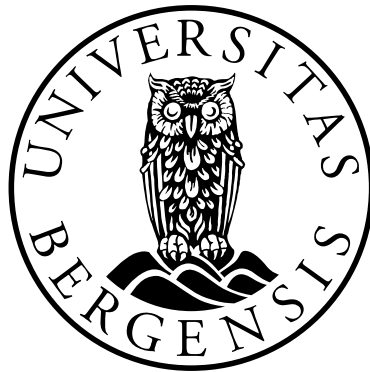


Expert Teams:

*Do Shared Mental Models of Team Members make a
Difference?*

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Abstract

The purpose of the present thesis was to investigate whether and how familiarity influences coordination, resilience, and efficiency in high performance teams in safety-critical organizations. Research has accumulated solid support for the general presumption that shared mental models are associated with team effectiveness (see overview, Kozlowski & Ilgen, 2006). Unfortunately, familiarity and shared mental models have seldom been the subject of investigation. This is surprising since the importance of team members having a shared understanding is underlined in dynamic situations that require high levels of flexibility and adaptability in the team (Cannon-Bowers et al., 1993; Salas & Fiore, 2004).

The first study investigated whether knowledge about individual team members would augment the effect of operational skills in predicting operational effectiveness in trained expert teams. The second study investigated the consequences of shared mental models (SMM) of team members in teams that are forced to coordinate their activities towards a shared goal in a distributed team setting. The third study investigated whether shared mental models of team members would transfer across new tasks or situations and, through better coordination, result in improved efficiency and less physiological arousal.

Study 1 included samples from 24 active duty officers who made up four submarine attack teams. Studies 2 and 3 included a total of 177 cadets from the Royal Norwegian Naval Academy. The findings from these three studies indicate that familiar teams used coordination strategies that enhanced efficiency. The coordination strategies used by familiar teams are characterized by less overt communication (statements per minute) during high workload (Study 1), a higher global anticipation rate (Study 2), and more adaptability and back-up statements during cross-training (Study 3). In addition, familiar teams showed more

overt communication (e.g., confirmation) when confronted with a novel situation (Studies 2 and 3). Familiar teams outperformed unfamiliar teams, being more accurate, quicker and achieving greater mission success (i.e., more hits). Familiar teams were more physiologically aroused (HR) during low workload (Study 2), and less during high workload (Study 1), recovery (Studies 2 and 3), and decreasingly so during training (Study 3).

These three studies extend previous research by presenting new empirical data on the significance of shared mental models of team members. Study 1 demonstrated that knowledge about team members (i.e., shared mental models of team members) adds to performance over and above the contribution of operational skills (Aim 1). Studies 2 confirmed Study 1 (within teams) and provide empirical evidence for the effect of shared mental models of team members in distributed teams (Aim 2). The findings from Study 3 suggest that shared mental models of team members are transferable across tasks and enhance the effects of cross-training (Aim 3). All studies extend previous research, but Study 3 in particular indicates that shared mental models of team members are distinctly different from transactive memory systems (Aim 3). Hence, a shared mental model of team members represents an independent, adaptive asset at team level that enhances team performance and efficiency.

These studies are the first to provide empirical evidence in support of the notion that shared mental models of team members are a mechanism that improves teams' efficiency, resilience, and coordination. This thesis confirms shared mental models of team members as an important and independent construct with an added value in relation to team performance and efficiency. It thus expands previous knowledge, where the focus has been on equipment, tasks, and team interaction. The findings are a contribution to and fill an

important gap in the literature on Shared Mental Models. Implications are discussed for training, staffing and safety issues in teams in safety-critical organizations.

List of papers

Paper I

Espevik, R. E., Johnsen, B. H., Eid, J., & Thayer, J. (2006). Shared Mental Models and Operational Effectiveness: Effects on Performance and Team Processes in Submarine Attack Teams. *Military Psychology*, 18, 23-36

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1. Introduction

“Imagine yourself on the operation table, surrounded by doctors and nurses with one goal: to save your life. Nobody in the room had met each other before the shift started ten minutes ago. The scope of the present thesis is to investigate whether familiarity influences coordination, resilience, and efficiency in high performance teams in safety-critical organizations.”

In safety-critical organizations (SCOs) such as aviation organizations and emergency services, as well as the military rotation of personnel through a 24/7 shift-work schedule, it is difficult to maintain stable person/role expectations over time. Many teams thus consist of team members with little or no previous history as a team. In this thesis, teams are defined as two or more people carrying out highly interdependent tasks based on expertise distributed among team members with clearly assigned roles and responsibilities, such as medical teams (i.e., anesthesiologist and surgeon). Such teams work in a dynamic environment (e.g., an operating theatre), share values and common goals (e.g., to save life) and exist for a limited lifespan (e.g., a work shift; Stagl, Salas, Rosen, Priest, Burke, & Goodwin, 2007).

Many SCOs require domain experts to work together in teams (e.g., emergency response units, control room operators, security task forces). Hackman (1998) concluded, however, that designing teams solely on the basis of members' expertise is no guarantee of success. In many cases, information management systems have been introduced to enhance team communication and information exchange. Stagl et al. (2007) pointed out, however, that merely connecting experts with collaborate technology was not sufficient to guarantee effective performance (e.g., distributed teams). In many cases, work teams in safety-critical

organizations will be forced to handle complex, difficult, and vital tasks in situations in which they are not familiar with the other expert members of the team.

The ability to adapt to high workload, time constraints, and uncertainty is vital to team performance and efficiency in high-intensity situations. The focus in this thesis is therefore on what teams do: their tasks, not their interpersonal interaction (Kozlowski & Ilgen, 2006). It is therefore important to identify team processes relating to performance and effectiveness. Performance consists of the activities teams engage in to coordinate each team member's effort to reach the common goal (i.e., exchange of information). Efficiency is the outcome of the team's performance and is understood in terms of accuracy, latency, and mission success (Cannon-Bowers & Salas, 1997; Motowildo, 2003). Conceptually, team processes capture how team members combine resources, coordinating their knowledge, skills and efforts to meet task demands (Kozlowski & Ilgen, 2006). Salas and Fiore (2004) stated that there is substantial evidence that team cognition, understood as a type of interrelationship between team processes (e.g., encoding, storage, and retrieval of information), is vital to team performance in high-workload environments such as aviation, medicine and the military.

Small group research has a long tradition of studying cognitive constructs such as group norms and role expectations that guide interpersonal interaction among team members (Kozlowski & Ilgen, 2006). Interpersonal interaction is important to team performance, for instance by influencing how willing we are to share information with other team members. In a knowledge-driven context, constructs that capture task-relevant interaction are of equal interest when performance and effectiveness are the subjects under investigation. Thus, familiarity is more than interpersonal relations and likes or dislikes. It is also about understanding other team members' behavior while performing tasks. If you do not

understand the behavior (what or why) of a team member, then coordination (e.g., back-up behavior) is difficult and your willingness to provide information is of less importance. Thus, it is surprising to discover that research on team cognition and task-related issues is rarely related to familiarity in teams. Mohammed, Ferzandi, and Hamilton (2010) stated in an overview of the field of team cognition that the role of “time together as a team” had been largely downplayed in past research on team cognition.

The sparse research on familiarity in teams that is available is also contradictory. After analyzing 74 major accidents in the airline industry, Woody, McKinney, Barker, and Clothier (1994) concluded that newly-formed (unknown) crews flew more safely than fixed (known) crews. This prompted a policy among several airlines of rotating crew members in order to ensure compliance with procedures, arguing that this results in increased safety. This view is challenged by Kanki and Foushee (1989), however. They found empirical evidence that, if the captain and co-pilot had recently flown together, they made fewer errors and engaged in more open communication in the information exchange context. Thus, a critical issue in SCOs is how team members’ familiarity will result in effective command, control, and communication (C³) to resolve safety-critical issues.

The literature on team processes offers two theoretical perspectives on team cognition that seem to take quite different approaches to explaining the outcome of team familiarity compared to unfamiliarity. In their concept of shared mental models (SMM), Cannon-Bowers, Salas, and Converse (1993) suggest that more effective teams share similar mental models and understandings of the situation at hand. Wegner (1986), on the other hand, proposes that effective team work is based on a transactive memory system whereby team members compartmentalize and specialize in different work segments. These apparently different perspectives raise the question of whether transactive memory systems

and the shared mental models of team members are distinctly different, and how these differences might impact on team performance in SCO's.

Research has accumulated substantial support for the general presumption that shared mental models are associated with team effectiveness (see overview, Kozlowski & Ilgen, 2006). Unfortunately, familiarity and shared mental models have seldom been the subject of investigation. This is surprising because the importance of team members having a shared understanding is underlined in dynamic situations that require high levels of flexibility and adaptability in the team (Cannon-Bowers et al., 1993; Salas & Fiore, 2004). This indicates an important asset in teamwork, the transferability to novel situations, and a vital ability in SCO's, where procedures and routine are dominant, but where anomalies have the potential to result in severe consequences if not handled correctly. However, if shared mental models are transferrable across different tasks (Salas, Sims, & Burke, 2005), we would assume that teams whose members have shared mental models will be able to adapt better to a new team performance situation. This may mean that shared mental models of team members enhance a team's ability to understand and learn novel tasks and situations. One important aim of the present thesis is thus to examine whether shared mental models of team members will transfer across new tasks or situations and ultimately result in improved performance.

