation was analyzed. It was found that the team communication process can be divided into a two-phase structure. An initial phase aimed at setting the structure of the meeting and sharing individually held information, and a second decision making phase in which the teams focus on making decisions on actions to take. The results indicate that, compared to average-performing teams, high-performing teams spent more time on the initial phase and made decisions more rapidly in the decision making phase. Moreover, high-performing teams engaged in more collective interpretation processes during the decision-making phase compared to average-performing teams and use of the whiteboard influenced the extent to which teams engaged in collective interpretation processes.

Implications

Theoretical implications

In the previous chapters, I have highlighted implications and discussions of the various finding of the individual studies reported in this dissertation, so I will not repeat the details in this section. Instead I will present the main theoretical implications of the present dissertation in terms of the contributions to the team cognition and team adaptation literatures.

Team cognition. First, focusing on adaptation, I draw attention to aspects of team mental models that have been underdeveloped in the team cognition literature. Research on team mental models has focused on properties of similarity and accuracy of team members' mental models (Mohammed, Ferzandi, & Hamilton, 2010). However, the review of the literature indicates, and the first two empirical studies support that apart from these often studied properties, other characteristics of team mental models such as complexity and flexibility may also be important for team functioning and adaptation. The reported research on these characteristics of team mental models provides insight in how mental models function in complex and adaptive environments. For instance, the finding that average mental model complexity interacted with team information search in predicting performance trajectories, provides support for a 'perceptual filter' theory of mental models, which indicates that mental models serve as 'filters' that influence the extent to which a team can effectively process information cues (Starbuck & Milliken, 1988). The study on the effects of mental model updating indicates that it is not so much accuracy of mental models per se but, the ability to readjust mental models to in response changes in the external environment that is important for adaptive performance.

Second, I present a model of team cognitive structures that provides an answer to controversies in the literature regarding the effects of similarity and diversity in knowledge structures (Ilgen et al., 2005). By applying the notion of complexity (Driver & Streufert, 1969) and the differentiation-integration logic developed in the organizational design literature (Lawrence & Lorsch, 1967), it is proposed that elements of similarity and variety are often complementary instead of opposing. Cognitive variety contributes to teams' external alignment, which teams require in order to deal with complex environments. At the same time cognitive similarity contributes to teams' internal alignment, which they need to coordinate information processing within the team. The empirical results from the study reported in chapter 4 provide preliminary evidence for this notion.

Third, the results of the study on the effects of team knowledge structures over time suggests that team mental models and a team's transactive memory system may differentially impact team outcomes at different time points in the team life cycle. Research on team knowledge structures has often implicitly assumed a generic effect over time, in the sense that the strength of the relationship between, for example shared mental models or transactive memory systems and team performance, does not depend on the specific time point or phase in a team's lifecycle. The results of chapter 4 indicate that this view does not seem to hold. For example, it was found that mental model complexity only started to have an effect on performance about halfway the teams' performance period, whereas transactive memory systems had an effect on team performance in the first session, which disappeared towards the midpoint and then picked up again. Although research already hinted at time-varying effects (Levesque, Wilson, & Wholey, 2001), empirical testing on when teams benefit most from high quality team knowledge structures is still in its infancy.

Team adaptation. The research presented in this dissertation contributes to team adaptation research by underlining the pivotal role of change in team members' knowledge structures in explaining team adaptation. Although, researchers have included cognitive constructs in their models of team adaptation (e.g. Burke et al., 2006; Marks, Zaccaro, & Mathieu, 2001), little research has been conducted on how team cognition contributes to team adaptation over time. In chapter 1, I presented an integrated model outlining the effects of cognitive structures and processes on team adaptation and aspects of that model were investigated in the various chapters of this dissertation. The findings of these studies provide support as well as additions to this model. Evidence was found that cognitive structures (mental model complexity and a team's transactive memory system) and cognitive processes (team information search and collective team situation awareness communication) depicted in the model are related with team adaptation. The results reported in chapter 3 also provide evidence for a mediating role of team interaction patterns in the relationship between team cognition and team adaptation. In addition, the findings indicate that cognitive structures and processes sometimes interact in driving team adaptation. Most importantly, I conclude that emphasis should be placed on the temporal development and change of cognitive structures over time, and on the factors that promote, and the factors that hinder adaptive change in team knowledge structures.

