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Review

Team mental models and their potential to improve teamwork and safety: A review and implications for future research in healthcare

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ABSTRACT

The importance of team mental models (TMMs) – team members' shared and organized understanding of relevant knowledge – for teamwork and team-performance, particularly in high-risk industries, has been recognized for almost two decades. In healthcare, however, systematic investigations on the influence of TMM on teamwork and team-performance had yet to be conducted at the time of this review, despite many authors considering the concept to be useful for medical teams. The lack of measurement procedures appropriate for settings as complex and dynamic as, for example, the operating room, represents a major obstacle for empirical research in healthcare. We systematically reviewed empirical studies on TMMs aiming to identify methods that could be applied in healthcare. In particular, we analyzed the methods used, and situations in which TMMs have been investigated. The reviewed studies were sorted according to task and team characteristics. We discuss the results of this review with regard to characteristics of healthcare teams including anaesthesia teams and teams of ward nurses. Each of these examples represents a distinct teamwork setting (e.g. long- vs. short-lived teams) and hence requires a different approach to TMM measurement (e.g. focus on task-model vs. focus on team-model). Implications for study design, feasible measurement approaches, and questions for future research on TMMs in healthcare are discussed. In sum, our findings highlight the possible significance of TMM research in healthcare and its potential benefits for team-performance and, ultimately, patient safety.

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1. Introduction

Recent research highlights the role of teamwork for providing safe patient care across different areas of healthcare. In surgery, for example, teamwork behaviors such as communication and information sharing have been found to be related to patient outcomes (Mazzocco et al., 2009; Williams et al., 2010). At the same time, studies on anaesthesia teams have underlined the significance of adaptive coordination for clinical performance (Burtscher et al., 2011, 2010; Manser et al., 2009). The importance of teamwork has been acknowledged in intensive care and mental health (Liberman et al., 2001; Miller et al., 2009; Reader et al., 2006). Finally, a recent review has highlighted the pivotal role of effective team leadership for patient safety in various medical fields (Künzle et al., 2010). In view of the importance of teamwork, there is a need to identify the prerequisites of successful teamwork – e.g. factors enabling team members to coordinate their work smoothly and effectively. Other high-risk industries such as aviation and the nuclear industry have long recognized the importance of teamwork to improve safety (Grote et al., 2010; Sasou et al., 1993; Thomas et al., 2004; Wilson et al., 2005). Research in these areas has identified team mental models as one of the key mechanisms that make effective teamwork possible (Cannon-Bowers et al., 1993; Salas et al., 2005).

Team mental models (TMMs) have been defined as team members' shared and organized understanding of relevant knowledge – i.e. aspects of their common work (Cannon-Bowers et al., 1993; Klimoski and Mohammed, 1994). A widespread picture for is that of all members being "on the same page" with respect to how the common task is to be performed (Mohammed et al., 2010). This state is thought to be the cognitive basis of the smooth and effortless coordination observed in many expert teams. In fact, a recent meta-analysis covering a wide range of different teams revealed that TMMs had a significant effect on both team-processes as well as on team-performance (DeChurch and Mesmer-Magnus, 2010). Moreover, a review of extant literature furnished further support for the important role of TMMs (Mohammed et al., 2010). Interestingly, none of the studies included in either of those papers dealt with TMMs in medical teams. This is even more surprising since many authors have pointed out the relevance of TMMs in healthcare (Healey et al., 2006; Manser, 2009; Musson and Helmreich, 2004; Rall and Gaba, 2005; Wilson et al., 2005). From a theoretical point a view, nothing would contradict applying the TMM concept to medical teams. Thus, there must be other reasons for the current lack of empirical studies. In our view, the complexity and dynamic nature of most healthcare settings – the operating room being a striking example – has precluded empirical research on TMMs to date. As studies have mainly been conducted in laboratory or simulator settings involving simple tasks, we do not know whether existing methodology will be applicable to the complex and dynamic tasks that most medical teams have to face. In fact, we have yet to determine how TMMs in healthcare may be assessed.

The current article aims to address this gap by identifying measurement methods used successfully in other high-risk industries that could potentially be used to investigate TMMs in medical settings. In so doing, we aim to foster empirical research on prerequisites of successful teamwork in healthcare. Eventually, these findings could contribute to the enhancement of clinical performance and patient safety.

This paper is organized as follows. Firstly, we will discuss the theoretical basis of the TMM concept. Then, we will review the respective empirical literature systematically, analyzing the settings in which TMMs have been investigated and the methods used in those studies. The results of this analysis will be related to characteristics of medical teams and implications for future research on TMMs in healthcare will be discussed – in particular regarding appropriate study designs and measurement methods. Moreover, we will discuss the potential benefits of such research for team-performance improvement and hence, patient safety.

2. Theoretical background

2.1. Team mental models, team-processes, and team-performance

The important role of TMMs is emphasized in many current theoretical models of teamwork (Burke et al., 2006; Salas et al., 2005). In general, the TMM concept refers to the team members' shared and organized understanding of relevant knowledge – i.e. aspects of their common work (Cannon-Bowers et al., 1993; Klimoski and Mohammed, 1994). Researchers have categorized the content of TMM. Cannon-Bowers et al. (1993) have distinguished four types of mental models: the equipment model (e.g. equipment functions, limitations of the system), the task model (i.e. procedures, actions and strategies to perform a task), the team model (i.e. shared knowledge of other team members' knowledge and skills), and the team interaction model (i.e. how team members should interact within a given task). These four classifications have been reduced to two types of content: task-related content and team-related content (Mathieu et al., 2000). *Task-related TMMs* refer to a specific task and include goals, subtasks, and performance requirements. The content of task-related *TMMs* is usually obtained through a task-analysis (e.g., Smith-Jentsch et al., 2005). *Team-related TMMs* on the other hand are more generic; they include requirements of interpersonal interaction and skills of other team members (Mohammed et al., 2010). Moreover, team members can share attitudes and beliefs such as those regarding how a team should cooperate in general (Cannon-Bowers and Salas, 2001).

