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Team mental models and team performance: A field study of the effects of team mental model similarity and accuracy

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Summary We conducted a field study of 71 action teams to examine the relationship between team mental model similarity and accuracy and the performance of real-world teams. We used Pathfinder to operationalize team members' taskwork mental models (describing team procedures, tasks, and equipment) and teamwork mental models (describing team interaction processes) and examined team performance as evaluated by expert team assessment center raters. Both taskwork mental model and teamwork mental model similarity predicted team performance. Team mental model accuracy measures were also predictive of team performance. We discuss the implications of our findings and directions for future research.

Introduction

In the past decade, research on team effectiveness (e.g., Cohen & Bailey, 1997; Hollenbeck, Colquitt, IIgen, Lepine, & Hedlund, 1998; Edmondson, 1999; Simons, Pelled, & Smith, 1999) has burgeoned as teams have become increasingly common in organizations of all kinds (Devine, Clayton, Philips, Dunford, & Melner, 1999). A number of theorists have adopted a cognitive perspective, suggesting that team mental models—defined as 'team members' shared, organized understanding and mental representation of knowledge about key elements of the team's relevant environment' (Mohammed & Dumville, 2001, p. 90)—may enhance team members' coordination and effectiveness in performing tasks that are complex, unpredictable, urgent, and/or novel (Marks, Zaccaro, & Mathieu, 2000). Team members who share similar mental models can, theorists suggest, anticipate each other's responses and coordinate effectively when time is of the essence and opportunities for overt communication and debate are limited (Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000).

In recent years, a number of researchers have begun to test the effects of team mental models on team performance. These studies have documented the beneficial effects of team mental models on team task

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effectiveness (Marks et al., 2000; Marks, Sabella, Burke, & Zaccaro, 2002; Mathieu et al., 2000; Mathieu, Heffner, Goodwin, Cannon-Bowers, & Salas, 2005; Rentsch & Klimoski, 2001; Stout, Cannon-Bowers, Salas, & Milanovich, 1999; Smith-Jentsch, Mathieu, & Kraiger, 2005; Webber, Chen, Payne, Marsh, & Zaccaro, 2000). While encouraging, these studies leave several questions unanswered. The results of recent studies suggest that teams benefit when their members share similar mental models of the team's *task* (e.g., Mathieu et al., 2000). Is it also important that team members share similar mental models of team *interaction processes*? Although the theoretical literature suggests that team members are likely to have multiple mental models (of team-related goals, processes, equipment, and membership, for example), only two published studies have, to our knowledge, reported analyses of team members' multiple mental models (Mathieu et al., 2000; Mathieu et al., 2005). Further, do the beneficial effects of team mental models depend on the accuracy of the mental models? Some theorists (e.g., Rentsch & Hall, 1994) have argued that only shared and accurate team mental models enhance team performance, but few studies have examined the consequences of team mental model accuracy. These studies (Marks et al., 2000; Mathieu et al., 2005; Webber et al., 2000) reached contradictory conclusions. Finally, can researchers capture and operationalize team mental models in action teams operating in their naturalistic environment, and, if so, do team mental models predict the effectiveness with which action teams perform their complex and varying tasks? Existing team mental model research is dominated by laboratory studies offering precision and control; complementary field studies are needed, as several authors have noted (e.g., Marks et al., 2000; Mathieu et al., 2005). We contribute to the growing literature on team mental models by addressing these three questions in a field-based replication of prior shared mental model research.

Mental Models

Originally proposed by Cannon-Bowers, Salas, and Converse (1990), the team mental model construct grew out of prior theory and research in cognitive psychology regarding individuals' mental models. Rouse and Morris (1986, p. 360) defined a mental model as a 'mechanism whereby humans generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future system states.' Mental models are organized knowledge frameworks that allow individuals to describe, explain, and predict behavior (Norman, 1983; Rouse & Morris, 1986). Mental models specify relevant knowledge content as well as the relationships between knowledge components (Webber et al., 2000). An individual's mental model (of, for example, a car, a disease, or a process such as child development) reflects the individual's perception of reality (Brunswik, 1956). Accordingly, mental models vary in their accuracy and coherence (e.g., McKeithen, Reitman, Rueter, & Hirtle, 1981; Nilsson, 1965; Rentsch & Hall, 1994). Further, mental model accuracy is predictive of individual performance (e.g., Kraiger, Salas, & Cannon-Bowers, 1995; Rowe & Cooke, 1995).

Team Mental Models

When the members of a team organize their knowledge of team tasks, equipment, roles, goals, and abilities in a similar fashion, they share mental models—team mental models. Team mental models,

the theoretical literature suggests, allow team members to anticipate one another's actions and to coordinate their behaviors, especially when time and circumstances do not permit overt and lengthy communication and strategizing among team members. Under these circumstances, team members must rely on preexisting knowledge to predict the actions of their teammates and to respond in a coordinated fashion to urgent, high stakes, and/or novel task demands (e.g., Marks et al., 2000; Mathieu et al., 2000).