This dissertation taps into and adds to a recent stream of research that focuses on the importance of cognitive updating for understanding adaptive performance (Christianson, 2009; Rudolph, Morrison, & Caroll, 2009; Weick, 2010). For instance, Christianson (2009) investigated how healthcare providers updated their understanding regarding patient conditions in response to changes in patients' symptoms over time. Rudolph and colleagues (2009) study updating as a diagnostic sensemaking task in which individuals iteratively postulate and test hypotheses about the situation, and take actions over time. The present dissertation adds to this stream of research that updating may occur in response to two types of change in the entity's environment and that it may be worthwhile to disentangle the two resulting types of updating. First, momentary changes in the environment—for example, the spreading of a specific fire—requires updating in team situation awareness. Second, changes in the recurring structural relationship between elements of the environment—for example, alterations in the use of construction materials that change how building fires spread in general—requires updating in team mental models. Furthermore, I have indicated the existence of a number of cross-linkages among updating of team mental models, situation awareness, and interaction patterns.

Methodological implications

In addition to theoretical contributions mentioned above, a number of novel methods were applied for measuring the cognitive constructs reported on in this dissertation. Although, more research is required to further investigate the reliability and validity of these approaches, they provide some fruitful avenues for furthering research in team cognition.

In Chapter 3 a method was introduced for analyzing adaptive updating in mental models. Updating was assessed as the change in centrality of pivotal concepts in team members' mental models. This method enabled the explication of the effects of specific changes in the structure of team members' mental models on team adaptive performance. Whereas, previous research has indicated the importance of mental model change (e.g. Marks et al., 2000), this seems to be the first study that explicitly operationalized these concepts into a variable that can be used to test hypotheses on cognitive flexibility.

In chapter 4 a measurement method for mental models was introduced that enables researchers to separately assess external alignment and internal alignment in team cognitive structures. With the often used similarity rating approach for assessing mental models (DeChurch & Mesmer-Magnus, 2010), similarity and diversity are opposite poles on the same dimension. Therefore, aspects of external alignment and internal alignment have often been considered as opposing constructs. In contrast, with the free concept mapping approach used in chapter 4, external alignment (mental model complexity) and internal alignment (mental model similarity) could be separately assessed. As can be seen from the results of this study, these factors were not opposing but were actually correlated and both constructs explained unique variance in team performance trajectories.

In chapter 5 and in chapter 6 a communication approach to assess team level situation awareness processes was used. In chapter 5, an approach of content coding was used, which made it possible to trace patterns of emergence and transition of situation hypotheses over time. In chapter 6, a typology of communication actions was developed that differentiates between the levels of team situation awareness communication. Moreover, not only single communication utterances were identified but sequences of team situation awareness communication that appeared to be related to team performance. Finally, this research goes beyond comparative methods in applying idiosyncratic methods to explore the temporal structure of the teams' communication processes. The combination of visual depiction combined with statistical testing made it possible to identify structural aspects of the team communication processes which could not have been identified with traditional comparative methods. Although the approaches applied in these chapters are still in their infancy they provide promising new possibilities for analyzing team meta-cognition processes from ongoing communication data. Such online assessment of team cognition as it emerges in real time can help team researchers to more closely approach a truly temporal account of team adaptation (Ballard, Tschan, & Waller, 2008; Keyton, Beck, & Asbury, 2010).

Practical implications

In highly dynamic environments, teams need to be increasingly able to adapt and change to novel circumstances. The reported studies indicate that cognitive factors in team performance may play an important role in team adaptation. Both internal and external alignment were positively related to team performance. The results of this study seem to support the utility of cognitive complexity for team performance in complex dynamic environments. Hence organizations may benefit from selecting team members with rich knowledge structures. This may imply that they take into account not only members' specific skills but also their more general understanding of a complete system. Moreover team members could be encouraged to continuously refine their mental models in order to maintain the requisite variety for acting in complex dynamic environments—or using Weick's terms: they should be encouraged to 'complicate themselves' (Weick, 1979). Also, team training may be directed at increasing the internal alignment of team members' knowledge structures. For example, by encouraging team members to express and discuss their mental models among each other they may not only increase the amount of concepts and linkages within their individual mental models but also increase the overlap among their mental models.