Apart from their content, TMMs have two distinct properties: similarity and accuracy (Marks et al., 2000). When different people perform a task together as a team, each of them has their own conception of what it entails and how it should be done, i.e. everyone has a different mental model. *Similarity* refers to the degree to which the team members' mental models are consistent with one another (Mathieu et al., 2005). Having a similar TMM enables team members to anticipate each other's needs and actions and thus to coordinate more efficiently, resulting in a superior team-performance. TMM similarity is thought to be particularly relevant in dynamic environments where situational constraints such as time pressure rule out explicit planning and coordination (Rico et al., 2008). The relationship between team-performance and TMM similarity has been empirically supported; teams holding a more similar TMM exhibited superior performance (Mathieu et al., 2000; Rentsch and Klimoski, 2001). Moreover, team processes have been shown to influence this relationship. For example, Marks et al. (2002) found that the link between TMM similarity and team-performance was completely mediated by team-coordination. Communication was also found to be influenced by TMM similarity (Marks et al., 2000).

Similarity, however, does not necessarily result in improved performance. Imagine a situation, where individual mental models are similar but seriously flawed – e.g. every team member has the same wrong conception of their common task. In said situation, the team is unlikely to complete their task successfully (Mathieu et al., 2005). To account for such situations, researchers have proposed a second TMM property: accuracy. *TMM accuracy* is an index of the correctness of the individual members' mental models; in order words, it describes the degree to which they resemble the "true state of the world" (Edwards et al., 2006). For example, if there is a gold standard for a procedure, TMM accuracy indicates the degree to which the team members' models are consistent with this standard. Since most complex tasks lack a step-by-step standard solution, accuracy is usually measured by comparison to expert models. Typically, these subject matter experts (SME) are chosen on the basis of their prior experience with the respective task ((Smith-Jentsch, 2008). For example, to identify an expert team-related TMM, Mathieu et al. (2005) interviewed team researchers who had many years of experience in conducting studies, particularly in applied settings. Highly accurate TMMs have also been shown to be positively related to team-performance (Edwards et al., 2006).

2.2. Measuring team mental models

In spite of its sophisticated conceptual basis, the measurement of similarity and accuracy is still an issue since a standard procedure is yet to be established. A variety of different approaches have been used thus far (Langan-Fox et al., 2000; Mohammed et al., 2000), including pair-wise comparison ratings, cognitive mapping techniques, and Likert-type questionnaires. Pair-wise comparison ratings require team members to rate the relatedness of pairs of concepts from a predefined set. These concepts represent the content of the TMM such as different aspects of the team's task (Stout et al., 1999). In order to assess TMMs, network analysis software (e.g. UCINET, Pathfinder) has been used to analyze and compare individual relatedness scores as well as to relate individual scores to those of experts (Edwards et al., 2006). Cognitive mapping also makes use of predefined concepts that have to be sorted into a given structure by each member (Marks et al., 2000). Thereby, the number of overlapping concepts within a team reflects the degree of similarity, whereas the average overlap with an expert model reflects the degree of accuracy. Likert-type questionnaires are also frequently used to assess TMMs. For example, team members are asked to indicate the appropriateness of certain actions relating to their task (Marks et al., 2000). Questionnaire data have been analyzed using inter-rater agreement indices such as r_{wg} (James et al., 1984, 1993) as a measure of similarity.

2.3. The role of situational characteristics

Situational characteristics including task interdependence and team type have been found to moderate the influence of TMMs on teamwork; for example, certain types of TMM were found to be more predictive for team-process in action teams (DeChurch and Mesmer-Magnus, 2010). Since medical teams vary considerably in terms of these aspects, it is very likely that a TMM measure that is appropriate for one team would not work well for another. Thus, the appropriateness of a measurement method for a certain healthcare setting needs to be carefully judged to ensure accurate and feasible measurement generating meaningful results. For example, a time-consuming measurement method may be the appropriate choice for a study in a simulated environment. Yet, it is not feasible in a real-life setting; it would be both impractical and unethical to ask healthcare professionals to complete a 30-min questionnaire right before they attend an operation. In view of the large quantity of different team types and settings in healthcare, it is therefore necessary to review setting characteristics systematically.

Situational characteristics that are likely to affect TMMs in healthcare will now be discussed. Firstly, the level of task interdependence, i.e. the extent to which team members are required to coordinate their actions, differs between settings (Tesluk et al., 1997; Wageman, 1995). The more interdependent the subtasks of each team member, the higher the need of coordination to reach the common goal and thus, the increased need of a shared understanding (Kraiger and Wenzel, 1997). A team of surgeons performing a cardiac bypass operation is characterized by a high-level of task interdependence; by contrast, the majority of ward nurses' routine tasks are loosely coupled. Secondly, the degree of standardization of the task might influence the TMM–team-performance relationship. A highly standardized task such as the induction to general anaesthesia has, by definition, a performance standard – i.e. there exists a commonly accepted best practice. Consequently, such a task requires all team members to hold a highly accurate TMM. By contrast, an un-standardized task allows different approaches to solve it; team members only have to agree on which approach they choose. Therefore, TMM similarity should be more important than accuracy. A third factor concerns the setting. In high-risk industries where demands on teamwork and coordination are high, TMMs can be a critical success factor. Additionally, aspects of the team itself such as the members' educational background and experience, similarity of training, or how long they have functioned together as a team can influence the TMM and its effects (Mohammed et al., 2010). Researchers have suggested that teams that remain intact for longer periods (i.e. several months or even years) have the possibility to gradually develop a shared understanding during work – e.g. by means of communication and explicit discussions – whereas short-lived teams lack this opportunity (Rico et al., 2008). Conversely, ad-hoc assembled teams with varying membership such as anaesthesia teams have to rely on factors other than long-term interactive experience to build a TMM (Kolbe et al., 2009).