Multiple mental models: Taskwork and teamwork

The theoretical literature on team mental models suggests that the members of a team are likely to hold not one, but multiple mental models (Klimoski & Mohammed, 1994). Cannon-Bowers, Salas, & Converse (1993) proposed that a team is most likely to be effective if team members share four mental models. The *equipment* model captures team members' shared understanding of the technology and equipment with which they carry out their team tasks. The *task* model captures team members' perceptions and understanding of team procedures, strategies, task contingencies, and environmental conditions. The *team interaction* model reflects team members' understanding of team members' responsibilities, norms, and interaction patterns. And the *team* model summarizes team members' understanding of each others' knowledge, skills, attitudes, strengths, and weaknesses. Each mental model may be influential in predicting team performance.

Few researchers have examined the influence of multiple team mental models on team performance. Mathieu et al. (2000) argued that the four mental models proposed by Cannon-Bowers et al. reflect two content areas: taskwork (subsuming Cannon-Bowers et al.'s first two models) and teamwork (subsuming Cannon-Bowers et al.'s last two models). In a laboratory study of two-person teams, Mathieu et al. (2000) assessed the similarity of team members' mental models and found that taskwork mental model similarity and teamwork mental model similarity were both significantly positively related to team processes (e.g., coordination, cooperation, and communication), which were in turn significantly related to team performance. The direct relationship between team mental model similarity and performance was not significant. In a similar, but more recent laboratory-based study, Mathieu et al. (2005) showed that taskwork mental model similarity, but not teamwork mental model similarity, was significantly related to both team processes and team performance.

Building on existing theory (Cannon-Bowers et al., 1993) and following Mathieu et al. (2000, 2005) lead, we argue that both taskwork mental model similarity and teamwork mental model similarity enhance team performance. Taskwork mental models, as we use the term, describe the content and structure of team members' mental models of the equipment and procedures that teams like theirs use to complete their tasks. Teamwork mental models describe the content and structure of team members' mental models of team interaction processes in teams like theirs.

Hypothesis 1: Team mental model similarity is positively related to team performance.

Team mental model accuracy

Just as the accuracy of an individual's mental model(s) may influence the quality of the individual's decision making and performance (e.g., Rowe & Cooke, 1995), so the accuracy of a team's mental models may influence the quality of the team's decision-making and performance. Mental model accuracy is distinct from mental model similarity. As Mathieu et al. (2000) commented, 'Similarity

does not equal quality—and teammates may share a common vision of their situation yet be wrong about the circumstances that they are confronting.' (p. 281). If a team's taskwork mental model is to some extent inaccurate—if, for example, team members' understanding of task priorities is shared, but misguided—team performance is likely to suffer. Team members may, for example, work in a coordinated fashion to achieve ancillary, rather than primary, goals. Similarly, if team members' shared teamwork mental model is inaccurate, team members are likely to suffer little conflict regarding team process issues, but they may nevertheless work inefficiently and ineffectively toward their goals (Marks et al., 2000). Supporting these arguments, Marks et al. (2000) found that team mental model accuracy was significantly positively related to team performance. However, Webber et al. (2000) did not find a significant relationship between team mental model accuracy and team performance. Mathieu et al. (2005) accessed the 'quality' of team mental models (relative to differing experts' mental models) and found that neither taskwork mental model quality nor teamwork mental model quality was significantly related to team processes or performance.

Based on conceptual arguments and Marks et al.'s (2000) results, we expected team mental model accuracy to be positively related to team performance. Further, we expected team mental model accuracy and similarity to interact in predicting performance. If team members have similar mental models of team tasks and of team processes, but their mental models are inaccurate, team members may experience little conflict, but focus on the wrong priorities or use inappropriate strategies, lowering the overall level of team performance (Marks et al., 2000). Consistent with these arguments, Mathieu et al. (2005) found that the interaction of teamwork mental model similarity and teamwork mental model quality predicted team processes and performance; teams exhibited the best processes and performance when they shared high-quality teamwork mental models.

Hypothesis 2: Team mental model accuracy is positively related to team performance.
Hypothesis 3: The relationship between team mental model similarity and team performance is moderated by team mental model accuracy; the more accurate a team's mental model, the stronger the relationship between team mental model similarity and team performance.

Team mental models in the lab and in the field

After a careful review and comparison of industrial and organizational psychology research conducted in the laboratory and in the field, Flanagan and Dipboye (1981, p. 45) concluded: 'Recommendation #1: Laboratory and field settings should be used in a complementary manner . . . Recommendation #2: Topic areas that are investigated primarily in one setting should receive greater attention in the other setting.' This advice is perhaps most appropriate when specific aspects of the research design—for example, the complexity and duration of the task or the level of research participants' involvement—may result in differences in the strength of the relationships observed among the variables in the lab versus the field (Greenberg & Eskew, 1993; Ilgen, 1986; Wofford, 1999).