The thesis will first investigate whether and, if applicable, how familiarity might impact on team performance. Some teams are physically separated (distributed) and have fewer opportunities to coordinate due to the absence of paralinguistic, non-verbal and other sensory cues. Thus, any advantages of familiarity within teams could be hampered by physical separation between team members, and this is the subject of the second investigation. Expert teams also encounter novel situations, and the last question to address

is whether familiarity with other team members will prepare teams for the unexpected (novel situations) or, to put it another way, whether they will learn more quickly.

The thesis starts with a brief outline of team cognition, followed by a presentation of the two cognitive constructs that are intended to capture familiarity in teams: transactive memory systems (Wegner 1986) and shared mental models (Cannon-Bowers et al., 1993). The next step outlines the construct of shared mental models of team members, and presents the aims of the three studies, the research model, and how the studies were conducted and operationalized. The findings are then presented and discussed. In the following, these issues are set out in more detail.

1.1 Team cognition

Kozlowski and Ilgen (2006) contend that teams are at the center of how work gets done in modern life. The idea seems to be that many tasks exceed the individual's capability to cope efficiently and are more effectively solved by coordinated action by multiple individuals. This is based on teams being able to respond more quickly and being more adaptable than individuals to changing, complex and often unexpected events in the environment. This assumption has encountered several challenges, and investigations of many disastrous aviation, military, medical and industrial accidents have found teamwork breakdowns (e.g., coordination, communication; Wilson, Salas, Priest, & Andrews, 2007).

In a complex and dynamic environment, teams often face rapidly evolving and ambiguous situations where one correct solution is not always evident or possible. In addition, modern technologies increase the pressure through information overload and limiting time available to act. Salas, Rosen, Burke, Nicholson, and Howse (2007) states that modern operational environments are characterized by a historically unparalleled

accelerating rate of change that requires team flexibility, adaptability, and resilience. To cope, team members must integrate, synthesize, and share information, and they need to coordinate and cooperate to accomplish their mission as task demands change. For teams, then, a dynamic, shifting and complex environment gives rise to commensurate team task demands that members have to resolve through a coordinated process that combines their cognitive, motivational/affective and behavioral resources (Kozlowski & Ilgen, 2006). Research has accumulated extensive knowledge about behavior (e.g., back-up behavior) and attitudes (e.g., team orientation) that teams need in order to be effective (Salas et al., 2005; Kozlowski & Ilgen, 2006).

Team cognition has been identified as a key component in achieving mission goals in dynamic, team-based, stressful, and distributed operations (Salas et al., 2007). By this is meant that team members possess knowledge that allows them to function effectively as an entity, even during periods of high workload (Orasanu, 1990). There are a number of possible theoretical perspectives on team cognition. Kozlowski and Ilgen (2006) underlined four cognitive constructs that have amassed sufficient research to support their value in terms of enhancing team effectiveness, namely team climate, team learning, transactive memory system and team mental model. Cannon-Bowers and Salas (2001) underline the problem of using several constructs and the dividing lines between them by commenting that authors have not been consistent in their definition of team cognition, listing no less than 20 labels that have been used to describe various types (e.g., collective cognition, team knowledge, team mental models, shared knowledge, transactive memory, shared mental models, etc.). Rentsch and Woehr (2004) argue that all these perspectives share the assumption that common cognitions among team members will be associated with team effectiveness. Salas and Fiore (2004) contend and suggest that team cognition regarding the

nature of team members, or team member familiarity, is a potential important determinant of team functioning and team performance.

An extensive search within the cognitive theoretical framework of team performance revealed that there are two constructs that have addressed familiarity. They are transactive memory systems (Wegner, 1986) and shared mental models (Cannon-Bowers et al., 1993). These perspectives argue that team members need to know each other as team members. This includes being familiar with their knowledge, abilities, preferences, strengths, and weaknesses. This is proposed as a necessary prerequisite for maximizing performance.

1.2 Transactive memory systems

Wegner (1986) proposed transactive memory systems (TMS) as a means of explaining how couples foster the development of a common memory. Moreland (1999) applied TMS to teams and conceptualized them as a set of distributed, individual memory systems that combine the knowledge possessed by particular team members with a shared awareness of who knows what. Thus, with regard to teams, TMS is a group-level collective system for encoding, storing, and retrieving information distributed within the team. In this theoretical framework, it is proposed that each team member uses the other members as an external memory aid, thereby creating a compatible and distributed memory system. In this model, team effectiveness depends on team specialization and increased capacity. Moreland (1999) posits that this will enable the team to plan its work more sensibly, assigning tasks to the people who will perform them best and improving coordination because the team members can anticipate rather than simply react to each others' behavior. Using laboratory experiments in which small groups were trained to perform complex tasks (assemble radios), these researchers assessed the impact of various types of individual and group training on group performance. Their findings indicated that groups performed better when their

members were trained together rather than separately, and they suggest that the benefits of group training depended heavily on the operation of transaction memory systems (Moreland, 1999).

In both laboratory and field settings, transactive memory systems have been linked to performance and job satisfaction (Austin, 2003; Lewis, 2004; Pearsall & Ellis, 2006).

Conceptually, transactive memory systems should reduce the cognitive load on individuals and lower redundancy (Hollingshead, 1998). In an overview, Kozlowski and Ilgen (2006) concluded that TMS as a concept was still in its infancy and that there was a lag between empirical research and theoretical development. They also underline the importance of distinguishing it from other related concepts, and especially shared mental models.

Mohammed et al. (2010) concluded in a review that empirical studies were needed to determine how shared mental models and transactive memory systems relate to team processes and outcomes. Lewis (2006) suggests that the two concepts are related but distinctly different.

Since TMS theory and research has concentrated on knowledge about team output and the utilization of task knowledge among team members (DeChurch & Mesmer-Magnus, 2010; Mohammed et al., 2010, Kozlowski & Ilgen, 2006), this theoretical framework does not address or explain the team processes required to deal with the unexpected. A team facing a novel critical situation needs more than task-specific knowledge to adapt and cope (Mohammed et al., 2010). Knowledge about how a team member behaves, for instance when he or she is almost overwhelmed by the workload, is not addressed in TMS research. This thesis attempts to fill this gap in the literature by investigating the possible impact on performance and efficiency of having a shared awareness and knowledge of how team

members behave when they, as a team, encounter a new, novel, and uncertain situation characterized by high workload and time constraints.

1.3 Shared Mental Models

The significance of shared mental models and team coordination was emphasized in the research project “Tactical Decision Making under Stress” (TADMUS), initiated after the USS Vincennes shot down an Iranian civilian airbus in 1988. TADMUS was an applied research program in the U.S. Department of Defense. In brief, the goal of the TADMUS program was to develop training, simulation, decision support, and display principles that would help to mitigate the impact of stress on decision-making (Cannon-Bowers & Salas, 1998). The program placed particular emphasis on information processing and tactical decisions made by shipboard command teams in air defense operations under conditions involving short decision times, high operational workload, and ambiguous and incomplete information. One of the conclusions from the TADMUS project was the importance of swift and accurate coordination of information and behavior in order to successfully cope with the demands of emergency combat situations (Cannon-Bowers & Salas, 1998).

Research into team effectiveness supports the conclusions from the TADMUS project, showing that effective teams can maintain performance even under conditions of high workload when opportunities for communication are reduced (e.g., Kleinman & Serfaty, 1989). This indicates a need for team coordination strategies that are implicit and automatic (Kleinman & Serfaty, 1989; Entin & Serfaty, 1999). Wittenbaum, Vaughan & Stasser (1998) argue that coordination is an essential component of successful team performance. They underline that successful teams coordinate their efforts by communicating implicitly. Coordinating implicitly saves time, but it can also increase the possibility of failure (Wittenbaum et al., 1998). It is therefore suggested that successful implicit coordination

rests on the team's ability to share a common understanding of the situation (Cannon-Bowers et al., 1993; Klimoski & Mohammed, 1994; Moreland, Argote, & Krishnan, 1996; Rentsch & Hall, 1994; Mathieu, Rapp, Maynard, & Magos, 2010; Mathieu, Heffner, & Goodwin, 2005; Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000; Marks, Sabella, Burke, & Zaccaro, 2002).

Cannon-Bowers et al. (1993) proposed that shared mental models are the mechanism that allows this type of coordination (implicit). The construct of shared mental models is drawn from theories of individual mental models used to explicate individual cognitive functioning or understanding. At the individual level, mental models refer to a structure of known elements (e.g., declarative knowledge) and the relationship between those elements (Shavelson, 1974). These structures serve as mechanisms that people use in order to describe the purpose and form of a system, as well as its functioning in its present and future state (Rouse & Morris, 1986). Cannon-Bowers and Salas (1990) proposed extending the concept of individual mental models to the team performance domain, hypothesizing that team performance is a function of the extent to which members held similarly organized expectations in relation to the task or each other. Shared mental models are defined as a shared organized understanding and mental representation of key elements of the team's relevant environment. These shared mental models enable team members to form accurate explanations and expectations of the task. This will in turn enable team members to coordinate their actions and adapt their behavior to the demands of the task and to other team members (Cannon-Bowers et al., 1993). Shared mental models (SMM) are assumed to enable team members to predict task needs and the actions of other team members, and thus enable them to adapt their own behavior accordingly without communicating explicitly. A number of studies have indicated that shared mental models contribute to increased team effectiveness (Volpe, Cannon-Bowers, Salas, & Spector, 1996; Urban, Bowers, Monday, &

Morgan, 1995; Stout, Cannon-Bowers, Salas, & Milanovich, 1999; Mathieu et al., 2000, 2005, 2010).