2.4. Team mental models and teamwork in healthcare

The prevalent framework of team research is the input-process-outcome (IPO) model and its recent variations. The IPO-model describes teamwork as interplay of input, process, and outcome variables (Ilgen et al., 2005; Mathieu et al., 2008; McGrath, 1984). Input factors refer to factors that enable and constrain members' interactions. They exist on in individual-level (e.g. expertise, motivation), the team-level (e.g. team size, TMM), and the organizational/contextual level (e.g. environmental complexity, organizational policy) (Mathieu et al., 2008). Input factors drive team processes such as team members' coordination and communication. Outcomes are in turn the results and by-products of these processes with performance being the most widely studied criterion. Indicators of performance include quality (e.g. quality of a product), quantity (e.g. how many products), and safety (e.g. incidents during production).

Research on teamwork in healthcare has also adopted the IPO-Model (Reader et al., 2009). The focus, however, lay on investigating relationships between processes and outcomes. For example, team coordination has been shown to predict the performance of teams in anaesthesia (Manser, 2009). Furthermore, specific leadership styles such as shared leadership have been identified as a central factor to enhance team-performance and safety in critical care teams (Klein et al., 2006; Künzle et al., 2010). By contrast, there is much less research on input factors, most particularly TMM. However, recent research has begun investigating input factors with promising results (Balslev et al., 2009; Haig et al., 2006; Reader, 2007). For example, Balslev et al. (2009) found that a small group of paediatricians who watched a video of a case exhibited an enhanced shared cognition, as measured through analysis of their discussion after watching that case, compared with another group of paediatricians who had studied a written case description. However, these studies are primarily qualitative; a systematic empirical investigation on the relationships between TMM, team-processes, and team-performance in healthcare had not been conducted at the time of this review.

3. Methods

3.1. Search strategy and selection of studies

We searched articles in two major electronic databases: PsychInfo (American Psychological Association) and Medline (US National Library of Medicine). The search was limited to publications between 1993 and 2009, which included post-publication of the seminal work regarding TMMs (Cannon-Bowers et al., 1993). We combined the key words "team", "mental", and "model" and their respective variations. Since our main research interests were the situational features and measurements of TMMs, we also included the related terms "shared mental model", "shared cognition", and "group cognition". A reference check of the existing reviews on TMMs was also performed to identify additional papers. The search resulted in a total of 463 different publications.

Following the literature search process, initial selection was based on the abstracts. In view of this review's focus, we only included empirical studies published in peer-reviewed journals. At least one of the search terms had to be mentioned in the abstract. As a result, 68 papers remained in the data pool.

As a final step, we extracted those empirical studies that investigated TMMs quantitatively by scanning for the following three criteria:

TMMs as main topic. Studies were included only if they dealt with TMMs as their main topic. Studies that dealt with concepts basically identical or at least very similar to TMMs (e.g. shared mental models) were included unless they explicitly referred to a differently defined concept such as transactive memory or cognitive consensus.

Empirical assessment of TMMs. TMMs had to be empirically assessed in some form. Studies using TMMs only as a theoretical construct for ex post explanations were excluded.

Research on team-level. Only studies involving empirical research on the team level with at least one quantified variable were included. Consequently, we excluded qualitative studies and single case studies.

A total of 33 studies met the inclusion criteria.

3.2. Data extraction and pooling procedure

Using our comparison of existing team typologies as a starting point, we selected the features of the studies that were most relevant for the purpose of the current review: provide researchers with a reference regarding settings and methods to design future studies on TMMs in healthcare. Relevant data were extracted in four steps and later integrated to allow for a comparison to different medical teams. Table 1 provides an overview of the study characteristics we extracted and a detailed discussion of these characteristics follows.

We considered basing our categorization on an existing team and work group classification. For example, Sundstrom and colleagues' classification distinguishing between six different team types (production, service, management, project, action and performing, advisory) provides a systematic, predefined scheme for structuring studies (Sundstrom et al., 2000). However, we chose a data-driven categorization procedure that focuses on the actual features of the included studies instead of a top-down approach, for two main reasons: Firstly, not all aspects of common team typologies are relevant to teamwork in healthcare. Secondly, our classification is based on the whole performance situation – in contrast to classifications solely focusing on the teams themselves. Thus, we were able to consider differences between laboratory, simulator, and field studies. These differences are less important from a theoretical point of view. They are, however, essential for the planning and design of studies on TMMs, particularly in complex settings such as healthcare, which restrict the use of lavish and time-consuming measurement methods.

3.2.1. Identification of situational characteristics

As a first step, the selected studies were thoroughly read by the first author to identify the characteristics of the task, team, mode of interaction – direct vs. indirect -, and various timeframe aspects. The resulting data were validated against the original studies by the second author and discrepancies were resolved by discussion. The extracted characteristics were as follows.

Table 1
Overview of extracted characteristics.

	Characteristic	Categories
Task characteristics	Setting	Laboratory, simulator, field
	Task domain	Open category
	Task content	Open category
	Task structure	Structured vs. un-structured
	Level of task interdependence	Low, medium, high
Team characteristics	Team size	Number of members
	Professional background	Similar vs. diverse
	Assignment	Random vs. non-random
	Role composition	General vs. specialized
Interaction	Mode of interaction	Direct vs. indirect
Timeframe	Task duration	Open category
	Team life span	Open category
Characteristics of the TMM	Type of TMM	Task, team, team interaction, attitudes/beliefs
	Property of TMM	Similarity, accuracy
	Measurement of TMM	Open category
	Analysis of TMM	Open category
	Other IPO-variables	Open category

Note. Open category refers to characteristics that could not be classified beforehand.