In the case of team mental model research, differences between field and lab settings may result in differences in the predictive validity of taskwork and teamwork mental models. Laboratory studies of the effects of team mental models typically examine small two- or three-person teams that engage in relatively simple, clearly defined and discrete tasks for short periods of time (e.g., Marks et al., 2000). Field studies, like ours, examine larger teams that perform tasks of greater complexity, variety, uncertainty, consequence, and duration. As a result, laboratory teams' taskwork mental models are likely to be more specific—less abstract—than are real world teams' mental models. Laboratory teams' taskwork mental models may be more predictive as well. In the lab, shared task knowledge is likely to dominate as the driving force influencing task performance. In the field, task uncertainty and

unpredictability may attenuate the influence of shared taskwork models on performance. Teamwork mental models may, however, be of greater importance in the field than in the lab. In the field, where tasks are relatively uncertain and unpredictable, team members' shared expectations of team processes may facilitate coordination and decision making. In the lab, team members may lack the time to develop and act on shared expectations of team processes and such expectations may be less important for task performance.

In addition, field studies of team mental models pose measurement challenges for researchers, as relatively well-established, lab-based measures may be inappropriate for the field. Consider the strategy that Marks et al. (2000) used to measure team mental models in the lab: the researchers asked participants in their study to describe the sequences of actions that they thought that and each of their team members should ideally perform. While this strategy is appealing and tenable when teams are small (three people or fewer) and team members' tasks are finite and fairly well-defined, this strategy would prove far too demanding and complex for respondents who are members of relatively large action teams, such as those we studied, that perform tasks of much greater variety and uncertainty. These observations suggest that field studies of team mental models should indeed 'be used in a complementary manner' to extend and validate the findings of laboratory-based research. We offer not a comparison of field and lab research, but a field-based study that replicates prior lab-based studies of team mental models.

Organizational Context

Participants in this research were members of the Singapore Armed Forces (SAF). The SAF is comprised of three branches: the Singapore Army, the Republic of Singapore Air Force, and the Republic of Singapore Navy. The 71 combat teams that participated in this study came from three infantry battalions from the Singapore Army.

Unit Context

Each infantry battalion has three fighting companies, each consisting of three fighting platoons. Each platoon has approximately 30 soldiers, organized in three infantry sections, each commanded by a section leader. In this article, we refer to the sections as combat teams. Each combat team is trained, over a 2-year period, to operate in the larger context of the platoon operations. As this study was conducted in the early phase of the training cycle, the combat teams were undergoing basic team level skills and tactics training. Hence, it was possible to collect team level performance data.

Team Context

Each combat team was made up of seven to eight soldiers. A team leader of Sergeant rank was also assigned to each team. The teams were trained to perform small unit operations such as securing a key installation or overcoming a small enemy force. The soldiers received training in these operations, as a team, and also underwent extensive physical fitness training (e.g., completing obstacle courses, taking long road marches). Team members spent most of their time together during the training phase. Further, the soldiers remained in the same teams for the duration of their 2 years of military service.

Method

Sample and procedures

To test our hypotheses, we studied 71 combat teams in the Singapore Armed Forces. The teams were composed of incoming soldiers, beginning their compulsory service of 2 years in the Singapore Armed Forces. Seven to eight soldiers were assigned to each team and teams were nested within three infantry units (battalions). Soldiers were randomly assigned to teams and all teams received the same training program. The teams were military combat teams trained to perform small unit operations such as securing a key installation or overcoming a small enemy force. The soldiers received training in these operations, as a team, and also underwent extensive physical fitness training (e.g., completing obstacle courses, taking long road marches). Team members spent most of their time together during the training phase. Further, the soldiers remained in the same teams for the duration of their 2 years of military service.

Data collection took place at two times. At Time 1, 10 weeks after the teams were formed, we collected survey measures of team members' and subject matter experts' (SMEs) taskwork and teamwork mental models. More specifically, we gathered mental model measures from 548 team members (477 soldiers and 71 team leaders) and from three SMEs. Team members ranged in age from 18 to 23 years ($M = 19.1$ years, $SD = 1.03$) and were predominantly of Chinese ancestry (as is typical of the Singaporean population). At a minimum, team leaders had completed high school and team members had completed junior high school. As military service is compulsory for Singaporean males over the age of 18, all research participants were male. The three SMEs were Army captains with at least 5 years of military service. We used their ratings to define the expert (i.e., accurate) mental models.

At Time 2, 3 weeks following Time 1 data collection, teams participated in a 1-day assessment center, in which an assessor rated each team's combat performance readiness based on each team's performance during six military tasks. In total, 24 assessment center assessors provided performance ratings. The response rate was 91 per cent for team members and 100 per cent for assessment center assessors and SMEs.