More specifically, in order to coordinate their activity, teams with a shared mental model will not only reduce the amount of communication they use (i.e., coordinate implicitly), they will also change their communication patterns from pulling (requesting) to pushing (presenting) information when the workload increases. According to Entin and Serfaty (1999), this shift in communication pattern is reflected in the ratio that results when the number of transfers of information is divided by the number of requests for information (“the global anticipation ratio”). An increase in “the global anticipation ratio” is seen as being a strong indication of a shared mental model (Entin & Serfaty, 1999). As an example, Orasanu (1990) reported that superior performing teams increased the push of information from team members and reduced requests for information from the team leader during periods of high workload.

1.3.1 Multiple mental models

Salas et al. (2005) contend that shared mental models are a core aspect of the successful coordination of information and behavior in expert teams. They reviewed 138 models from the literature and proposed five essential behaviors that promote team effectiveness. These behaviors are team leadership, mutual performance monitoring, backup behavior, adaptability, and team orientation. Salas et al. (2005) underline shared mental models as a supporting and coordinating mechanism that is especially important in relation to performance monitoring, backup behavior and adaptability. Shared mental models are based on the assumption that highly effective operational teams are able to understand the system at several levels. To make this possible, multiple shared models must be in action at the same time (Cannon-Bowers et al., 1993). Rouse and Morris (1986) proposed a taxonomy of

mental models in which every level or type of model differed in importance depending on which task was to be solved. Some problems are solved through one type of mental model, while other problems are solved by integrating several mental models.

Cannon-Bowers et al. (1993) proposed four types of shared mental models:

(a) *Technology/equipment*. To extract information, team members need to share an understanding and knowledge of how to control the technology and equipment with which they are interacting. This includes operating procedures, limitations and likely failures.

(b) *Task at hand*. It is also important that team members understand the task at hand and how to carry it out. This is shared knowledge about what information is important and how different types of information must be combined to give meaning. It is also important for the team members to understand the dynamics of the environment and how this impacts on their tasks (i.e., time constraints or uncertainty). This includes task procedures, task strategies, environmental constraints, likely contingencies, and scenarios.

(c) *Team interaction*. Each team member has to understand his/her own role in the overall task, what they as an individual team member contribute and how this is accomplished. This requires a common understanding of who needs what and when in the team. This will enable the team members to understand when they must monitor other team members to support them with the proper behavior or information, if required. This includes their roles/responsibilities, information sources, interaction patterns, communication channels, as well as role interdependencies.

(d) *Team members*. Team members must be familiar with the knowledge, skills, abilities, preferences, and other task-relevant attributes of their team-mates. It is proposed that their expectations of the behavior of their team-mates will vary as a function of who makes up the team. And a shared mental model of team members enables team members to

adjust their own behavior to the other team members (e.g., one team member is on the verge of becoming overwhelmed by a high workload and other team members give support by taking on some of workload).

Shared mental models related to the equipment, task, and team interaction are particularly emphasized in the research (Volpe et al., 1996; Urban et al., 1995; Stout et al., 1999). It is proposed that the importance of shared mental models of team members increases when teams operate in dynamic situations that require high levels of flexibility and adaptability (Cannon-Bowers et al., 1993). This is because it is proposed that familiarity fosters understanding in the team with regard to how team members operate, what they are likely to do, and what information they will require. This enhances the ability to develop viable expectations of performance. In spite of repeated statements underlining the importance of shared mental models of team members, few empirical studies have been published on this factor. This is surprising given how widespread teams unfamiliar with each other are in our society.

1.4 The missing link or shared mental models of team members

While the SMM theory appears promising in relation to explaining connections between familiarity and team efficiency, the literature on SMM has gone in different directions and faced challenges that have remained unaddressed since the concept was introduced in 1993 by Cannon-Bowers et al. One line of thinking started when Klimoski and Mohammed (1994) proposed combining team interaction models and team member models into one category: team mental models. Mathieu et al. (2000; 2005; 2010) and others (Klimoski & Mohammed, 1994; Lim & Klein, 2006) argue that shared mental models of team interaction processes have a significant effect on team performance. This was followed up by research, especially by Mathieu et al. (2000; 2005; 2010). For instance, based on self-

reports from team members with no previous history as a team, Mathieu et al. (2000) investigated the similarity of team members' ratings of team processes and showed that similarity enhanced team effectiveness. The problem with this line of research is not the important findings relating to the similarity of the understanding of the interaction process, but that the incorporated shared mental models of team members seem to be almost non-existent in the studies conducted so far. This indicates a crucial gap in research following the same track as Klimoski and Mohammed (1994).

To my knowledge, only two studies exist within the SMM theoretical framework that address familiarity in teams and thereby attempt to capture the shared mental models of team members. First, Cooke, Gorman, Duran and Taylor (2007) compared experienced command and control (CiC) teams and ad hoc student teams in relation to the performance of a task unknown to both types of team. They concluded that the superior performance during low workload by the experienced CiC teams was due to their having a better understanding or knowledge of appropriate communication strategy, and not to familiarity within the team. This study can thus be seen as another example of the Klimoski and Mohammed (1994) position. But, Cooke et al. (2007) also unexpectedly found that experienced teams had no advantage during high workload, showing no differences in performance or coordination compared to the inexperienced student teams. This contradicts the core of the SMM approach, which proposes that a shared mental model enables the team to implicitly coordinate its actions and be more efficient in a high intensity and novel situation. These authors contend that future studies should attempt to disentangle the relative contribution of familiarity. Thus, in view of these findings, it is still an open question whether teams with extensive previous knowledge about members' characteristics perform better than teams without such knowledge.

Smith-Jentsch, Kraiger, Cannon-Bowers, and Salas (2009) concluded that their study was the first to demonstrate that shared mental models regarding specific team-mates (who had worked on previous teams) are positively associated with requests for backup on the job. An extensive literature search indicates that this is also the only study that has tried to capture shared mental models of team members. However, they were unable to establish whether the connection between familiarity and backup behavior facilitates team performance outcome. In addition, studies of backup behavior have produced inconsistent results. Porter, Hollenbeck, Ilgen, Ellis, West and Moon (2003) found that backup behavior enhanced performance, while Barnes, Hollenbeck, Wagner, DeRue, Nahrgang, and Schwind (2008) found that team members who receive a lot of back-up from other team members reduce their task work in subsequent tasks. Based on the sparse and inconsistent results, Smith-Jentsch et al. (2009) suggested that future research should investigate the importance of familiarity and backup behavior in team performance.

The transactive memory system theory and findings relating to it provide insight into an important knowledge about team processes. It is still an open question, however, whether transactive memory systems represent the fourth content domain in the shared mental model theory (i.e., the shared mental model of team members proposed by Cannon-Bowers et al., 1993). Several researchers seem to fall into this line of thinking, which is evidenced by little research being conducted into shared mental models of team members and, implicitly, by the transactive memory system often being cited as an example of a shared mental model of team members (e.g., Salas et al., 2009). At the same time, several researchers, including those who incorporate transactive memory systems into the domain of shared mental models of team members as examples (Smith-Jentsch et al., 2009), call for empirical evidence for the boundaries and scope of the concept in question, i.e., shared mental models of team members. Kozlowski and Ilgen (2006) underline the need for clear

conceptual and empirical demarcations between team cognitive constructs of mental models and transactive memory. This is followed up by Salas et al. (2009), who argue for a need to provide operational and measurable definitions of what shared cognition is and what contributes to it. Mohammed et al. (2010) state that there is still much conceptual confusion about what distinguishes shared mental models of team members from transactive memory. The present thesis aims to address this issue and examine whether transactive memory systems and shared mental models of team members are distinctly different. It will also investigate whether shared mental models of team members add to team performance.

Taken together, this leaves the concept of shared mental models of team members in a difficult position, with little empirical support and confusion with regard to its conceptualization. It might also be covered by other concepts (transactive memory systems). This leaves a vital gap in the literature, and more research on familiarity in the SMM approach is clearly needed.

1.5 Aims of the studies

1.5.1 Study 1

The aim of this study was to investigate whether knowledge about individual team members would augment the effect of operational skills in predicting operational effectiveness in trained expert teams. More specifically, the objective was to examine whether a shared mental model of team members would add to team performance (communication, physiological arousal, and efficiency) over and above what could be explained by operational skills. This would contribute to closing the gap caused by the lack of empirical support for the notion of shared mental models of team members outlined previously.

1.5.2 Study 2

If shared mental models of team members contribute over and above operational skills, it is an open question how this will affect the output of (distributed) teams that are forced to cooperate despite being in different geographical locations. This is of vital importance, since society in many cases relies on seamless cooperation between distributed teams. The aim of the present study was to investigate the consequences (for communication, physiological arousal, and efficiency) of shared mental models of team members in teams that are forced to coordinate their activities towards a shared goal in a distributed team setting.

1.5.3 Study 3

The aim of the third study was to examine whether shared mental models of team members will transfer to new tasks or situations and, through better coordination, result in improved efficiency and less physiological arousal. One issue of particular interest was how shared mental models of team members would influence team performance and adaptation to a radically changed context represented by cross-training (each member is trained in the specific tasks, duties, and responsibilities of his or her fellow team members) and in a high fidelity simulation exercise.