Task characteristics. The analyzed studies were categorized for five task characteristics: "task domain" (e.g. military, aviation), "setting" (i.e. laboratory, simulator, or field), "task content" (e.g. monitor a power plant), "task structure" (i.e. structured vs. unstructured), and "level of task interdependence." The latter was coded into three categories adapted from the task interdependence classification of Tesluk et al. (1997): low (team members work mostly separately), medium (team members need to cooperate according to a given sequence), and high (each team member needs to cooperate with each other constantly).

Team characteristics. We recorded team size, team members' professional background, and how the members were assigned to their teams. Furthermore, the team's role composition was coded into two categories: "general" (i.e. every member can solve every subtask) and "specialized" (i.e. some subtasks require a certain member's special skills).

Mode of interaction. The form of interaction between the team members was coded into two categories: "Direct interaction" refers to team settings where the participants could see each other face-to-face during task execution and were thus able to use non-verbal communication. In contrast, when the team members were separated and could only communicate via headset or written communication, we assigned the "indirect interaction" category.

Timeframe. We included two time related aspects in our analysis: "task duration" and "team life span". In some cases, average member tenure had to be used as an approximation.

3.2.2. Clustering of studies according to settings characteristics

As a second step, we assigned the studies to different clusters of similar setting characteristics. We started with task characteristics because, in accordance with action theory, we considered the task to be the most important factor for distinguishing setting types (Frese and Zapf, 1994). The other variables were added stepwise until we reached a solution where each cluster represented a distinctive setting type of TMM research. Again, categorizations were validated and discrepancies were resolved by discussion.

3.2.3. Analysis of TMM characteristics

Once all studies had been assigned to clusters, they were reviewed to extract the characteristics germane to the TMM. The characteristics were as follows.

Type of TMM. We sorted the content of the respective TMM into four distinct categories adapted from existing classification schemes (Cannon-Bowers and Salas, 2001; Cannon-Bowers et al., 1993): the task model (i.e. procedures, actions and strategies to perform a task), the interaction model (i.e. how team members should interact within a given task), the team model (i.e. other team members' knowledge and skills), and the model of attitudes/beliefs (i.e. general beliefs influencing teamwork). We considered the first two as task-related and the latter two as task-independent models. The four categories were not mutually exclusive since some studies measured multiple types of TMMs.

Property of TMM. We coded both TMM properties – similarity and accuracy. Similarity was coded each time the overlap of mental models within team was calculated; accuracy was coded each time the overlap with an expert model or a standard was calculated. Again, as one can measure both properties in the same study, the categories were not mutually exclusive.

Measurement methods of TMM. The review by Mohammed et al. (2000) provided a useful orientation about the different methods of TMM measurements. Popular examples included Likert-type questionnaires, pair-wise comparison ratings, and concept mapping. Since there may be other measurement methods, this was an open category.

Analysis approaches of TMM. As with measurements, the review by Mohammed et al. (2000) was used as a reference for classifying approaches to analyzing the TMM. Amongst others, network analysis software (UCINET, Pathfinder), multi-dimensional scaling, and correlation techniques using the r_{wg}-coefficient have been used so thus far. This was also an open category.

IPO-variables. We classified the function of TMMs and all variables related to the TMM. The coding was based on the IPO-model. For example, if a study investigated whether the influence of TMMs on team performance was mediated by communication, team performance was coded as outcome, TMM as input, and communication as process variable (mediator). Additionally, we recorded the statistical significance of the investigated relationship between TMMs and other variables. For example, when TMMs were used to predict team performance we coded whether this relationship was found to be statistically significant.

3.2.4. Data synthesis and integration

Finally, we analyzed the TMM characteristics for similarities and discrepancies both within and between the previously generated clusters. In this step, special attention was paid to the interrelations between situational characteristics (e.g. task type) and characteristics of the TMMs themselves (e.g. measurement method). Thereby, we aimed to address questions such as whether certain measurement methods for TMMs were used predominantly in specific situations.

4. Results

By categorizing the 33 reviewed studies, we identified five different clusters of studies empirically investigating TMMs. Each resulting cluster comprised studies with similar setting characteristics: student project teams ($N = 5$ studies), command and control teams ($N = 10$), negotiation teams ($N = 6$), business and service teams ($N = 5$), and action teams ($N = 7$). Appendix A provides a detailed overview of assignation of studies to their respective cluster, and associated references.

The focus of the current study was on categorizing methods and settings of TMM research to allow for an evaluation of their applicability to medical teams. Consequently, we employed a more content-oriented approach focusing on qualitative similarities and differences between the studies. The clustering process highlights these qualitative characteristics. The results of the clustering process are illustrated in Tables 2 and 3. Table 2 specifies the five clusters in terms of situational characteristics (i.e. team, task, and setting) whereas Table 3 provides an overview of how TMMs were measured in the respective clusters. Taken together, the findings summarized in Tables 2 and 3 allow for analyzing relationships between performance situation and TMM measurement. In the following, we will discuss the situational and TMM characteristics for each individual cluster in detail.

4.1. Cluster 1: student project teams

In this cluster of studies, teams consisted of two to eight undergraduate students of the same subject working together for the duration of one academic term (see Table 2). Compared to other clusters, student project teams had a medium lifespan (i.e. 12–16 weeks on average). Projects were part of the curriculum and involved the joint development of a product (e.g. training scheme, software), which was graded by a supervisor. This joint-development product task required team members to creatively apply the knowledge and skills (e.g. programming, designing) they had acquired during their studies. In most cases, students were free to choose their team. Thus, team member assignment to the teams

Table 2
The five extracted clusters and the respective situational characteristics.