In addition to increasing internal and external alignment, practitioners interested in promoting team adaptation should attempt to leverage team members' ability to adaptively change their mental models and the adaptive processes that were found to be associated with adaptive mental model change. Teams may benefit from flexibility in their knowledge structures. Several ways may exist that may facilitate cognitive flexibility. For example, managers may promote critical or counterfactual mindset in team members, challenging them to continuously look for anomalies and question and update their mental models and situation awareness (Kray & Galinsky, 2003; Weick, Sutcliffe, & Obstfeld, 1999). Another way to promote flexibility may be to encourage team members to regularly elicit and critically reflect on their own and each others' knowledge structures (Gurtner, Tschan, Semmer, & Nagele, 2007).

Finally, Chapter 6 indicates the importance of collective interpretation processes during the team decision-making phase. This suggest that training team members to engage in communication practices, aimed at explaining their expertise information to others and collectively stating their interpretations of the situation, may facilitate collective decision making and adaptive performance. In addition, use of a whiteboard during group discussion led teams to engage in collective interpretation processes. Therefore, managers aiming to improve high level team information processing should provide teams with knowledge tools, such as whiteboards and encourage team members to make use of them in order to structure their communication (see also Rentsch, Delise, Salas, & Letsky, 2010).

Limitations and suggestions for further research

Of course there are several limitations that restrict the conclusions that can be drawn from the studies reported in this dissertation. Moreover, for the sake of parsimony I was bounded to address a confined number of topics and perspectives in this dissertation and there may be other issues that are relevant as well to the field of cognition and adaptation. Therefore, in this section I will address limitations of the present dissertation and give some suggestions for future research.

An important limitation refers to the use of time in this dissertation. Important characteristics of team adaptation and team cognition are that they both are temporal phenomena (Roe, 2008). Adaptation constitutes a change in configuration that occurs over time. Cognition also has a temporal nature in that communication, sensemaking, and information processing are processes with beginning and end points that manifest specific dynamics over time and knowledge structures develop and are adjusted over time. In the present dissertation I have tried to acknowledge and integrate these temporal aspects of team adaptation and team cognition as much as possible; however, due to limitations in scope, time, and data collection possibilities there were also limits on the extent to which a truly temporal perspective on team adaptation and cognition could be attained. These limitations mainly refer to the time scope and to the extent to which the focal constructs were measured repetitively over time.

First, as I indicated in the introduction to this dissertation, adaptation refers to a single adaptive instance—a team adapting to a change in task circumstances—as well as, to a more continuous form of repeatedly adapting to a continuously changing environment. Whereas, in contemporary organizations, teams often will have to adapt recurrently in response to their highly dynamic environments, empirical studies on team adaption—including some of the studies in the present dissertation—often focus on a single or a limited amount of adaption requiring situations (Lepine 2003; 2005; Waller, 1999; 2004). Singling out an instance of adaptive performance enables researchers to closely scrutinize the processes occurring during adaption. However, it does not allow us to draw conclusions about what provides teams with adaptive capability that facilitates them to remain adaptive in the long run. As Zaheer, Albert, and Zaheer indicated "theory that is valid for one time interval may not be valid for another." (1999, p. 725). Teams, performing under dynamic circumstances, repetitively or even continuously adapt and thereby are likely to develop particular capabilities to facilitate adaptation (Burke et al., 2006; Kozlwoski et al., 1998). For example, they may develop specific structures and processes for keeping track of and interacting with their environments (Ancona, 1990; Ancona & Caldwell, 1992), develop flexible interaction patterns and knowledge structures (Kozlowski, Gully, Nason, & Smith, 1999; Stachowski, Kaplan, & Waller, 2009), and introduce reflective meta-cognition processes (Gurtner, Tschan, Semmer, & Nagele, 2007; Hinsz, 2004). Future research could investigate teams with a longer duration, which experience more adaptive episodes, to identify characteristics and processes that enable these teams to remain adaptive in the long run.