Thus, this study investigates whether a familiar team learns faster than unfamiliar teams. If the results from the studies show an effect of familiarity on the output of expert teams (Study 1), improved performance in distributed teams (Study 2) and faster learning (Study 3), it will remain an issue whether or not this is caused by shared mental models. Thus, a second aim of the third study was to investigate whether the possible effect of

familiarity was caused by transactive memory systems or by shared mental models of team members.

1.6 Overall research model

On the basis of emerging research relating to shared mental models, it is reasonable to assume that knowledge about other team members will influence the team's outcome, processes, and resilience in relation to stressors in high-intensity situations. An IPO model was selected (see Figure 1) to investigate the Input (shared mental model of team members), Process (coordination behavior, e.g. implicit communication), and Outcome (performance outcome, e.g., mission success).

Outcome measures provide information about results, but not about how they were accomplished. It is essential, therefore, to consider processes that can contribute to the observed outcomes. Cooke, Salas, Kiekel and Bell (2004) propose that attributes of team cognition can be inferred from measuring team processes and behaviors. The general idea is that, if familiar teams outperform unfamiliar teams and show more processes connected to the SMM concept (e.g., backup behavior and anticipation ratio), then this will indicate the presence of a shared mental model of team members. Another strong indicator of a shared mental model is a shift in communication strategy in response to changing workload, since this is an indicator of a change between explicit and implicit communication strategies (Salas et al., 2007).

Although the IPO approach is well accepted and often used in teamwork research, Kozlowski and Ilgen (2006) have criticized it. Thus, while it has been challenged for being static and to some extent oversimplifying complex connections, the IPO model has proven highly robust and adaptable (Salas et al., 2009). It has been an aim of this thesis to

investigate the existence of shared mental models of team members and their impact at a given time, to uncover a possible difference in coordination and efficiency between familiar and unfamiliar teams. An IPO model suits this purpose, and the whole method will be in accordance with it.

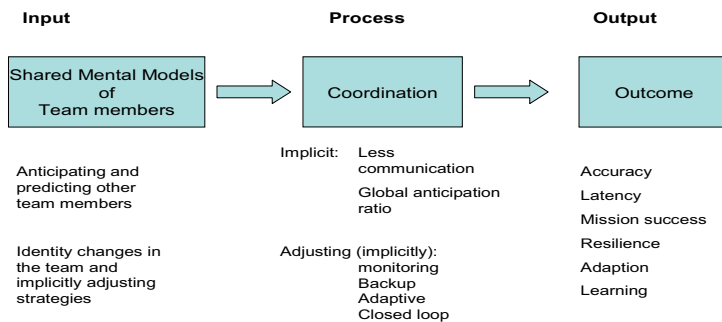


Figure 1: The overall research model: Input factors (e.g. Shared mental models of team members) function through Processes (e.g., backup behavior) to influence Output (e.g., mission success)- The IPO model (Goodwin, Burke, Wildman & Salas, 2009)

1.6.1 Input

This thesis aims to compare groups of familiar teams (with shared mental models of team members) to groups of teams unfamiliar with each other. Salas et al. (2005) propose that all four types of shared mental models enable the team to be more efficient. Following the logic of Salas et al. (2005), teams with shared mental models of team members will have three advantages compared to unfamiliar teams. First, they will be better able to identify changes in the team (e.g., a team member is nervous; has discovered a discrepancy in the surroundings). Second, and based on the identification of change, shared knowledge of each others' characteristics, preferences, tendencies, and abilities also increases the likelihood of understanding why the team member has changed behavior and what he or she will do next.

Therefore, shared mental models of team members can enhance the ability to predict team members' future actions and to know what reaction (e.g., support) this team member needs from other team members. Taken together, better identification of change and better prediction of team members' actions enable the team to implicitly adjust coordination strategy to one that suits this particular team best in a given situation. Thus, to confirm the presence of shared mental models of team members, change (e.g., from low to high workload) and the substance (e.g., implicit) of coordination strategies relating to the general SMM concept are of special interest (Salas et al., 2007).

1.6.2 Processes

Research in the TADMUS project was largely conducted on teams engaged in anti-air warfare on U.S. Navy vessels. The environments these teams have to master are characterized by dependence on team effort, proficiency in specific and shared tasks, and distinct roles among the team members (see Duncan, Rouse, Johnston, Cannon-Bowers, Salas, & Burns, 1996, for an overview). Through in-depth interviews, observations, and comparison of errors between experts and novices in expert teams, a number of core characteristics of coordination strategies in teams with shared mental models were extracted. They indicated that teams with a shared mental model will spend less time communicating and that the frequency of requests to repeat information or ask why a team member is taking some action will be reduced (Duncan et al., 1996).

Orasanu (1990) showed that effective aircrews dealt with difficult situations by using an increased amount of unasked-for information. At the same time, the captains reduced requests for information. Less effective teams displayed the opposite information exchange strategies. In the TADMUS project, the information exchange strategies used by effective teams were interpreted as an index of the presence of a shared mental model in the team. It

was stated that a shared mental model made it possible for the team to give each other vital information in a proper and orderly manner without the receiver asking for it. This enabled the team to focus on the essentials of the task they were facing. Thus, the number of times unsolicited information was offered was seen as important confirmation of the presence of a shared mental model. Hence, as an indication of a shared mental model of team members, less communication and fewer requests during high workload are anticipated for familiar teams (Duncan et al., 1996).

Implicit coordination depends on the team's ability to share a common understanding of the situation, which is a core element of the shared mental model approach (Cannon-Bowers et al., 1993). More specifically, to coordinate their activity, teams with shared mental models will not only reduce the amount of communication they use (implicitly), they will also change their communication patterns from pulling (requesting) to pushing (presenting) information when the workload increases. According to Entin and Serfaty (1999), this shift in communication pattern is reflected in the ratio that results when transfers of information are divided by requests for information ("the global anticipation ratio"). An increase in "the global anticipation ratio" during high workload is seen as a strong indication of a shared mental model (Entin & Serfaty, 1999). As an example, Orasanu (1990) reported that superior teams increased the push of information from team members and reduced requests for information from the team leader during high workload periods. Hence, an indication of a shared mental model of team members is expected to be an enhanced global anticipation ratio (more "push" of information) from low to high workload conditions (Entin & Serfaty, 1999).

Salas et al. (2005) emphasize that three out of five teamwork behaviors are closely connected to the shared mental model concept: adaptability, backup behavior, and mutual

monitoring behavior. Adaptability is defined as the ability to adjust strategies based on information gathered from the environment, which is dependent on backup behavior, or the team's ability to anticipate other team members' needs and carry out actions to spread the workload among members to achieve balance during high workload. Mutual performance monitoring is the ability to develop a common understanding of the team environment and apply appropriate task strategies to accurately monitor other team members' performance. Hence, more adaptability, backup behavior, and mutual performance monitoring behavior are expected to be indications of a shared mental model of team members.

In novel situations, it is expected that teams with a shared mental model of team members will implicitly adjust to more explicit communication and coordination processes. The explicit adjustment strategies pursued will manifest themselves in different ways if shared mental models of team members play a role in team coordination. A seemingly paradoxical effect will be that, in order to coordinate their activity, teams with shared mental models of team members will increase the amount of communication they use when confronted with a novel as opposed to a common situation. Hence, more communication when confronting a novel situation is anticipated to be an indication of a shared mental model of team members.

Salas et al. (2005) emphasize the presence of closed loop communication as a coordinating mechanism for avoiding misunderstandings in communication and facilitating continuous updating of the team's shared mental models. Closed loop communication means that team members confirm and repeat vital information such as time, place, geographical coordinates, etc. Hence, more closed loop communication when confronting an unfamiliar situation is anticipated to be an additional indication of a shared mental model of team members.

1.6.3 Output

It is reasonable to suspect that teams with a shared mental model of each other will coordinate their activities differently (better), showing more teamwork behavior such as back-up and monitoring (Salas et al., 2005; Smith-Jentsch et al., 2009). The result is enhanced performance (e.g., fewer errors, mission success, more accuracy, latency; Griepentrog & Flemming, 2003; Mohammed, Klimoski, & Rentsch, 2000; Stout et al., 1999).

From the above discussion, it is hypothesized that familiar teams will show enhanced efficiency as a result of better coordinating skills (i.e., inferred from the SMM concept) enabled by the shared mental model of team members. It is proposed that the importance of shared mental models will increase as teams have to perform in stressful conditions (Salas et al., 2005). Team performance in ambiguous, high fidelity situations will depend heavily on executive functions among team members, such as attention, memory, and planning. Cognitive flexibility is seen as a particularly important asset when confronted with a rapidly changing and hostile environment. Adaptive team functioning involves using and combining team roles/resources in a flexible manner in order to cope with a rapidly changing dynamic environment. Teams with shared mental models will be more resilient to stress effects, due to their redundancy and ability to supply, substitute, or select information based on a superior understanding of team role needs. Although stressors can reduce the amount of information flow, and team members may become more limited with respect to the tasks they can perform, teams with shared mental models of team members will be able to coordinate explicitly and implicitly when necessary because of their knowledge of the person/role expectations in the team (Duncan et al., 1996). This will put a lower cognitive load on a team with a shared mental model of team members than on those without one.