Measures

Mental models

Researchers commonly assess mental models by presenting respondents with a list of concepts and asking respondents to describe the relationships among the concepts (e.g., Marks et al., 2002; Mathieu et al., 2000; Stout et al., 1999). To assess team members' *taskwork* mental models, we asked each team member to judge the relatedness of 14 statements describing team procedures, equipment, and tasks. Participants were given the following instructions: 'On the following pages, you will be asked to judge the relatedness of pairs of statements. Specifically, you will be asked to rate how related are these statements to team effectiveness and to each other.' Team members rated the relatedness of all pairs of statements (91 pairs), using a 7-point response scale (1 = unrelated and 7 = highly related). Statements included: 'Team members conduct routine maintenance of their equipment and weapons in the field,' 'Team members are cross-trained to carry out other members' tasks,' 'Team members have a good understanding of the characteristics of the enemy's weapons,' and 'The team is highly effective.'

To obtain a measure of each team member's *teamwork* mental model, we asked participants to judge the relatedness of 14 statements describing team interaction processes and the characteristics of team members (e.g., 'Team members trust each other,' 'Team members accept decisions made by the leader,' 'Team members communicate openly with each other,' and 'Team members are aware of other team members' abilities'). Here, too, participants rated the relatedness of all pairs of statements

(i.e., 91 pairs), on a 7-point response scale (1 = unrelated and 7 = highly related). We included the item 'The team is highly effective' as one of the 14 items in both the taskwork and the teamwork mental models, as we sought to capture team members' understanding of the relationship of the mental model concepts to each other and to team effectiveness.

To obtain a measure of *experts*' taskwork and teamwork mental models, we asked three SMEs to complete the relatedness ratings that team members completed. Thus, SMEs rated the relatedness of 91 pairs of taskwork statements and of 91 pairs of teamwork statements. The three SMEs taskwork mental models were highly similar (i.e., the average similarity score among the three SMEs' taskwork mental models was 0.71), as were the SMEs' teamwork mental models (i.e., the average similarity scores among their teamwork mental models was 0.59). Accordingly, we averaged the SMEs' mental models to create the expert taskwork and teamwork mental models.

To develop the taskwork and teamwork statements, we drew on Cannon-Bowers et al.'s (1993) descriptions of team mental models and consulted with SMEs from the Singapore Armed Forces. Specifically, we began our research by asking a separate set of five SMEs who have extensive experience in training and evaluating this type of combat team to describe the characteristics critical for team effectiveness. We compiled the responses from these SMEs and categorized them into the taskwork and teamwork domains, ultimately choosing 14 statements for each mental model. See Appendix A for the 28 statements.

Like Marks et al. (2002) and Stout et al. (1999), we used the structural assessment technique Pathfinder (Schvaneveldt, 1990) to generate each team member's taskwork and teamwork mental models. Essentially, Pathfinder creates a model, or network, based on each respondent's ratings of the similarity between the each pair of statements in the model. Each statement in the model is represented as a node in the network. Statements that the respondent rated as high in similarity are closely linked in the respondent's model. Statements that the respondent rated as low in similarity are less closely linked in the respondent's model. Pathfinder represents the closeness of the link between of statements with a numerical weight. (See Appendix B for more detailed information about Pathfinder.)

Team mental model similarity

Building on prior mental model research using Pathfinder (e.g., Marks et al., 2002; Stout et al., 1999), we computed taskwork mental model similarity by: (a) using Pathfinder to assess the similarity between each team member's taskwork mental model and the taskwork mental model of every other member of his team; the similarity measure is the proportion of common links in relations to the total number of links present in both networks (Schvaneveldt, 1990); and then (b) averaging the similarity scores for each dyad within the team to calculate the average similarity of team members' taskwork mental models. We used the same procedures to calculate each team's teamwork mental model similarity score. Similarity score can range from 0 to 1. Hence, a score of 0.2 would mean that 20 per cent of the mental model structure is shared. (Please see Appendix B for a detailed example of the calculation of similarity scores, using Pathfinder.)

Team mental model accuracy

We computed team taskwork mental model accuracy by using Pathfinder to: (a) average the three SMEs' taskwork mental models, (b) compare the experts' average taskwork mental model to each team member's taskwork mental model to derive a similarity index, and (c) average these indices to form the team accuracy score. We used the same procedures to calculate teamwork mental model accuracy.