Second and related to this first point, a longitudinal perspective implies measuring focal constructs repetitively over time in order to assess development and changes in these constructs (Chan, 1998; Roe, 2008). In that respect, the present dissertation is longitudinal to a limited extent. In chapter 3, team members' mental models were assessed at two time points, which enabled the investigation of the changes that occurred in these mental models from before to after a task change. However, because there were only two measurement points, it was not possible to assess the dynamic trajectory of these changes or pinpoint when in time these changes actually took place. For chapter 4 measurements were collected for team performance and information search on seven consecutive periods, making it possible to investigate the dynamic trajectories of these variables and to predict parameters of these trajectories with a number of team cognition variables. However, because the team cognition variables were only measured at a single time, it was not possible to assess the dynamics of these variables over time or to analyze how these dynamics were related to team adaption. The here mentioned limitations are mainly due to constraints in the possibility to collect high-density repetitive data on team cognition with existing measurement methods, as these methods are often very intrusive and time consuming (Mohammed, Klimoski, & Rentsch, 2000). However, recent advances in textual and behavioral analysis methods may open up new ways to analyze team cognition that may lift the field to "truly longitudinal" understanding of team cognition (Ballard et al., 2008; Cooke, 2004).

Another limitation of the present dissertation is that whereas both a structural perspective on team cognition—mainly in chapter 3 and 4—and a communication perspective on team cognition—in chapter 5 and 6—were applied, the data of the studies provide only limited possibilities for an integrated analysis including both perspectives. Team cognitive structures and team cognitive processes are closely interrelated—they are influenced by and influencing each other in an intricate manner. For instance, diversity in knowledge structures is expected to impact team performance as it enables team members to bring to bear to a problem a wide variety of ideas and perspectives. This indicates that the composition of team members' cognitive structures would be represented in the specific pattern and content of team communication. Although this seems a plausible proposition, research that explicitly links such cognitive structures to actual team communication is scarce. On the other hand, in depth communication regarding higher level interpretations of a task situation is likely to lead to deeper, higher level understanding of that situation. In order to test such cognitive structure-communication interrelations more studies are needed that measure both structures and communication at several points in time.

Another limitation of the empirical studies in this dissertation is the use of simulation and observation studies in measuring the relationship between cognition variables and team adaptation. Because, observation studies do not enable us to rule out reversed causality and possible confounding variables, it is not possible to draw definite conclusions regarding causality of the role of team cognition in team adaptation. For example, it is not possible to conclude that the association between the change in mental models and team adaptive performance found in chapter 3, indicates a causal relation. It might as well have been the case that high team performance in the moments after the change afforded teams with some slack time to consciously readjust their mental models of the system and hence this would represent more a reflection than a cause of adaptation. Limitations regarding knowledge on causality is not only a limitation in the present study but extends to large areas of team cognition research, and in particular the field of shared mental model research. Therefore, this field could greatly benefit from studies that experimentally test some of the relations on team cognition that are up to now only been observationally established.

Another limitation refers to the fact that teams generally do not function in isolation but often constitute parts of larger organizations. Organizational factors, such as the specific structure in which the teams are embedded, the type of leadership, and institutional practices are likely to impact team adaptation and the cognitive aspects that are the topic of this dissertation. These factors may constitute important antecedents as well as moderators of the findings of this dissertation. Therefore, additional research is required to investigate the impact of the larger organizational context on team cognition and adaptation.

Finally, the studies reported on in this paper present interesting findings on the effects of interaction patterns that warrant additional research. Whereas previous research suggests that recurring team interaction patterns negatively affect team performance during crisis circumstances (Stachowski et al., 2009), in this dissertation recurring interaction patterns were found to have positive effects (chapter 3) and non-significant effects (chapter 6) on team performance in non-routine situations. The findings of a positive effect of interaction patterns on performance are congruent with research of Kanki and colleagues (Kanki & Foushee, 1989; Kanki, Folk, & Irwin, 1991) who found that higher performing teams had less variance in interaction pattern than less well performing teams. A possible explanation for these contradictory findings may be that it depends on whether the repeated action sequences are mindlessly constructed routines or deliberately adopted efficient standard operating procedures. Moreover, a high level of recurrence in interaction patterns during a non-routine period can be the result either of a mindless commitment to standardized response patterns or it can be an indication of the rapid development and recurrent implementation of newly developed situation appropriate interaction patterns. Because in the previous studies as well as in the studies reported in the present dissertation it could not be derived whether teams repeated existing action patterns or developed new interaction patterns, future research should more closely trace the development of and changes in interaction patterns over time in reactions to changes in the relevant task environment.