Knowing the other team members and knowing that they will be able to provide support if necessary will reduce the perceived risk of failure and increase positive outcome expectancies. Gradual mastery of new tasks will result in fewer errors and more positive outcome expectancies over time. Hence, another output variable will be less physiological arousal during high workload condition.

To sum up the IPO approach, it is suggested that a shared mental model of team members has an added value in team work. I anticipated that a shared mental model of team members would be a mechanism that improves coordination in the form of superior communication strategies (e.g., implicit) that enhance the ability to cope with high workload, physical separation and a novel situation, and result in greater efficiency and less physiological arousal.

2. Methods

2.1. Participants

2.1.1 Study 1

The total population of attack teams on Norwegian ULA class submarines participated in the study. Twenty-four active duty officers made up four attack teams (six members per team). The officers ranged in rank from Lieutenant Commander to Second Lieutenant. The purpose of the attack team was to discover, classify, and, if necessary, attack the enemy. The participants' mean age was 26.3 years (range = 24–33) and their experience ranged from four to 12 years in the submarine service. All members of the attack teams had worked together as teams for more than three months, with previous experience of operating in a simulator.

2.1.2 Study 2

A total of 108 cadets from the Royal Norwegian Naval Academy (mean age 24.2 years, range 21-32) were recruited to the present study. The subjects' military service background ranged from two to 10 years, 9.2% were female officers, and the subjects' ranks ranged from Second Lieutenant to Lieutenant. Although the training was mandatory, participation in the research project was voluntary, and seven cadets declined to take part in the study, leaving a total of 101 subjects. Due to equipment failure, there were 84 subjects who completed the full video recording. None of the subjects had previous experience of the simulator or other forms of simulator training in general.

2.1.3 Study 3

A total of 69 cadets from the Royal Norwegian Naval Academy (mean age 24 years, range 21-32) were recruited to the present study. The subjects' military service background ranged from two to 10 years, 10% were female officers, and the subjects' ranks ranged from Second Lieutenant to Lieutenant. Although the training was mandatory, participation in the research project was voluntary. Six of the cadets declined to participate in the part that involved Heart Rate (HR) measurement. Five subjects were lost due to equipment failure, leaving a total of 59 for the HR measurement. None of the subjects had previous experience of the simulator or other forms of simulator training in general.

2.2 Input measurements

2.2.1 Study 1

A questionnaire was developed to evaluate operational knowledge in the teams. The questionnaire was based on interpositional knowledge (IPK; Volpe et al., 1996). This IPK was developed in cooperation with expert personnel in the submarine service. IPK refers to

the amount of knowledge a team member has of others, their own, and the team's tasks, roles and proper responses in different situations.

One scenario was run with an intact original team (familiar team). The second was performed with a second in command (2iC) from a different team (unfamiliar team). The runs were administered in balanced order.

2.2.2 Study 2

Subjects were categorized as members of familiar or unfamiliar teams. To be included in the familiar teams group, the team members had to have completed the first year of basic officer training together at the Norwegian Naval Academy. During this first year, the cadets are organized into permanent teams of six persons that stay together for eight months. During this period, the fixed teams share the hardship of a number of extensive exercises as well as a nine-week period on a tall-masted ship on a transatlantic crossing. This results in extensive knowledge about individual differences in competencies, skills, abilities, preferences, and tendencies (Cannon-Bowers et al., 1993). The present study included 13 familiar teams.

The other category, the unfamiliar teams group, consisted of cadets from another cohort at the Royal Norwegian Naval Academy. The participants had no previous history together, either as individuals or as members of other teams, except for a one-week getting acquainted period at the start of the semester. To control for any learning effects of being a cadet at the Royal Norwegian Naval Academy, eight teams of third-year cadets were formed. They neither had experience of each other as members of the same team during their own first year nor any history of attending the same classes during the second or third year. No differences were found between third-year cadets and the group that had just started on any measures. Hence, in the following, they were treated as one category, unfamiliar teams. Together, these subjects formed a total of 15 unfamiliar teams.

2.2.3 Study 3

Subjects were categorized as members of teams with or without shared mental models of team members. To be included in the SMM of team members group, the team members had to have completed the first year of basic officer training together at the Norwegian Naval Academy. During this first year, the cadets are organized into permanent teams of six persons that stay together for eight months. During this period, the fixed teams share the hardship of a number of extensive exercises as well as an eleven-week period on a tall-masted ship on a transatlantic crossing. This results in extensive knowledge about individual differences in competencies, skills, abilities, preferences, and tendencies in their fellow cadets (Cannon-Bowers et al., 1993). Due to the design of the simulator, the original six member teams were randomly divided into two teams of three subjects. Eleven familiar teams were put together.

The other category, the unfamiliar teams, consisted of cadets from another cohort at the Royal Norwegian Naval Academy. The participants had no previous history together, neither as individuals nor as members of other teams, except for a one-week getting acquainted period, at the start of the semester. Together, these subjects randomly formed a total of twelve unfamiliar teams of three members.

2.3 Process measurements

Instrument. Verbal processes were examined using video and audio tape recordings (Sony TCM-459V) and video (Sony Super Steady Shot Handycam video HI8 CCD TR2200E PAL)

2.3.1 Study 1

Communication. Teamwork was evaluated on four dimensions: information exchange, communication, supporting behavior, and team initiative (based on ATOM; Smith-Jentsch,

Zeisig, Acton, & McPherson, 1998). The number of statements was registered as the total number of statements per minute and separated into three categories: request, transfer, and confirmation. Request and transfer were divided into information, actions, and problem solving. The sender and the receiver of every statement were also registered (Entin, Johnston, & Serfaty, 1998). Statements confirming request and transfer were registered (Salas et al., 2005).

2.3.2 Study 2

Communication. The number of statements was registered as the total number of statements per minute (Salas et al., 2005). In line with Entin et al. (1998), each statement was classified as a request for information, a transfer of information, an action or problem solving.

The global anticipation ratio was calculated by dividing the total number of transfers by the total number of requests (Entin & Serfaty, 1999). The index was computed within teams as well as between teams.

Non-verbal monitoring. Non-verbal behavior was examined on the basis of video recordings and labeled monitoring behavior (Salas et al., 2005). The number of glances at other positions, equipment, and other team members was registered. This resulted in a quantification of monitoring behavior.

2.3.3 Study 3

Communication. The number of statements was registered as the total number of statements per minute (Salas et al., 2005). To categorize information further, each statement was scored in accordance with Salas et al.'s (2005) team behavior indicating a shared mental model concept (i.e., adaptability, backup behavior, and mutual monitoring behavior). The present study focused on statements that it is proposed are related to implicit communication, i.e.

statements that were offered or carried through *without* being solicited by another team member. Thus each statement was categorized into:

- a. Updates/priorities, labeled adaptability, (e.g., "*we lost contact with the contact*" or "*that target is our main focus now*").
- b. Presenting information, actions, solutions, labeled backup, (e.g., "*the correct course is*" or "*I have given the target the correct bearing*").
- c. Offered information, actions, solutions, labeled mutual performance monitoring. (e.g., "*I can give you the bearing now*" or "*Do you need a classification*").

In addition, closed loop communication was quantified as indicators of an underlying mechanism to update shared mental models in general.

- d. Confirmation, labeled closed loop (e.g., "*received*" or "*did you get the bearing I sent you?*").

2.4 Outcome measurements

2.4.1 Study 1

Instrument. The attack teams and their reactions were observed during two different war games in a ULA-class tactical trainer. This simulator is a replica of the submarine central, the natural workspace of an attack team. The simulator presented information about own speed and depth, as well as all available information about other ships that would be present for the attack team on board a real ULA-class submarine. Computer software in the

simulator recorded target solutions, firing range, hits, and the course and speed of own and other vessels.

Efficiency. The criteria-based evaluation of efficiency consisted of latency and mission effectiveness (Cannon-Bowers & Salas, 1998). Latency was measured as the distance in meters to targets when firing, and torpedo hits. Mission success was the number of torpedoes that hit the target.

Physiological arousal. Cardiovascular responses were measured using the Ambulatory Monitoring System V. 3. 6. (AMS; Klaver, de Geus, & de Vries, 1994). The cardiac responses were measured using 8 mm Ag/AgCl ECG electrodes (Cleartrode, Disposable Pregelled Electrodes, 150, Standard Silver). Heart rate was recorded as beats per minute (bpm).

2.4.2 Study 2

Instrument. The study was carried out in a high fidelity simulator that is a replica of a naval operations room. Expert instructors from the Royal Norwegian Navy developed the scenario used in the present study. The scenario was event-based (Johnston, Payne, & Smith-Jentsch, 1998).

Efficiency. Measures were based on transcripts from the simulator, video and voice recordings. They were examined using a criteria-based evaluation of efficiency, consisting of accuracy, latency, and mission success (Cannon-Bowers & Salas, 1997).

Accuracy was a composite score based on observation of the following operational factors: discovered, monitored, made verbal contact, evaluated, made plans for handling the situation, informed (friendly vessel), and classification (the identity of the contact).

Latency was measured as an accumulated score based on reaction times (in seconds). To obtain this accumulated score, each of the eight events in the scenario was scored for how quickly the team responded.

Mission success was defined according to the specific objective of the mission, i.e., to avoid or minimize the hostile threat to an oil tanker.