Team performance

At Time 2, teams participated in a 1-day standardized military assessment designed to determine the operational effectiveness of each team. The assessment center was a combat circuit created in a jungle

environment. The circuit was comprised of a number of stations where team tasks were performed. The Singaporean Army used the expert assessors' ratings of each team's performance at each station to determine the team's operational readiness. Teams that performed poorly were required to undergo additional training prior to reevaluation. During the assessment, each team performed six independent military tasks typical of this type of combat team. Tasks included securing a vital road junction for friendly forces, patrolling a hostile territory to seek out 'enemies,' securing a critical installation or structure (e.g., a key bridge), overcoming an enemy outpost occupied by a small force, laying an ambush, reacting to an ambush, and evacuating injured comrades to the nearest helicopter landing point. All are common military tasks performed by small military units often as part of a larger mission or force. Most, if not all, military tasks including these six tasks require team members to synchronize their actions in order to complete the team task. Hence, the teams' tasks, both on and off the assessment center course, were high in task interdependence.

After a team completed a task, a trained assessor rated the team's efficiency in completing that task, on a single item measure with a 7-point response scale (1 = 'Low: The team is not efficient, the team takes a long time to get things done' and 7 = 'High: The team is highly efficient, this team gets things done in the shortest time possible'). Similarly, after each task, the trained assessor rated the quality of the team's actions in completing that task, using a single item measure with a 7-point response scale (1 = 'Low: This team does not take pride in its work, tasks are carried out using the most convenient way rather than the best way' and 7 = 'High: This team takes pride in its work, tasks are carried out in the best possible way'). We averaged the team's six efficiency scores to form an overall measure of team efficiency (alpha = 0.90) and averaged the team's six quality scores to form an overall measure of team quality (alpha = 0.87). Because the efficiency and quality measures were highly correlated ($r = 0.67$, $p < 0.01$), we combined the two measures to create our measure of team performance (composite alpha = 0.93).

Analyses

To test the hypotheses, we conducted a series of correlation and hierarchical regression analyses. We controlled for combat unit in all regression analyses. Although the Singapore Armed Forces dictate training policies, guidelines, and standards to all units, the three units had different commanders, used different trainers, trained in different locations, participated in assessment centers in different locations, and used different assessors in the assessment center exercises. By controlling for combat unit, we excluded from further analysis any between-unit variance in performance attributable to between-unit differences in leadership, work climate, training, assessment center location, or assessors. We considered including team size as a control variable as well, but chose not to because team size was not significantly related to any of the variables in our hypotheses.

Results

Correlational results

Table 1 presents the means, standard deviations, and correlations for all measures. As shown in Table 1, taskwork mental model similarity was significantly positively related to teamwork mental model similarity ($r = 0.55$, $p < 0.01$), suggesting that teams whose members share similar taskwork mental

Table 1. Descriptive Statistics for All Measures

Variables	*M*	*SD*	1	2	3	4
1. Taskwork MM Similarity	0.20	0.04	—			
2. Teamwork MM Similarity	0.20	0.04	0.55**	—		
3. Taskwork MM Accuracy	0.20	0.04	0.57**	0.33**	—	
4. Teamwork MM Accuracy	0.18	0.05	0.32**	0.53**	0.40**	—
5. Team Performance	4.12	1.04	0.29**	0.21*	0.42**	0.23*

Note: $N = 71$ teams;
*$p < 0.05$; **$p < 0.01$.

models are likely to have similar teamwork mental models as well. Likewise, taskwork and teamwork model accuracy were also related ($r = 0.40$, $p > 0.01$). Further, taskwork model similarity was significantly positively related to taskwork model accuracy ($r = 0.57$, $p < 0.01$) and teamwork model similarity was significantly positively related to teamwork model accuracy ($r = 0.53$, $p < 0.01$). Thus, teams whose members are high in mental model similarity also tend to be high in mental model accuracy. As expected, both taskwork and teamwork model similarity were significantly positively related to team performance ($r = 0.29$, $p < 0.01$; $r = 0.21$, $p < 0.05$, respectively). Similarly, taskwork and teamwork model accuracy were significantly positively related to team performance ($r = 0.42$ and 0.23, respectively; $p < 0.05$).

Tests of hypotheses

We now turn to a formal test of our hypotheses. We first report the results of our tests of the hypotheses with respect to taskwork mental models and then report the results of our tests of the hypotheses with respect to teamwork mental models

Taskwork mental model similarity and accuracy

In Hypotheses 1 and 2, we proposed that mental model similarity and mental model accuracy would predict team performance. In Hypothesis 3, we proposed that the relationship between mental model similarity and team performance would be moderated by mental model accuracy; the more accurate a team's mental model, the stronger the relationship between mental model similarity and team performance. To test these hypotheses *with respect to taskwork mental models*, we regressed team performance on both taskwork mental model similarity and taskwork mental model accuracy (Step 2) after controlling for combat unit (Step 1). We then entered the interaction of taskwork mental model similarity and taskwork mental model accuracy in Step 3.