Conclusion

The opening example of this dissertation demonstrates the importance of adaptation for teams functioning in dynamic high-reliability environments. Not only are teams crucial for the functioning of many contemporary organizations, they are also often the final safeguards responsible for the health and safety of many individuals. The research presented in this dissertation aims to further our understanding of how such teams adapt to novel and unexpected challenging circumstances. In this dissertation I have taken a perspective of team adaptation as a process occurring over time in which cognitive structures and process play a pivotal role. The results of the studies reported on in this dissertation support this view and suggest that in order to predict if a team adapts and understand how it adapts, we should find out what the team members know and how they think.

Summary

Summary

Organizations often deploy teams to cope with the ever increasing dynamism, complexity, and uncertainty of their environments. As a result, it is crucial for these teams to maintain high levels of performance not only under routine circumstances but also in case of complex and unpredictable non-routine situations. This is all the more critical since it is particularly during novel non-routine situations that effective team performance becomes most crucial and at the same time most difficult to uphold. Team adaptation refers to the effective process whereby, in response to changes in its task situation, a team changes its configuration—in terms of structures, behaviors, and cognitions—, over a specific period.

Although researchers have in their reasoning often applied team cognition concepts to explain team adaptation, studies that explicitly investigate the role of team cognition constructs in team adaptation are relatively scarce. With team cognition, I refer to both the cognitive structures—structured knowledge team members have regarding their task or team—and cognitive processes—activities such as information gathering, interpretation, and decision making that are performed by the team members during the performance of their task. Cognitive structures may facilitate or hinder adaptation and often have to be changed in order for a team to adapt and cognitive processes are generally considered to lie at the heart of the team adaptation process. Therefore, in order to add to our understanding of how such teams adapt to dynamic and challenging circumstances, this dissertation focuses on the role of cognition in team adaptation. More specifically, the aims of the dissertation are to investigate how characteristics of team members' cognitive structures impact team adaptation, how these cognitive structures change over time, and which role team cognitive processes play in team adaptation to novel task situations.

A literature review described in Chapter 2 focuses on the role of three team cognition constructs in predicting team adaptation: shared mental models, a transactive memory system, and team situation awareness. Mental models are organized knowledge structures of a specific domain or system, and the notion of *shared mental models* refers to specific compilation on the team level of the mental models of the individual team members. A *transactive memory system* refers to the division of cognitive labor in a team and the knowledge of what information is held by other members of the group. *Team situation awareness* refers to the momentary understanding team members have about a specific task situation. The findings of this chapter show that overall much of the research in the extant literature suggests that these cognitive structures facilitate the coordination and communication necessary for teams to adapt in turbulent and dynamic task settings. However, we conclude with a critical note, questioning the basic assumption that these structures always facilitate team adaptation. Moreover, we find that research on team mental models has mainly focused on characteristics of similarity and accuracy whereas aspects such as mental model complexity and change, which are likely to also be important for team adaptation, have been underexposed.

Chapter 3 describes a laboratory study into the relations among team cognition, team interaction patterns, and team adaptation. In the study, 46 three-person teams performed in a fire fighting simulation that was programmed so that the team task structure changed halfway the simulation. The results indicate positive relationships among the extent to which team members update their mental models in line with changes in the task environment, post-change team interaction patterns, and team adaptive performance. In addition, post-change team interaction patterns mediated the relationship between mental model updating and adaptive performance.