Physiological arousal. Cardiovascular responses were measured using an Ambulatory Monitoring System V. 3. 6. (AMS; Klaver, de Geus, & de Vries, 1994). Heart rate (HR) was recorded as beats per minute (bpm).

2.4.3 Study 3

Instrument. The study was carried out in a high fidelity simulator. Three consoles for operating the firing of missiles and receiving detected radar transmission were arranged in a triangle facing each other. Computer software in the simulator recorded target solutions, firing range, hits, and the course and speed of all aircraft.

Efficiency. Measures were based on transcripts from the simulator and examined using a criteria-based evaluation of mission success (Cannon-Bowers & Salas, 1998). Scores were defined according to the specific objective of the mission, which was to shoot down enemy aircraft and let friendly aircraft through.

Physiological arousal. Cardiovascular responses were measured using Polar pulse watches. Heart rate (HR) was recorded as beats per minute (bpm).

2.5 Procedure

For all the studies, the participants were informed about the study and invited to sign an informed consent one hour before each experiment started.

2.5.1 Study 1

All four attack teams were rated as operational and approved by their superiors as functioning at the highest level no longer two months before the start of this study. The two war game scenarios used in this study were consistent with the training program the attack teams normally undergo and were identical for all teams. The scenarios were event-based (Johnston et al., 1998), following a design similar to that used in the studies in the TADMUS project. The war games consisted of realistic stressors that gave the teams an increasing workload and need for coordination.

The participants completed the IPK questionnaire and were then equipped with the AMS before entering the simulator. Each of the two war games lasted 50 minutes. To examine stress reactivity, each run was separated into two distinct phases, a low-stress phase and a high-stress situation in which the attack teams had several torpedoes in the water and a manipulated problem with the torpedoes. The problem was identical for all teams and both conditions.

2.5.2 Study 2

Each of the original six-member teams was randomly divided into two three-member teams. These two (sub) teams then manned two different simulator cubicles (i.e., naval vessels) with the common goal of providing close protection to an oil tanker in littoral waters. The tanker was sailing to an oil refinery. The two (sub) teams/vessels were faced with the challenge of coordinating their activities and controlling the area close to the tanker.

This involved surveillance and coordination of air and surface traffic in the area, and subsequent military actions to protect the tanker and prevent hostile actions.

To examine the effects of workload, the scenario was separated into two phases, low and high workload. Team members were randomly assigned to one of two identical vessels and randomly assigned to three different positions in the operations room. These positions were electro-optical surveillance and firing, commanding officer, and overall picture.

The subjects were told that the intention of the exercise was to prepare them for the next mission in the ongoing exercise they were participating in. The officer cadets were not given monetary rewards, and they were informed that the outcome of the experiment would not influence their military leadership grades. Each team was told that the team that, after training, performed best would be given the next high-profile mission in the ongoing exercise they were taking part in.

The study started with a 30-minute briefing on the scenario, describing the setting, order, intelligence information, the outline of the simulator and function of the equipment. This was followed by 30 minutes' hands-on training in the designated position in the simulator. After this, the personnel were equipped with ambulatory cardiac recording equipment before entering a 30-minute planning phase. Baseline Heart Rate was recorded for five minutes before entering the simulator. Continuous recordings were obtained during the scenario in the simulator. After completion, another five minutes were recorded during recovery. All recordings were obtained while the subjects were seated.

2.5.3 Study 3

Pulse watches were administered and baseline HR was recorded while the participants were seated. HR was recorded through baseline, cross-training sessions, high fidelity simulation and recovery. The subjects were told that the intention of the exercise

was to discover how quickly they were able to learn and cooperate. The officer cadets were not given monetary rewards, and they were informed that the outcome of the exercise would not influence their military leadership grade. Each team was told that the team that, after training, performed best in the final test would be given the next high profile mission in the ongoing exercise they were taking part in.

During the training scenarios, the three-member teams had to work interdependently towards the common goal of providing protection for an aircraft carrier in littoral waters. The aircraft carrier was at anchor, and its protection (safety) depended on the teams' ability to shoot down unfriendly aircraft and allow friendly aircraft to operate in the area. This involved surveillance and coordination of air traffic in the area and subsequent military actions to protect the aircraft carrier. This put great constraints on the teams' efforts to coordinate their activities within the limited time at their disposal. The scenario was designed to include realistic stressors that gave the teams an increasing workload and a greater need for coordination and communication between team members.

Team members were randomly assigned to three different positions (team roles) in the operations room. They were: Early Warning (EW), Classification (CL), and Weapons control (WE). The main task of EW was to detect and get a bearing on unknown radar transmissions. EW was then given the task of discovering potential targets early and sending the data (radar characteristics) to CL, who was then able to classify them (from the checklist she or he alone held) as friendly or hostile. EW was also tasked with calculating the speed and course of potential targets based on own bearings and CL bearings. The main task of WE was to update the overall picture. The WE had a map of the area on the console but no sensor to give him/her a bearing or radar characteristics. Thus, WE's ability to fire missiles was entirely dependent on cooperation between all positions. All team roles depended heavily on the performance of the other two.

The study started with a 30-minute briefing on the scenario, describing the setting, order, intelligence information, the outline of the simulator, and a functional demonstration of the equipment. This was followed by 30 minutes' hands-on training in the designated position in the simulator.

In order to examine the effects of cross-training, each team underwent an identical training period consisting of three similar 20-minute scenarios: C1, C2, and C3. All team members rotated between each of the team roles in scenarios C1, C2, and C3. In the final scenario, team members were again assigned their original role – the same as in C1. The high fidelity simulation scenario (S) was more intense, with more contacts from different directions, and a higher workload.

After completion, a five-minute HR recovery period was recorded. All recordings were obtained while the subjects were seated.

2.6 *Raters*

Two paid, independent raters categorized the information exchange in the teams in Studies 2 and 3. They were unfamiliar with the SMM theory, the scenario, and experimental set-up. Both raters were introduced to and trained in the use of the Noldus program (Noldus, 1991; Noldus, Trienes, Hendriksen, Jansen, & Jansen, 2000). The two raters established a common understanding of the categories by rating several videos together before the actual recording of the videos. The inter-rater reliability showed an intra-class correlation of .98 ($p < .01$) in Study 2 and .93 ($p < .01$) in Study 3. This was based on the average of the two raters' independent evaluations of three teams. The rating of the information exchange in Study 1 was conducted by the author.

2.7 *Design and statistics*

2.7.1 Study 1

T-tests for independent samples were used to test differences in IPK between the different attack teams. Analyses of performance during the simulator run were based on a repeated measures design (Ferguson, 1981), and *t*- tests for dependent samples were used to test differences between the two conditions. Due to the specific predictions about the directions of the means, one-tailed tests were used (Ferguson, 1981). Analyses of physiological arousal were performed using a 2 (known vs. unknown teams) \times 2 (low-stress vs. high-stress phase) factorial design (Ferguson, 1981), using a two-way analysis of variance (ANOVA); both factors were treated as repeated measures. Preplanned simple effects and contrasts were measured by means of one-tailed *t*- tests due to the direction of the predictions of the means (Wilcox, 1987).

2.7.2 Study 2

The study was carried out using a 2 (familiar teams vs. unfamiliar teams) \times 2 (high vs. low workload phase) factorial design. Analyses of HR were performed as a manipulation check for the different phases of the simulation. Thus, a 2 (familiar teams vs. unfamiliar teams) \times 4 (baseline vs. low workload vs. high workload vs. recovery) factorial design (Ferguson, 1981) was used. The first factor was treated as a between-group factor and the second factor as a within-group factor in all analyses. When hypotheses based on specific predictions of the directions of the means were tested, non-significant interaction effects were followed up. (See Wilcox, 1987 for a discussion.) Stoline and Spjotvoll HSD tests for unequal sample sizes were used as post-hoc tests.

2.7.3 Study 3

Efficiency and processes scores were studied using a 2 (familiar vs. unfamiliar) x 3 (C1 vs. C2 vs. C3) factorial design (Ferguson, 1981). The first factor (groups) was treated as a between-group factor and the second factor (sessions) as a within-group factor in all analyses. An independent-samples *t*-test was conducted to compare efficiency and process differences between familiar and unfamiliar teams during the high fidelity simulation.

Analyses of HR were performed using a 2 (familiar vs. unfamiliar) x 6 (baseline vs. C1 vs. C2 vs. C3 vs. high intensity simulation vs. recovery) factorial design (Ferguson, 1981). The first factor was treated as a between-group factor and the second factor as a within-group factor in all analyses. All effects were followed up using a Tukey post-hoc test.

3. Results

3.1 Study 1

In this study, submarine crews were studied during simulated attack operations. No differences were found between the teams on interpositional knowledge. The examination of the scores for IPK of the four 2iCs indicated that the scores were almost identical.

When expert teams changed from an unknown to a known team member (role of second in command), the number of hits on target increased, while information exchange (statements per minute) and type (requests) decreased. Looking at who said what, a similar pattern emerged; the commanding officer and the known 2iC verbalized significantly less compared to when the 2iC was unknown. All exchange of information in the triad, commanding officer – the rest of the team – 2iC, decreased when the 2iC was known. There were no differences between the commanding officer and the rest of the team. In addition, the commanding officer and the known 2iC exchanged significantly fewer requests compared to the unknown 2iC.

Familiar teams showed less increase in physiological arousal (heart rate per minute) from low to high workload.

This study demonstrated that knowledge about team members adds to performance, over and above the contribution of operational skills.