As shown in Table 2, after controlling for combat unit in Step 1, both taskwork model similarity and accuracy accounted for 19 per cent of the variance in team performance ($F(2, 66) = 12.39$, $p < 0.01$). Both predictors were significant ($p < 0.05$). However, the interaction term was not (change in $R^2 = 0.00$, $F(1, 65) = 0.15$, $p > 0.05$). The results thus support Hypotheses 1 and 2, but not Hypothesis 3.

Teamwork mental model similarity and accuracy

Table 3 reports the results of regressions used to test Hypotheses 1–3, *this time with respect to teamwork mental model similarity and accuracy.* After controlling for combat unit, both teamwork mental model similarity and teamwork mental model accuracy were significantly positively related to team

Table 2. Hierarchical Regressions of Team Performance on Taskwork Mental Model Similarity and Accuracy

Variable	Team performance				
	B	SE B	β	ΔR^2	R^2
Step 1				0.29**	0.29**
Unit 1	−0.13	0.27	−0.06		
Unit 2	1.10	0.25	0.51**		
Step 2				0.19**	0.48**
Unit 1	−0.41	0.24	−0.17*		
Unit 2	1.06	0.22	0.49**		
Taskwork MM similarity	8.33	3.00	0.32**		
Taskwork MM accuracy	5.38	3.22	0.19*		
Step 3				0.00	
Unit 1	−0.41	0.24	−0.17*		
Unit 2	1.5	0.23	0.49**		
Taskwork MM similarity	3.80	12.15	0.15		
Taskwork MM accuracy	0.87	12.15	0.03		
Similarity × accuracy	22.71	59.04	0.30		

Note: $N = 71$ teams.
*$p < 0.05$; **$p < 0.01$ (one tailed).

Table 3. Hierarchical Regressions of Team Performance on Teamwork Mental Model Similarity and Accuracy

Variable	Team performance				
	B	SE B	β	ΔR^2	R^2
Step 1				0.29**	0.29**
Unit 1	−0.13	0.27	−0.06		
Unit 2	1.10	0.25	0.51		
Step 2				0.10**	0.39**
Unit 1	−0.44	0.27	−0.19		
Unit 2	1.01	0.23	0.47**		
Teamwork MM similarity	4.65	2.96	0.18†		
Teamwork MM accuracy	4.74	2.64	0.21*		
Step 3				0.00	
Unit 1	−0.40	0.29	−0.17		
Unit 2	1.01	0.23	0.47**		
Teamwork MM similarity	−0.49	11.22	−0.02		
Teamwork MM accuracy	−0.64	11.63	−0.03		
Similarity × accuracy	26.53	55.87	0.38		

Note: $N = 71$ teams.
*$p < 0.05$. **$p < 0.01$ (one tailed); †$p = 0.06$.

performance, explaining 10 per cent of the variance in team performance ($F(2, 66) = 5.51$, $p < 0.01$). The interaction of teamwork mental model similarity and accuracy was not significant (change in $R^2 = 0.00$, $F(1, 65) = 0.23$, $p > 0.05$). The results support Hypotheses 1 and 2, but not Hypothesis 3, the interaction hypothesis.

Discussion

During the past decade, as interest in teams has grown, organizational theorists have drawn on research in cognitive psychology to posit that teams whose members share accurate team-related mental modelsÂwill outperform teams whose members differ in their team-related mental models (e.g., Cannon-Bowers et al., 1993; Klimoski & Mohammed, 1994). Our findings lend further credence to these arguments. Our findings suggest that teams whose members structure and organize their team-related knowledge in a similar fashion are likely to find it relatively easy to coordinate their activities. They are likely to agree upon team priorities and strategies, yielding efficient task performance.

Unlike Mathieu et al. (2000), we found a direct relationship between team mental model similarity and team performance. This may reflect the context in which the teams that we studied are trained to operate. They are expected to perform under high stress and intense time pressure. Under such circumstances, there is very little time for explicit coordination and communication. To succeed in their tasks (e.g., reacting to an enemy's ambush), team members must have a shared understanding of the emerging situation and the collective action required. It is precisely in this type of context that shared mental models have been hypothesized to be most predictive of team performance.

Our findings suggest that team mental model accuracy is also instrumental for team performance. Teams whose average mental models were most similar to experts' mental models performed better than did teams whose average mental models were less similar to experts' mental models. We speculate that teams whose mental models were most accurate pursued more effective task performance strategies than did teams whose mental models were less accurate.

We note that mental model similarity and mental model accuracy were positively correlated (average $r = 0.55$). If a team's teamwork or taskwork mental model is highly accurate, the model is—by definition—widely shared among team members. That is, a highly accurate team mental model reflects the presence of highly accurate individual team member mental models—hence, considerable within-team homogeneity. Inaccurate mental models may also be widely shared among the members of a team, however. That is, team members may all subscribe to similar but nevertheless quite inaccurate mental models. Thus, team mental model accuracy and similarity are not redundant constructs or measures, as evidenced by the significance of both taskwork mental model similarity and taskwork mental model accuracy in predicting team performance.