Name of cluster	Setting	Task domain	Task content	Task structure	Task interdependence	Team-size (range)
Student project teams	Field	University	Product development	Un-structured	High	2–8
Command and control teams	Laboratory/Simulator	Military	Military-type mission	Structured	High	2–4
Negotiation teams	Laboratory	Diverse	Strategic negotiation	Un-structured	High	3
Business and service teams	Field	Business	Diverse	Un-structured	High	Various
Action teams	Field/Simulator	High-risk industries	Diverse	Structured	High	Various
Name of cluster	**Professional background**	**Assignment**	**Role composition**	**Mode of interaction**	**Team life span**	**Task duration**
Student project teams	Similar (students)	Non-random	General	Direct	Few months	12–16 weeks
Command and control teams	Similar (students)	Random	Specialized	Indirect	Few hours	Max 40 min
Negotiation teams	Similar (students)	Random	General	Direct	Few hours	Max 1.5 h
Business and service teams	Diverse (professionals)	Non-random	Specialized	Direct	Various	Various
Action teams	Similar (professionals)	Non-random	Specialized	Direct	Various	Few hours

Table 3
The five extracted clusters and the respective characteristics of the TMM.

Name of cluster	Type of TMM	Property of TMM	Measurement of TMM	Analysis of TMM
Student project teams	Team (3) Attitudes(2) Interaction (2) Task (1)	Similarity (5)	Likert-type questionnaire (2) Open-ended questions (2) Rating scale (1)	r_{wg} (2), Higgins Formula (1) Content analysis (1) Individual coding system (1)
Command and control teams	Task (7) Interaction (3) Team (3)	Similarity (10) Accuracy (5)	Pair-wise comparison ratings (7) Concept mapping (3)	Pathfinder (4) Individual coding system (3) UCINET (2), Mantel Test (1)
Negotiation teams	Unspecified (4) Task (1) Team (1)	Similarity (4)	Likert-type questionnaire (3) Open-ended questions (1) TMM independent variable (2)	Average agreement to scale (3) Content analysis (1) Predefined – TMM is IV (2)
Business and service teams	Attitudes (2) Team (2) Task (2)	Similarity (5)	Likert-type questionnaire (3) Pair-wise comparison ratings (2)	Coefficient of variation (1) Average agreement to scale (1) Multidimensional scaling (1) Randomization test (1) Average Euclidean distance (1)
Action teams	Task (4) Interaction (2) Team (1) Unspecified (1)	Similarity (6) Accuracy (5)	Likert-type questionnaire (2) Card sorting (3) Pair-wise comparison ratings (1) Observation (time based) (1)	Phi coefficient (2) Pathfinder (1) Average Euclidean distance (1) r_{wg} (1), average correlation (1)
Summary (only multiple mentions included)	Task (13) Team (11) Interaction (7) Attitudes (4) Unspecified (4)	Similarity (28) Accuracy (9)	Likert-type questionnaire (10) Pair-wise comparison ratings (9) Concept mapping (3) Open-ended questions (3) Card sorting (2)	Pathfinder (5) Average agreement to scale (4) Individual coding system (3) r_{wg} (3), Content analysis (2) UCINET (2), Phi coefficient (2) Average Euclidean distance (2)

Note. Numbers of studies in each sub-category are given in parentheses.

was "non-random." Because every member could at least theoretically solve each subtask individually, the teams' role composition in this cluster was categorized as "no specialization" (see Table 2).

Regarding features of the TMM, two main similarities came into view. The first was that all studies had a longitudinal design capturing the TMM at several points in time. Bushe and Coetzer (2007), for example, measured TMMs at the beginning, in the middle, and at the end of the term, enabling them to analyze the team's mental model development in terms of similarity and accuracy. The other common feature was that studies in this cluster focused on the team model. For example, Levesque et al. (2001) used team members' assessments of communication processes, team climate, and team structure. In contrast to the other clusters, we found more variety within this cluster in terms of the TMM measurement. The only method applied twice was Likert-type scale teamwork questionnaires combined with the use of the respective team's r_{wg}-score as a measure of the degree of similarity (Eby et al., 1999; Levesque et al., 2001). All other studies applied unique TMM measurement approaches (see Table 3).

4.2. Cluster 2: command and control teams

This cluster was the most cohesive cluster in terms of task, team, and TMM characteristics. Regarding the task, all studies involved computer simulations of a military environment (e.g. helicopter cockpit) in which teams had to carry out a certain mission (e.g. reconnaissance). These missions had a clear task structure involving explicitly defined goals (e.g. destroying enemy vehicles). Task duration was relatively short, ranging from three to 40 min (see Table 2). Accordingly, the teams' life spans were categorized as short, although some teams had to perform the same task several times in the course of a study (Banks and Millward, 2000;

Mathieu et al., 2005, 2000). Regarding team size, this cluster was characterized by student participants who were randomly assigned to teams of two to four team members (see Table 2). The teams' role compositions were consistently categorized as "specialized" because participants were assigned different responsibilities (e.g. pilot vs. gunner). Finally, in seven out of ten studies, teams were not allowed to communicate face-to-face, but had to use headsets.

Regarding TMM content, we found that this cluster had a clear emphasis on task-related content, as most of the studies investigated either the task or the team interaction model (see Table 3). The majority of studies used relatedness ratings between predefined concepts or task attributes to assess TMMs. The concepts usually represented actions specific for a concrete performance situation such as "hide in forest", "lay mines", and "build barriers" for a tank simulation (Marks et al., 2000). TMM data were analyzed with network analysis that provided a measure of similarity for the TMM (e.g. Pathfinder metric of closeness). One exception to this approach was the Edwards et al. (2006) study, as they used the Mantel test to assess the degree of similarity. Another approach to analyzing the TMM in this cluster was the concept mapping technique (Marks et al., 2002). In the majority of the studies, TMMs were related to team-performance, with team processes (e.g. communication, coordination, or backup behavior) mediating this relationship. Furthermore, in many cases the influence of external factors (e.g. prior training, briefing, stress) on the TMM was investigated.