3.2 Study 2

In this simulated naval threat scenario, familiar teams outperformed unfamiliar teams on all outcome measures: higher mission success, higher accuracy, and shorter response latencies.

The familiar teams were more aroused (heart rate per minute) during low workload. During recovery, only familiar teams showed a decrease in arousal.

Within the sub-teams (vessels), familiar teams increased their global anticipation ratio from low to high workload, while the unfamiliar teams showed no differences. Unfamiliar teams decreased their monitoring behavior (non-verbal) from low to high workload and were more involved in task-irrelevant communication.

Investigating the communication between the vessels (distributed teams), familiar teams increased statements per minute and the number of transfers from low to high workload. Familiar teams increased transfers from low to high workload.

This study demonstrated that knowledge about team members (familiar teams) adds to performance, both when teams are separated and within teams. In both conditions, they were working towards a common goal and in a situation that was new to all participants (simulation facilities).

3.3 Study 3

Teams were exposed to the same unknown simulator and naval scenarios in their cross-training (1-3) and high fidelity simulation exercise. Familiar teams performed significantly better, hitting more targets than unfamiliar teams in cross-training sessions 2 and 3 and in the high fidelity simulation. Unfamiliar teams were on a par with familiar teams in the first cross-training session, but did not improve (learn) through cross-training sessions (2, 3) as the familiar teams did.

Only familiar teams showed a decrease in physiological arousal (heart rate per minute) through cross-training sessions, high fidelity simulation, and recovery.

Facing a situation unknown to all participants, familiar teams were more explicit, engaging in more information exchange (statements per minute) as well as more closed loop communication (confirmation). Only familiar teams decreased their closed loop communication (confirmation) during cross-training.

The familiar teams showed more process behavior, indicating higher adaptability (updates) and backup behavior (unsolicited help) during cross-training and in the high fidelity simulation. No differences were observed for mutual performance monitoring behavior (verbal or non-verbal).

This study demonstrated that knowledge about team members transfers to new tasks and situations and results in better coordination, improved efficiency, and less physiological arousal.

4. General discussion

The findings of these three studies indicate that familiar teams used coordination strategies that enhanced efficiency. The coordination strategies used by familiar teams are

characterized by less overt communication (statements per minute) during high workload (Study 1), a higher global anticipation rate (Study 2), and more adaptability and backup statements during cross-training (Study 3). In addition, familiar teams showed more overt communication (e.g., confirmation) when confronted with a novel situation (Studies 2 and 3). Familiar teams outperformed unfamiliar teams, being more accurate and quicker, and achieving greater mission success (i.e. more hits). Familiar teams were more physiologically aroused (HR) during low workload (Study 2) and less during high workload (Study 1), recovery (Studies 2 and 3), decreasingly so during training (Study 3).

These three studies extend previous research by presenting new empirical data on the significance of shared mental models of team members. It is assumed that shared mental models of team members enabled the familiar teams to anticipate each others' future behavior and thereby tailor their own behavior accordingly (Cannon-Bowers et al., 1993). Thus, shared mental models allow team members to adapt better to the environment, including to task demands and their fellow team members. All outcome measures indicate greater efficiency in the familiar teams, even when confronted with new and unfamiliar situations. It is reasonable to assume that these results are a result of a better shared mental model of team members in familiar teams than in unfamiliar teams. In order to explain how these results were achieved, it is necessary to evaluate the processes that might have contributed to the observed outcomes. Attributes of team cognition can be inferred by measuring team processes and behaviors (Cooke et al., 2004). Hence, when familiar teams outperform unfamiliar teams, show more processes, and behaviors related to the SMM concept (e.g., backup behavior and anticipation ratio), this will indicate the presence and effect of shared mental models of team members. The essentials of shared mental models are the switch in communication strategy from explicit closed loop communication to implicit communication, while maintaining high levels of performance (Entin & Serfaty, 1999). This

shift in communication strategies in response to changing workload condition is seen as an indicator of a shared mental model (Salas et al., 2007). The following were anticipated as inferred implicit communication and taken as indications of a shared mental model: less communication (Duncan et al., 1996; MacMillan, Entin, & Serfaty, 2004), fewer requests, more transfers, a higher global anticipation rate (Entin & Serfaty, 1999), more closed loop communication in novel situations (Kanki, Lozito, & Foushee, 1989; Orasanu & Salas, 1993) monitoring behavior, backup behavior, and adaptability (Salas et al., 2005; 2007).

4.1 Implicit communication inferred to be shared mental model of team members

At the core of the SMM approach is the assumption of implicit coordination. The need for explicit coordination of information exchange will thus be lower in teams with a highly developed shared mental model (Salas et al., 2007; Duncan et al., 1996; Kleinman & Serfaty, 1989). In Study 1, the less exchange of information seen in the familiar team is a strong indication of a more developed shared mental model of team members. This argument is reasonably valid since all teams had similar operational shared mental models (equipment, task and roles).

Familiar teams in Study 1 also made fewer requests and thus coordinated their activity differently and more implicitly than unfamiliar teams. Orasanu (1990) showed that successful teams responded to high workload by leaders reducing requests. This is in line with Urban et al. (1995), who claimed in a study of hierarchical and non-hierarchical teams that efficient teams are characterized by minimal use of question-answer sequences. The finding of fewer requests in Study 1 is in accordance with Aim 1 and supports the notion that

superior coordination and results are explained by a more developed shared mental model of team-members.

Further analysis of the information exchange within the attack teams in Study 1 revealed an interesting pattern, namely that more information was exchanged between the commanding officer (CO) and the 2iC in the unfamiliar teams. There was also more information exchange from the 2iC to the CO in the unknown teams. This is further evidence for the notion that the information structure in the unfamiliar team was distorted and was characterized by a need to control each others' needs, intentions, and actions. The CO and the 2iC were the team members who made most of the decisions. Thus, the lack of a shared mental model of team members results in an increase in the need for explicit coordination among the senior decision-makers in the expert teams. This implies that shared mental models of team members enable an expert team to be more implicit in their coordination. This is understood to be a vital finding, and the general advantage a team of experts has from having a shared mental model (equipment, task, interaction) is hampered if a shared mental model of team members is lacking. This indicates that shared mental models of team members influence shared mental models of equipment, tasks and interaction. Mathieu et al., (2005, 2010) support this, providing evidence for the hypothesis that shared mental models of tasks and interaction mediated each other.

Orasanu (1990) showed that airline pilots used low workload periods to develop shared mental models. This made it possible for them to employ different communication strategies during high workload, thus enabling them to communicate more implicitly. The change of communication strategy that took place within the familiar teams in Study 2 when they went from the low to the high workload phase is a strong indication of shared mental models in action. Entin and Serfaty (1999) suggest that an increase in the global anticipation

rate (total transfers/total requests) is a strong indication that a team switches its communication from explicit to implicit and that this change shows that shared mental models are operating. In Study 2, unfamiliar teams responded to the high workload without changing communication strategy, which is understood as meaning that there was no difference in terms of transfers of and requests for information. On the other hand, familiar teams increased the global anticipation rate by switching from pulling (requesting) to pushing (transferring) information when in the high-workload condition. Entin and Serfaty (1999) contend that an increase in the global anticipation rate as shown by familiar teams in Study 2 is a strong indication of shared mental models operating and evidence that shared mental models of team members contribute to better performance and efficiency (see Aim 1, p. 26).

Another indication of shared mental models is proposed by Salas et al. (2005). They suggested a strong connection between monitoring behavior and shared mental models. They proposed that mutual performance monitoring only occurs in teams with an adequate shared mental model. Thus, the decrease in monitoring behavior shown by the unfamiliar teams in Study 2 indicates a lack of an adequate shared mental model of team members and thereby that team members engage less in behavior such as identifying mistakes, providing feedback and helping team members with a heavier workload than themselves. This could have a detrimental effect on the effectiveness of the team. It is reasonable to assume that, when unfamiliar teams engaged in more task-irrelevant communication during high workload, they were less able to understand that other team members were uncertain and needed help (Kanki & Foushee, 1989).

Cannon-Bowers et al. (1993) underlined that, in tasks that are relatively procedure-based (i.e., the response to various task contingencies can be specified), the importance of a

shared mental model of team members is diminished because the task involves relatively little behavioral discretion. Submarine attack teams operate under a strict regime that leaves little behavioral discretion outside the procedures laid down in the operation order and communication rules. Thus, the attack teams in Study 1 have all the characteristics that are suggested as (Cannon-Bowers et al., 1993) reducing the importance and impact of shared mental models of team members. The findings of Study 1 indicate the presence of shared mental models of team members through superior performance and the implicit communication strategies associated with the concept. Study 1 thus shows the opposite, namely superior performance and efficiency in an environment with low behavioral discretion. Taken together, this is sound evidence for and confirmation of the impact of shared mental models of team members on expert teams and is in accordance with Aim 1. Study 2 (within vessels) replicated and supported the findings of Study 1, with superior efficiency and implicit communication strategies. Hence, taken together and seen in relation to the first aim of this thesis (see Aim 1, p. 26), these findings provide strong support for the notion that shared mental models of team members have an added value in terms of team performance and efficiency.