We were surprised that the results did not reveal a significant interaction of team mental model similarity and accuracy. Perhaps this reflects the often-noted difficulties of finding significant interactions (Aguinis, 1995; Aguinis & Stone, 1997; Schneider, 1978). Given the limited number of studies that have tested the consequences of mental model accuracy, additional studies of this topic are clearly needed. Mathieu et al.'s (2005) strategy of measuring multiple experts' mental models and using their results to calculate not accuracy, but quality, is also intriguing.

Limitations and strengths of the research

Like all research, our research is limited in a number of respects. First, our measure of team mental models—like other measures of team mental models (e.g., Marks et al., 2002; Mathieu et al., 2000; Rentsch & Klimoski, 2001; Stout et al., 1999)—required us to choose the specific concepts that we asked respondents to compare. Team member's mental models may, however, differ not only in structure but in content, as well. Second, our mental model measure did not allow us to assess the perceived causal relationships implicit in respondents' mental models; the links between nodes in a Pathfinder network are based on ratings of relatedness or similarity, not causality. Perhaps measures

that allow respondents to report the content and structure of, as well as the causal relationships underlying, their mental models might prove even more predictive of team performance. Third, although our sample size of 71 teams is fairly typical of team studies, it nevertheless limited our statistical power. Finally, we conducted the research among combat teams of the Singaporean Army. Our findings are likely, we believe, to generalize to other action teams whose members perform complex, interdependent, and often unpredictable tasks. Additional research is needed, however, to test the generalizability of our results.

The limitations of the research are offset, we believe, by its methodological strengths. These include our examination of a relatively large sample of real teams in the field, our use of multi-source measures, our development of team mental models based on SMEs' descriptions of the teams we studied, and our assessment of team performance based on experts' ratings of team's real-time (not retrospective) performance. The literature on team mental models has been dominated by laboratory studies of small, short-lived teams. Our findings suggest that shared mental models influence the performance of real-world action teams. Further, our findings—and those of other recent, field-based studies of team mental models (e.g., Smith-Jentsch et al., 2005)—demonstrate the feasibility of studying mental models in real-world teams. The size, task complexity, uncertainty, and duration of real-world teams are likely to far exceed the size, complexity, uncertainty, and duration of lab teams. As a result, teams in the field are likely to have mental models of greater complexity and abstraction than teams in the lab—a point that warrants further examination.

Directions for theory and research

Our findings extend the literature by demonstrating that both mental model similarity *and* mental model accuracy are associated with effective team performance in the field. Needed now are studies that provide further tests of the fundamental propositions of team mental model theory as well as tests of nomological network within which the constructs of team mental model similarity and accuracy are embedded. In designing this study, we relied on Cannon-Bowers et al.'s (1993) proposition that teams have four mental models (and Mathieu et al.'s (2000) study of taskwork and teamwork mental models). But, this proposition awaits testing. It seems likely that some teams may have additional team mental models that are consequential for team performance—perhaps, for example, a mental model of their customers' (or constituents') demands and priorities and the best way to meet these demands and priorities. Perhaps team mental models that differ in their focus (taskwork, teamwork, etc.) may differ in their consequences as well. Further, researchers (e.g., Mathieu et al., 2000; 2005) have only just begun to explore the team processes that mediate the relationships between team mental model similarity and accuracy and team performance. Similarly, researchers have little explored the antecedents of team mental model similarity and accuracy (see Marks et al., 2000 and Rentsch & Klimoski, 2001 for exceptions). Finally, we know too little about the relationships between team mental models and both new and established team constructs and measures: team demographic diversity, team affective diversity, team leadership, team psychological safety, team conflict, transactive memory, team cognitive resources, and more (e.g., Edmondson, 1999; Jehn, Northcraft, & Neale, 1999; Barsade, Ward, Turnver, & Sonnenfeld, 2000). For example, it seems plausible that teams that are high in surface (demographic) and deep (personality, values) diversity may have difficulty developing shared mental models of their task and ideal team processes. Team mental models represent a new perspective on team dynamics and effectiveness—but one that should ideally complement and supplement, not supplant, more established perspectives. An integration of these perspectives will yield practical insights and strategies likely to lead to enhancements in team effectiveness.

Conclusion

Our findings suggest that team mental models do matter. Numerous questions remain, but the current findings advance understanding of shared cognition in teams, and suggest that continuing research on team mental models is likely to yield new theoretical insights as well as practical interventions to enhance team performance.

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Appendix

Appendix A

The table below shows all the 28 items used for in the pairwise comparisons to assess team members' taskwork and teamwork models.