Chapter 4 describes how theories that advocate cognitive similarity and theories that advocate cognitive diversity seem to lead to opposing inferences regarding team performance under dynamic circumstances. The chapter introduces a model of team cognition that integrates these divergent viewpoints. It is proposed that teams require external alignment in order to deal with complex environments and internal alignment to coordinate their internal information processing. The chapter describes a study that tests this notion with a sample of 64 teams performing in a dynamic complex management simulation. The chapter adopts a longitudinal approach in that team information search processes and team performance are measured repetitively over time and team cognition variables are used to predict the temporal trajectories of these variables. Findings of the study indicate that both internal and external cognitive alignments are crucial for team performance development over time. Team mental model complexity, transactive memory systems, and shared mental models had an influence on team performance trajectories. Finally, evidence was found for a moderation effect of team mental model complexity on the effect that team information search has on team performance trajectories.

In chapter 5 the nature of teams' cognitive adaptation processes was explored. A case study is presented on a single team in which it is investigated how this team alters its understanding of an unexpected dynamic situation over time. A sample of the audio communication of the operations team of the organization responsible for coordinating the air defense of the northeast quadrant of the United States during the terrorist attacks of eleven September 2001 was analyzed. It is concluded that in ambiguous situations, teams construct temporary 'working hypotheses' of the situation that enable them to maintain sense and coordinate their actions. The formation and abandonment of these working hypotheses over time consisted of an iterative process of using and discarding working hypotheses as events unfolded and sensemaking occurred.

Chapters 6 contains an investigation of how the central command teams of an emergency management organization developed an understanding of the unfolding crisis management situation and made decisions on what actions to take. This chapter takes a communication perspective on team cognition as team situation awareness formation was assessed from the communication among the team members. The data for this study contains video recordings of emergency management command teams as they performed in a crisis management simulation. The findings indicate that the team communication process can be divided into a two phase structure. An initial phase aimed at setting the structure of the meeting and sharing individually held information and a second decision making phase in which the teams focus on deciding which actions to take. Compared to average-performing teams, high-performing teams spent more time on the initial phase and made decisions more rapidly in the decision making phase. Moreover, high-performing teams engaged in more collective interpretation processes during the decision making phase compared to average-performing teams, and schematic use of the whiteboard influenced the extent to which teams engaged in collective interpretation processes.

Together the studies reported in this dissertation highlight the pivotal role of team cognitive structures and processes in team adaptation. Specifically the role of change in team members' knowledge structures turns out to be an important and under-investigated aspect of team cognition. In addition to these theoretical contributions, the dissertation also introduces a number of novel methods for measuring the cognitive structures and processes relevant to team adaptation. Although more research is required to further investigate the reliability and validity of these approaches, they provide some fruitful avenues for furthering research in team cognition, and particularly to arrive at a truly temporal account of team adaptation.

Samenvatting

Samenvatting

Om het hoofd te bieden aan de alsmaar toenemende dynamiek, complexiteit en onzekerheid van hun omgeving worden er door organisaties steeds vaker teams ingezet. Daarom is het cruciaal dat deze teams niet alleen in routine situaties maar ook in complexe en onvoorspelbare niet-routine situaties een hoog prestatieniveau kunnen handhaven. Dit is des te kritisch gezien dat tijdens niet-routine situaties een goede teamprestatie vaak zeer belangrijk is en tegelijkertijd zeer moeilijk te handhaven. Teamadaptatie is gedefinieerd als het effectieve proces waarmee, in reactie op een verandering in de taak situatie, een team zijn configuratie (in termen van structuren, gedragingen en cognities) aanpast gedurende een specifieke periode.

Hoewel teamonderzoekers vaak concepten uit de cognitiewetenschappen toepassen om teamadaptatie te verklaren zijn er nauwelijks studies die expliciet de rol van teamcognitie in teamadaptatie onderzoeken. Met teamcognitie verwijs ik zowel naar de cognitieve structuren (de gestructureerde kennis van teamleden betreffende hun taak of team) als naar de cognitieve processen (activiteiten zoals het verzamelen van informatie, het interpreteren hiervan, en het maken van beslissingen door de teamleden gedurende het uitvoeren van de taak). Cognitieve structuren kunnen adaptatie zowel bevorderen als hinderen en moeten vaak worden veranderd zodat een team zich kan aanpassen en cognitieve processen worden vaak beschouwd als een centraal aspect in het adaptatieproces. Om ons begrip over hoe teams zich aanpassen aan dynamische uitdagende situaties te vergroten richt ik in deze dissertatie de aandacht op de rol van teamcognitie in teamadaptatie. Meer specifiek zijn de doelen van de dissertatie om te onderzoeken hoe kenmerken van de cognitieve structuren van de teamleden invloed hebben op teamadaptatie, hoe deze cognitieve structuren veranderen over tijd en welke rol team cognitieve processen spelen in de aanpassing van teams aan nieuwe situaties.