4.3. Cluster 3: negotiation teams

Negotiation teams consisted of students performing tasks that involved negotiating a common strategy with the aim of reaching a consensus. Both task duration and team lifespan were categorized as short, with a maximum duration of 20 min and 1 h 30 min respectively (see Table 2). As the task was characterized by intra-team discussion, this setting required "direct communication." However, team role composition and member assignment varied considerably within this cluster (see Table 2).

In terms of TMM content, these studies took a more general perspective on shared understanding within the teams. For example, researchers used statements such as "We understand each other" and "We know how to deal with each others' problems and solutions" (Swaab et al., 2007). As a result, TMM content could not all be classified in one of the four categories we used (see Table 1). All studies focused on TMM similarity yet neglected accuracy of the TMM. These findings were consistent with the fact that tasks in this cluster were comparatively un-structured and had no single correct solution. Lack of both structure and a single agreed solution rendered defining and assessing task-specific content difficult. Furthermore, in absence of just one single correct solution, comparing the members' mental model to an expert model appears to be inappropriate. Despite applying various unique methods of measuring and analyzing TMMs, results concerning the relationships to other variables were consistent. Regarding team communication (oral or written) either before or during task execution, significant relationships were identified between similarity and communication variables, such as team members' participation in a discussion (Bonito, 2004).

4.4. Cluster 4: business and service teams

Studies in this cluster involved real-life teams in business organizations that were predominantly characterized by member diversity in terms of their professional background. Team members were usually recruited by executives (i.e. team member assignment was "non-random") and could communicate directly. In terms of team size and lifespan, we found considerable variety within this cluster (see Table 2). On average, teams were bigger and worked together for longer periods than teams in the other clusters (see Table 2). Task content varied among studies (e.g. problem solving, decision making), but in general, the tasks investigated in this cluster were the least structured.

Concerning TMM content, we identified a preference in this cluster to investigate task-independent content. Two studies, for example, worked with models of shared attitudes/beliefs, including strategic orientation (Ensley and Pearce, 2001), and teamwork in general (Rentsch and Klimoski, 2001). The task model was only assessed once, which is not surprising given the un-structured nature of the tasks. All five studies used surveys with only one measurement point. Three studies used Likert-type scale questionnaires, while the other two applied pair-wise comparison ratings. As was found with the "Negotiation teams" cluster, none of the studies in this cluster assessed TMM accuracy; all of them focused on similarity. This can again be attributed to the un-structured nature of tasks in this cluster. In the five studies included in this cluster, similarity was captured using five different methods (see Table 3), including a unique randomization test (Langan-Fox et al., 2001). In addition to team-performance, other outcome variables (e.g. team commitment) were mostly related to characteristics of team composition (e.g. team members' educational background, team size).

4.5. Cluster 5: action teams

The teams in this final cluster were similar to the action teams in the classification by Sundstrom and colleagues (Sundstrom et al., 2000), as they represented teams of specialists who performed tasks that required extensive team coordination and that were repeated under different conditions. These teams included, for example, air traffic control teams (Smith-Jentsch et al., 2001), military combat teams (Lim and Klein, 2006), and basketball teams (Webber et al., 2000). With regard to task characteristics, the teams resembled the "Command and control teams" of cluster 2 since their tasks involved a dynamic environment, had clearly structured goals, and task duration was comparatively short in most cases. Team characteristics, however, differed significantly compared to cluster 2. The teams' lifespan in cluster 5 was much higher with a range from 12 weeks to 5 years. Moreover, team members were non-randomly assigned and could communicate directly during task execution (see Table 2).

In terms of TMM content, researchers emphasized task-related aspects, primarily assessing the task model and the team interaction model (see Table 3). This included rating the effectiveness of task-specific strategies such as "try using a battery-operated backup radio" and "try communicating from another position" for air traffic controllers (Smith-Jentsch et al., 2005). Compared to other clusters, TMM accuracy measurements were used more frequently. Excepting the aforementioned methods of TMM measurement, Waller et al. (2004) applied a different approach. They assessed the development of the TMM with a team level measure (i.e. number of team meetings during task execution). Besides the relationship between TMMs and team-performance, work experience was found to be positively related to similarity and accuracy (Smith-Jentsch et al., 2001).

4.6. General findings

Although our categorization emphasis of the TMM literature was on identifying and sorting the characteristics of each cluster, several results emerged from our analyses that were cluster-independent. First of all, even though the studies cover a variety of high-risk industry domains, no study of medical teams could be found. Furthermore, task interdependence was not a differentiating factor between studies. All team tasks, as far as we could classify them on the basis of the given information, can be considered highly interdependent according to our classification. Both findings are in line with the results of a recent meta-analysis (DeChurch and Mesmer-Magnus, 2010). With regard to TMM measurement, our findings verify that there is no standard procedure to measuring the similarity and accuracy of TMMs. In the 33 included studies, researchers used seven different methods for measuring and 10 different methods for analyzing the TMM (see Table 3). Moreover, there is no consistency regarding the property of TMM. Only nine studies included a measure of accuracy, whereas almost all studies made use of a similarity score (see Table 3).

Of the 28 studies investigating the relationship between TMMs and team-performance measures, 22 found a significant correlation – which again confirms the finding that "there is a cognitive foundation to teamwork" (DeChurch and Mesmer-Magnus, 2010). With regard to team-performance, however, we found a wide variety of measures such as self-reports (Rentsch and Klimoski, 2001), observational data (Waller et al., 2004), supervisor grades (Bushe and Coetzer, 2007), or the number of safety-related incidents (Smith-Jentsch et al., 2005).

5. Discussion

This paper provides a systematic overview of TMM research in terms of measurement methods and areas of application. Before discussing the implications of our findings for teamwork in healthcare we briefly outline some general tendencies in TMM research that emerged from our analysis.