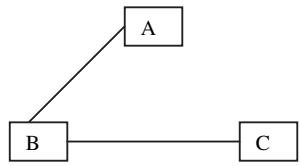
Taskwork Mental Model Survey Items
1. Team members are proficient with their own weapons.
2. Team members are proficient with other members' weapons.
3. Team members are very good at IA drills.
4. Team members have a good understanding of the characteristics of the enemy's weapons.
5. Team members conduct routine maintenance of their equipment and weapons in the field.
6. Team members are allowed to bring their personal weapon home.
7. Team members understand the team's task.
8. Team members agree on a strategy to carry out the team task.
9. Team members understand other members' tasks.
10. Tasks in the team are assigned according to individual member's ability.
11. Team members are cross-trained to carry out other members' tasks.
12. Team members adhere strictly to the team's SOP.
13. Team members understand the battlefield situation.
14. The team is highly effective.
Teamwork Mental Model Survey Items
1. Team members work well together.
2. Team members often disagree with each other on issues faced by the team.
3. Team members trust each other.
4. Team members communicate openly with each other.
5. Team members agree on decisions made in the team.
6. Team members accept decisions made by the leader.
7. Team members interact with one another outside the camp compound.
8. Team members back each other up in carrying out team tasks.
9. Team members are similar to each other (e.g., personality, temperament, and abilities).
10. Team members are aware of other team members' abilities.
11. Team members are aware of other team members' personal backgrounds (e.g., family background, hobbies, and habits).
12. Team members know other team members' family members.
13. Team members treat each other as friends.
14. The team is highly effective.

Appendix B

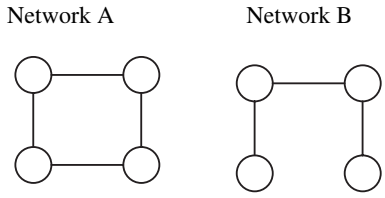
Pathfinder takes in raw scores (i.e., pairwise comparisons) in a form of upper or lower triangle matrix and generates a network for each member. In analyses, a link between two concepts in the Pathfinder network is only included if and only if the link is a minimum length path between the two concepts (Branaghan, 1990). Below is an example of the Pathfinder network for the three nodes (i.e., *A*, *B*, and *C*) given their pairwise ratings, based on a 1–7 response scale ranging from 1 = 'Related,' to

7 = 'Unrelated.' In this case, the link between A and C does not exist simply because A to C *via* B is the minimum length path (i.e., $1 + 3 = 4$ which is less than 5, the direct path from A to C).

	A	B	C
A	-		
B	1	-	
C	5	3	-



This allows the PF network to capture the essential links by reducing the 'noise' in the raw proximity data. After that, Pathfinder compares two networks at a time to assess their similarity. The similarity score is calculated using the following formula $(X/[T - X])$ where X is the number of common links between the two networks and T is the total number of links in both networks. For example:



In this example, Network A shows four links. Network B shows three of the same links. Hence, the Network A–Network B similarity score is $(3/[7 - 3]) = = 0.75$, where 3 is the number of common links between the two networks and 7 is the total number of links in both networks. We hope this example further clarifies how Pathfinder calculates the similarity between two networks.

QAP correlations, calculated using the network analysis program UCInet, are very similar. Essentially, 'QAP correlations are equivalent to Pearson correlations between the two identical elements of two mental model matrices (Mathieu et al., 2005, p. 43).' To compare QAP correlations and Pathfinder similarity scores, we randomly selected five teams from our database and subjected the raw data from the 29 (i.e., team size of 8, 6, 6, 5, and 4) members of these teams to both Pathfinder analysis and QAP analysis. That is, we used Pathfinder to calculate the similarity scores for each of the 74 dyads and we also used QAP in UCInet to calculate the correlation between the networks in each dyad. We then calculated the correlation between each dyad's similarity score and each dyad's QAP correlation. The average correlation between the similarity scores generated by Pathfinder and the QAP scores for the 74 dyads was 88. The table below shows the actual similarity scores from Pathfinder and QAP scores for one of the teams. The correlation is 0.89 .

	*M*1	*M*2	*M*3	*M*4	*M*5	*M*6	*M*7	*M*8
*M*1	—	0.30	0.24	0.15	0.31	0.43	0.34	0.19
*M*2	0.42	—	0.28	0.16	0.33	0.39	0.24	0.17
*M*3	0.30	0.21	—	0.21	0.53	0.42	0.35	0.14
*M*4	0.05	−0.10	0.17	—	0.21	0.23	0.22	0.08
*M*5	0.25	0.26	0.50	0.16	—	0.41	0.40	0.11
*M*6	0.50	0.45	0.44	0.05	0.50	—	0.43	0.24
*M*7	0.53	0.39	0.36	0.13	0.51	0.69	—	0.15
*M*8	0.06	−0.07	−0.01	0.08	−0.04	0.11	0.03	—

Note: QAP scores are reflected in the lower triangle; Pathfinder similarity scores are reflected in the upper triangle.