Hoofdstuk 2 geeft een overzicht van de literatuur over de rol van drie teamcognitie constructen in het voorspellen van teamadaptatie: team mentale modellen, een transactief geheugen systeem en team begrip van de situatie. Mentale modellen zijn de georganiseerde kennisstructuren die mensen hebben van een specifiek domein of systeem en het construct *team mentale modellen* verwijst naar de specifieke samenstelling op het teamniveau van de mentale modellen van de individuele teamleden. Een *transactief geheugen systeem* verwijst naar de verdeling van cognitieve taken in een team en de kennis van wie over welke informatie beschikt. Het *team begrip van de situatie* verwijst naar de kennis over en het begrip van de situatie dat teamleden hebben op een bepaald moment. De bevindingen van het hoofdstuk laten zien dat het merendeel van de publicaties in de literatuur suggereert dat deze cognitieve structuren de coördinatie en communicatie die nodig zijn voor teams om zich aan te passen in turbulente en dynamische situaties bevorderen. We concluderen echter met een kritische noot waarin we de basale aanname dat deze structuren teamadaptatie altijd bevorderen in twijfel trekken. Een bijkomend bevinding is dat onderzoek over team mentale

modellen vooral gefocust is op de kenmerken van gelijkheid en accuraatheid terwijl aspecten zoals de complexiteit en de aanpasbaarheid van mentale modellen, die waarschijnlijk ook belangrijk zijn voor teamadaptatie, onderbelicht zijn.

Hoofdstuk 3 beschrijft een laboratorium studie naar de relaties tussen teamcognitie, teaminteractiepatronen en teamadaptatie. In deze studie namen 46 teams van drie personen deel aan een computersimulatie waarin zijn bosbranden moesten blussen. De simulatie was zo geprogrammeerd dat de taakstructuur halverwege de taak veranderde. De resultaten laten positieve relaties zien tussen de mate waarin de teamleden hun mentale modellen aanpassen in overeenkomst met de veranderingen in de taaksituatie, de interactiepatronen van de teams na de verandering en de adaptieve prestatie van de teams. Verder mediëren teaminteractiepatronen gedeeltelijk het effect van het aanpassen van de mentale modellen op de adaptieve prestaties van de teams.

Hoofdstuk 4 beschrijft hoe theorieën die cognitieve gelijkheid voorstaan en theorieën die cognitieve diversiteit voorstaan tot tegenstrijdige conclusies lijken te leiden over teamfunctioneren onder dynamische omstandigheden. Het hoofdstuk introduceert een teamcognitie model waarin deze verschillende perspectieven worden geïntegreerd. Er wordt geopperd dat teams externe cognitieve afstemming nodig hebben om te kunnen functioneren in complexe omgevingen en dat ze interne cognitieve afstemming nodig hebben om hun interne informatieverwerkingsprocessen te coördineren. Het hoofdstuk beschrijft een studie waarin dit idee getest wordt met 64 teams die deelnemen aan een dynamische en complexe managementsimulatie. In het hoofdstuk wordt gebruik gemaakt van een longitudinale aanpak waarin teaminformatieverzamelingprocessen en teamprestatie herhaaldelijk over tijd worden gemeten en teamcognitie variabelen gebruikt worden om het temporele traject van deze variabelen te voorspellen. De resultaten van de studie geven aan dat zowel interne als externe afstemming van cruciaal belang zijn voor de ontwikkeling van teamprestatie over tijd. De complexiteit van de team mentale modellen, transactieve geheugen systemen en gedeelde mentale modellen waren van invloed op de teamprestatie trajecten. Ten slotte was er bewijs voor moderatie van team mentale modellen op het effect van teaminformatieverzamelingprocessen op teamprestatie trajecten.