More than a decade after the seminal review of TMM (Mohammed et al., 2000), there is still no consensus among the scientific community regarding the measurement of TMMs. Quite the contrary: rather than adopting existing measurement approaches, researchers tend to modify them or develop new ones. This is even more surprising as most studies refer to the same theoretical background such as the initial conceptualization of TMMs (Cannon-Bowers et al., 1993). Although we could not identify a standard method of measuring TMMs that would be applicable in a broad range of research settings, our review revealed three general tendencies in TMM research.

Firstly, the majority of researchers use aggregates of individual team member scores rather than team-level measures. TMMs are viewed as a derivative, which has to be inferred from the data, and not as a directly observable phenomenon (Mathieu et al., 2005). Secondly, our results confirm the finding that pair-wise comparisons and Likert-type scales are the most common methods to assess TMM (Mohammed and Dumville, 2001). Finally, there is a strong tendency to restrict TMM research to teams with highly interdependent tasks. This is in line with the common notion that high task interdependence increases the importance of a shared understanding (Kraiger and Wenzel, 1997; Mathieu et al., 2005). Unfortunately, this assumption also limits the generalization of results regarding the relationship of TMMs and team-performance, as settings of low task-interdependence such as factory assembly domains are not assessed.

But what do these findings mean for TMM research in healthcare? We will address this question by comparing the setting characteristics of empirical studies identified in this review with those of teamwork settings in healthcare.

5.1. Measuring team mental models in different healthcare settings

Of course, it would be an insurmountable task to provide suggestions for every team in healthcare. Instead, we will discuss implication for two specific teams, different in structure but which both play an important role along the patient care path – anaesthesia teams and teams of ward nurses. Anaesthesia teams represent a short-lived action team in a highly dynamic work environment whereas ward teams are an example of long-term cooperation under more stable conditions.

5.1.1. Anaesthesia teams

Anaesthesia is one of the leading specialties in addressing patient safety issues including research on human factors and teamwork (Gaba, 2000; Weinger and Slagle, 2002). Teams in anaesthesia are characterized by varying membership and short task cycles. Depending on the situation they can consist of an anaesthesia nurse and an anaesthesia physician who is often still in training. During complex cases such as open-heart surgeries or lung transplantations, an anaesthesia attending physician can also be present. Routine phases of simple cases such as pre-medication can normally be managed by a single anaesthesiologist. Therefore, these teams have neither much experience of working together nor do they have a chance to develop a common understanding during work. Anaesthesia as a task involves a highly dynamic environment with standardized procedures – for example a rapid sequence induction – always being at risk to be interrupted by non-routine events such as hemodynamic instability or technical malfunctions (Rall and Gaba, 2005; Weinger and Slagle, 2002).

If one compares the characteristics of anaesthesia teams with our categorization, they resemble the teams in clusters 2 and 5. Given these similarities – well-structured tasks are carried out under time-pressure in a dynamic environment – TMM research should focus on task-related mental models. In these situations, an accurate and similar TMM can help to reduce the need to coordinate within the team (Stout et al., 1999). For example, if team members have a shared understanding of the steps involved and who should do what during induction, there is no need for a lengthy discussion about it. This frees cognitive resources that can be used to attain a higher level of vigilance, which in turn enables the team to detect and manage unexpected events more quickly (e.g. a sudden drop in the patient's blood pressure). Furthermore, since many procedures are highly structured, team members' roles can be clarified via the task model. In contrast, the short life cycle makes it difficult to draw on a team-model consisting of each other's competencies to decide who is most qualified for which task.

Unfortunately, common methods for assessing task-related content such as concept mapping or pair-wise comparison ratings are time-consuming, which makes their application in clinical work settings (e.g. operating room) unfeasible. These difficulties, however, can be overcome in simulation-based studies. Patient simulators allow for measuring TMMs in an ecologically valid environment. Moreover, they provide researchers the opportunity to systematically investigate the relationships between TMM, team-processes, and team-performance under controlled conditions. As team-trainings in simulated healthcare environments have become mandatory parts of the curriculum in many teaching hospitals, there are many possibilities to carry out TMMs research. In a first step, one should investigate if a more similar and accurate TMM also pertains to a better team-performance – which we would strongly expect. After having established this link, the impact of specific trainings on TMM could be investigated.

5.1.2. Teams of ward nurses

Teamwork is also pivotal in the context of nursing; a worldwide survey among critical care nurses identified staffing levels and teamwork as most highly regarded priorities (Williams et al., 2007). Furthermore, a recent literature review highlighted the importance of teamwork skills – including establishing a common understanding – for scrub nurses (Mitchell and Flin, 2008). For ward nurses, team-based structures are a common model of work organization (Makinen et al., 2003). These teams vary in size depending on the size of the unit but typically consist of five to eight members (Kalisch and Begeny, 2005). Working together for longer periods, these teams have longer life spans than anaesthesia teams. Additionally, their work environment can be regarded as more routine. Finally, task content is more diverse, ranging from direct interactions with patients to documentation. With regard to these characteristics, teams of ward nurses bear similarities to the business and service teams in cluster 4.

In view of these similarities, a focus on team-related content seems suitable for TMM research in this setting; the variety of loosely coupled tasks makes it hard to determine an appropriate task-model. In this setting, the team – rather than the task – is the constant. Thus, having a shared understanding regarding each other's knowledge and skills would facilitate efficient coordination. If everyone agreed that a certain member was best at a specific task, there would be an instant agreement that he or she should carry it out. Since there is no single correct solution for most team-related content, we expect TMM similarity to be more important than accuracy.

Regarding measurement methods, questionnaires are a good choice as they could be used during daily practice. The stability of the teams borne of working together on a daily basis would enable investigation into the development of TMMs over time. In this case, TMMs would be both an input as well as an outcome of team-processes. One research question in this context would concern the existence of a tipping point for developing a TMM – i.e. a point in time after which the quality of the team-model would not improve through routine cooperation.

5.2. Team mental models and teamwork in healthcare from a broader perspective

Although the two examples discussed above might have created this impression, medical teams are neither necessarily uni-disciplinary nor do they operate in isolation from each other. Instead, the increasing complexity of healthcare and the resulting growing interdependence among (teams of) care providers has lead to many inter-disciplinary or inter-professional teams (McCallin and Bamford, 2007; Rafferty et al., 2001). Furthermore, different types of teams have to cooperate closely along the patient care path. In the operating room, for example, the tasks of the surgical team, the anaesthetic team, and the nursing team are heavily interlinked (Gaba et al., 2001; Helmreich and Schaefer, 1994). Given their high demand for teamwork and coordination, inter-professional teams and multi-team settings provide interesting opportunities for applying the concept of TMMs, which will be discussed in the following section.

5.2.1. Inter-professional teams

Inter-professional teams can be comprised of various healthcare providers including consultants, junior doctors, nurses, cardiac technicians, and physiotherapists (Gair and Hartery, 2001); they can be found in different areas of healthcare ranging from the intensive care unit to psychiatric rehabilitation (Liberman et al., 2001; Reader et al., 2007). This diversity makes general recommendations regarding TMM measurement a complicated matter. We think, however, that TMM research can be of great benefit in this area. Inter-disciplinary teams often suffer from conflicts between professions due to different attitudes towards optimal patient care (Ponzer et al., 2004). Reducing these conflicts – i.e. establishing a shared understanding regarding what is in the patients' best interest – would remove a major obstacle to effective teamwork and thus promote patient safety. The face validity of this approach is obvious; but how can a shared understanding be appropriately operationalized and measured? TMMs provide both a sound theoretical basis as well as elaborate measurement methods to investigate convergence of attitudes and its effects in inter-disciplinary medical teams.

With regard to the diversity of inter-professional teams, a more general perspective in terms of TMM content focusing on attitudes/beliefs appears to be more promising. This could include a shared understanding of what is perceived to be good communication and a common attitude towards patient safety as the first priority. As there is not necessarily a single correct attitude towards teamwork and communication, TMM similarity should be emphasized. For example, a study could test whether cross training fosters the development of a similar understanding regarding what is "good" teamwork in inter-professional teams.

5.2.2. Multi-team settings

As for multi-team systems, the staff in an operating room can be regarded as one team requiring a TMM of the operation in general. At the same time, there are at least three different sub-teams: the surgeons, the anaesthetists, and the nurses. During some phases of the operation the whole team needs to work together closely; during others it splits into the respective sub-teams or "teams of teams" (Gaba et al., 2001; Salas, 2008). One could hypothesize that the members of each of these sub-teams need to have a more specific TMM of their respective task than within the overall team. Then, members of one sub-team would need a different kind of TMM than members of different sub-teams. The intra-team model would be more task-related, whereas the inter-team model would be more team-related.

Since multi-team systems studies have not been conducted, the results of our review do not provide a sound basis for concrete suggestions regarding measurement and design of TMM studies in this context. However, the systematic overview on which methods have been used provides a good starting point for designing future studies.

5.3. Limitation of this study

In this review, we focused exclusively on TMMs. There are, however, similar concepts used within various disciplines (Mohammed and Dumville, 2001). Although it would be interesting to compare them, we decided to scrutinize only TMM research. Furthermore, we focused on qualitative characteristic of the studies included in this review. In so doing, we neglected quantitative aspects such as the varying strength of the relationship between TMMs and team-performance across different settings. Yet, as the aim of the current review was triggering research on TMMs in healthcare, we regarded concentrating on the more practical aspects – situational characteristics and measurement methods – as a justified decision.

6. Conclusion

In this paper, we presented an overview of the current state of empirical research on TMMs. Thereby, we provided researchers with a reference regarding the matching of teamwork settings and measurement methods to design future studies on TMMs in healthcare. Moreover, we discussed how TMMs could be investigated in healthcare using concrete examples of different types of medical teams.

The growing complexity of healthcare has resulted in an increased need for teamwork and inter-disciplinary coordination in order to maintain a safe and effective patient treatment. In view of this, healthcare providers "being on the same page", sharing attitudes toward safety, and having a common understanding of

Table A1
The five clusters of studies on TMM of included in this review.

Number and name of cluster	Number of included studies	References
1: Student project teams	5	Bushe and Coetzer, 2007; Carley, 1997; Eby et al., 1999, study 2; Levesque et al., 2001; Peterson et al., 2000
2: Command and control teams	10	Banks and Millward, 2007; Edwards et al., 2006; Ellis, 2006; Gurtner et al., 2007; Marks et al., 2002, studies 1 and 2; Marks et al., 2000; Mathieu et al., 2000, 2005; Stout et al., 1999
3: Negotiation teams	6	Banks and Millward, 2000; Bonito, 2004; Park, 2008; Swaab et al., 2007, studies 1–3
4: Business and service teams	5	Ensley and Pearce, 2001; Kang et al., 2006; Kellermanns et al., 2008; Langan-Fox et al., 2001; Rentsch and Klimoski, 2001
5: Action teams	7	Lim and Klein, 2006; Smith-Jentsch et al., 2001, studies 1 and 2; Smith-Jentsch et al., 2008, study 1; Smith-Jentsch et al., 2005; Waller et al., 2004; Webber et al., 2000

Note: If multiple studies were reported in one paper, the number of the study included in this review is listed.

each other's roles and responsibilities are vital needs. Based on the findings of the current review, we think that the concept of TMMs provides the theoretical background and the measurement methods necessary for operationalizing and empirically investigating these phenomena. Research on the development and the effects of TMMs in medical teams can help to identify barriers to teamwork and ways to overcome them. Eventually, this knowledge will be useful in tailoring specific team trainings to promote improved inter-professional-cooperation, team-performance, and ultimately patient safety.

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Appendix A

Table A1.

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