In hoofdstuk 5 wordt de aard van team cognitieve adaptatieprocessen onderzocht. Er wordt een casestudie gepresenteerd, over een enkel team, waarin wordt onderzocht hoe in dit team het begrip van een onverwachte dynamische situatie wordt aangepast over tijd. Het betreft een analyse van een selectie van de audiocommunicatie van het operatieteam van de organisatie die verantwoordelijk was voor het coördineren van de luchtverdediging in het noordoostelijke kwadrant van de Verenigde Staten tijdens de terroristische aanvallen van 11 September, 2001. De conclusie is dat teams in ambigue situaties tijdelijke 'werkhypothesen' over de situatie construeren die ze in staat stellen om een gevoel van betekenis te behouden en hun acties te coördineren. Het vormen en loslaten van deze werkhypothesen over tijd verloopt volgens een iteratief proces van het gebruiken en verwerpen van werkhypothesen terwijl de gebeurtenissen zich ontvouwen en de teamleden een begrip proberen te vormen van de situatie.

Hoofdstuk 6 bevat een onderzoek naar hoe de centrale commandoteams van een crisismanagementorganisatie zich een begrip vormen van een zich ontwikkelend incident en hoe ze beslissingen nemen over te nemen acties. Dit hoofdstuk gaat uit van een communicatie perspectief van teamcognitie waarin de vorming van het team situatie-begrip wordt afgeleid uit de communicatie tussen de teamleden. De gegevens van de studie bestaan uit videoopnamen van de crisismanagement commandoteams terwijl ze deelnamen aan een crisismanagement simulatie. De bevindingen geven aan dat het teamcommunicatieproces opgedeeld kan worden in twee fasen. Een initiële fase gericht op het structureren van de bijeenkomst en het delen van informatie die is verzameld door de individuele teamleden en een tweede beslisfase waarin de nadruk ligt op het nemen van beslissingen over te nemen acties. Vergeleken met matig presterende teams, besteden goed presterende teams meer tijd aan de initiële fase en nemen zij hun beslissingen sneller in de beslisfase. Verder hielden de goed presterende teams zich meer bezig met collectieve interpretatieprocessen gedurende de beslisfase vergeleken met matig presterende teams en het gebruik van een whiteboard bevorderde de mate waarin teams zich bezig hielden met collectieve interpretatieprocessen.

Samengenomen leggen de studies die beschreven zijn in deze dissertatie de nadruk op de centrale rol van team cognitieve structuren en processen in teamadaptatie. In het bijzonder de rol van een aanpassing in de kennisstructuren blijkt een belangrijk en weinig onderzocht aspect te zijn van teamcognitie. Behalve de theoretische contributies introduceert de dissertatie ook een aantal nieuwe methoden voor het meten en analyseren van cognitieve structuren en processen die relevant zijn voor teamadaptatie. Hoewel meer onderzoek nodig is om de betrouwbaarheid en validiteit van deze methoden verder te testen, lijken ze een veelbelovende benadering te zijn voor het bevorderen van onderzoek naar teamcognitie and specifiek het ontwikkelen van een werkelijk temporele uiteenzetting van teamadaptatie.

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Curriculum Vitae

Curriculum Vitae

Sjir Uitdewilligen was born on May 26, 1980 in Schinnen, The Netherlands. He attended St-Jan's College in Hoensbroek, where he graduated in 1998. He subsequently travelled one year through Australia and studied Philosophy at Leiden University for one year. In 2000 he started his study of Economics at Maastricht University. During his studies he was a visiting undergraduate student at Ghent University and at the Tecnológico de Monterrey in Mexico City. He graduated and obtained his M.Sc. in International Management in 2005. In 2006 he obtained his M.Sc. (cum laude) in Cognitive Psychology, Work- and Organizational Psychology. In January 2007, Sjir started his dissertation research at the department of Organization and Strategy at the School of Business and Economics of Maastricht University. In 2009, he was a visiting doctoral researcher at the Schulich School of Business of York University in Toronto. Currently, Sjir works as an assistant professor at the department of Work- and Social Psychology at the Faculty of Psychology and Neuroscience of Maastricht University.

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