4.2 *No clues – distributed coordination*

There has been increasing focus on coordination in distributed teams (DeChurch & Mathieu, 2009). This is particularly important when teams are physiologically separated, have fewer opportunities to coordinate through monitoring behavior, and are exposed to an increased level of abstraction, ambiguity, and what Fiore, Salas, Cuevas and Bowers (2003) call team opacity. In these situations, Fiore et al. (2003) propose a decrease in team members' situation awareness due to the absence of paralinguistic, non-verbal, and other

sensory cues. This may imply that shared mental models of team members' team coordination will be hampered by physical separation.

The coordination strategy that familiar teams use between vessels in Study 2 implies that, in accordance with Aim 2, shared mental models of team members contribute even if there is no face-to-face contact between the two sub-teams (vessels). Although differences in communication pattern were not prevalent between the two vessels (distributed teams), there were indications that familiar teams engaged in more implicit communication. This argument is based on an increase in the frequency of transfers of information from low to high workload condition. This is especially interesting since unfamiliar teams showed no such increase. This indicates that familiar teams verged on being more implicit in their communication. This further strengthens the notion that shared mental models of team members also have an impact in distributed teams (see Aim 2, p. 26).

Contrary to what was expected, familiar teams in the distributed condition (between vessels) in Study 2 increased the number of statements per minute from low to high workload compared to unfamiliar teams. One explanation could be that familiar teams adjusted their communication based on what Salas et al. (2005) describe as the ability to identify changes in the team, task or team-mates, and to implicitly adjust strategies as needed. Hence, the team members were not experts on the subject matter, but used their shared mental models of each other to be able to sense that other team members were struggling and needed help (e.g., information). If this is correct, it implies that novices in relation to a task use their familiarity to enhance communication, to be more implicit by pushing information (more transfers), to keep the distributed other team members up to speed in relation to a new and unfamiliar situation. Familiar teams thereby seem to monitor each other more efficiently through verbal clues, such as a tone of voice indicating that help

is needed, and act accordingly. The last argument is supported by the differences in transfer; familiar teams initiated more unsolicited communications during high workload than unfamiliar teams. Familiar teams may thereby have been more able to anticipate that the other teams (vessels) needed to share information or have something done, and acted accordingly. This indicates a learning strategy that is adaptable to a new situation when the team consists of novices in relation to the subject matter and is only connected through verbal clues. This will be further elaborated when novel situations in connection with Study 3 are discussed. Unfortunately, it is not possible, based on Study 2, to know how task experts would have coordinated when separated physically. But when novices are on the verge on being implicit, this is a strong indication that task experts will increase their global anticipation ratio when in a distributed situation. Thus, with reference to our second research aim (Aim 2, p. 26), there seem to be strong indications that a shared mental model of team members improves performance and efficiency when teams are separated physically.

4.3 Do shared mental models of team members improve learning?

Study 3 addressed how shared mental models of team members would influence team performance and adaptation to a radically changed context represented by cross-training and a high fidelity simulation exercise (Aim 3, p. 27). Cross-training refers to a strategy in which each member is trained in the specific tasks, duties, and responsibilities of his or her fellow team members (Cannon-Bowers & Salas, 1998; McCann, Baranski, Thompson, Pigeau 2000, Marks et al., 2002). There appear to be few previous studies that have assessed differences in the outcomes of shared mental models of team members when team members

are confronted with a series of new and unfamiliar training sessions represented by cross-training and a high fidelity simulation exercise.

Mainly in Study 3 but also in Study 2, the difficulties of understanding the situation and task may initially have prompted more explicit communication. Since the situation in Study 3 was new and unknown to the team members, the familiar teams were, as expected, more explicit in their initial communication. This is explained by a need to make sure that each team member received proper information. Through more communication (statements per minute) and more closed loop communication (confirmations), each team member ensured that every aspect of the situation was received and understood (Kanki et al., 1989; Orasanu & Salas, 1993). Thus, in contrast to the less successful unfamiliar teams, the familiar teams seemed to develop and update their shared mental models (equipment, task, interaction) while they were engaged in problem-solving and task work during the initial training scenarios (Bowers, Jentsch, Salas, & Braun, 1998). When, unlike the unfamiliar teams, the familiar teams decreased their closed loop communication as the cross-training progressed, it is reasonable to assume that the initial strategy was no longer necessary as knowledge about the task increased (Entin & Serfaty, 1999). This is supported by the efficiency measures. During the first cross-training session, there were no differences (hits on target) between familiar and unfamiliar teams, but only familiar teams improved (learned) during the next training sessions. This was expected and strengthens the assumption that the shared mental models of team members enhance learning through superior coordination strategies (Aim 3, p. 27).

In line with the logic of shared mental models, all teams will increase their shared mental model of equipment, the task and interrelations and move towards more implicit communication as the cross-training progresses. Salas et al. (2005) proposed a strong

connection between adaptability, backup and mutual performance monitoring behavior and shared mental models. They proposed that mutual performance monitoring, backup behavior and adaptability occur more often in teams with adequate shared mental models. This is supported by Study 3, where the findings indicated that familiar teams showed a higher frequency of adaptability and backup behavior.

There were no differences in mutual performance monitoring (verbal or non-verbal) in Study 3. One explanation could be that the heavy workload reduced team members' opportunities to watch other team members due to time constraints. It is also possible that familiar teams monitored each other more efficiently through verbal clues, such as a tone of voice indicating that help was needed, and acted accordingly (e.g., offering action, which was significantly higher for the familiar teams). The ability to draw on knowledge of each team member's tone of voice is supported by the findings from Study 2, where physically separated teams seemed to be able to coordinate implicitly (increased transfer). The differences in adaptability, whereby familiar teams initiated more updates (adaptability) and unsolicited help (backup, information, action, problem-solving), strengthen this assumption. They thus anticipated that the team needed to share information or have something done, and acted accordingly. This may be the most important difference relating to the availability of shared mental models. Taken together with the finding that familiar teams showed a higher rate of confirmations in order to keep everybody in the team up to date with the evolving situation, it seems that a shared mental model of team members in the familiar teams contributes to a coordination strategy that is superior to that of unfamiliar teams.

Study 3 shows that the shared mental model of team members is a mechanism that improves coordination, as evidenced by better communication strategies, and results in enhanced adaptation (learning) to a new task and situation, as demonstrated by improved

performance and outcomes in high workload conditions. Thus, this provides strong support for the suggestion that shared mental models of team members are transferable across different tasks (see Aim 3, p. 27).

4.4 *Transactive memory systems*

The second part of the third aim was to examine whether TMS and the shared mental model of team members were distinctly different concepts. Research based on the TMS approach has concentrated on knowledge about the task the team is meant to solve and the team's ability to draw on team members' different memories of it (task knowledge) (Mohammed et al., 2010). Thus, since participants in Study 3 encountered a novel situation and task, it is difficult to attribute differences in performance between familiar and unfamiliar teams to TMS.

Only familiar teams improved efficiency (i.e., hits on target) after one cross-training session, while unfamiliar teams did not. Since the observed communication indicated coordination strategies that are inferred from the SMM concept (closed loop, adaptive and, backup behavior), this is strong evidence for the assumption that the shared mental model of team members caused the observed better performance by familiar teams, and not TMS.

The better performance by familiar teams in Study 3 is a strong indication that the shared mental model of team members is distinct and different from TMS, having an independent and added value in relation to the coordination processes that explains the superior efficiency of the familiar teams in cross-training sessions 2 and 3 and the high fidelity simulation (Aim 3, p. 27).

The TMS perspective underlines the importance, in relation to being able to perform the overall task, of distributed knowledge of team members' skills and knowledge, but it

does not add to performance when the workload is high, interdependence between roles are high, the situation is new, time is limited, and coordination is crucial. In such cases, the cost of distributed knowledge is the possibility that performance will be hampered (Kozlowski & Ilgen, 2006). This thesis has shown that there is more to familiarity in the team cognition domain than awareness of who knows what about the task at hand. A shared mental model of team members seems to be distinctly different from TMS and appears to add value to coordination in teamwork (Aim 3, p 27).

4.5 *Physiological arousal*

An extensive literature search indicates that no studies have combined physiology with the SMM approach. This is somewhat surprising since several authors (Kleinman & Serfaty, 1989; Orasanu & Salas, 1993; Salas et al., 2005) underline that the importance of shared mental models as a coordinating mechanism increases in teams that have to perform under stressful conditions. In the three studies, Heart Rate (HR) was used as a manipulation check of high workload. Heart Rate is often used as a measure of a stress response (Kudielka, Buske, Kirschbaum, Hellhammer, & Kirschbaum, 2004). Schommer, Hellhammer and Kirschbaum (2004) have found a decrease in HR during stress response over time. Hence, it is possible that a shared mental model of team members decreases HR in high workload situations. Study 1 supports the importance of this assumption. It also shows that, in addition to better performance, teams that are expert in subject matter and have a shared mental model of team members show increased stress resilience. This is based on the finding that only the unfamiliar teams showed a significant increase in HR from low to high intensity scenarios. Viewed together with more implicit coordination and more hits on target, this finding provides solid evidence for the notion that a shared mental model of

team members adds to teamwork over and above the contribution of operational knowledge and skills (see Aim 1, p. 26).

Contrary to what was expected, familiar teams in Studies 2 and 3 were not less physiologically aroused (HR) than unfamiliar teams during high workload conditions, as was the case in Study 1. In Study 2, the situation and task were unknown (not experts in the subject matter as in Study 1), and one explanation could be that the novelty of the situation itself affected and thus mediated physiological arousal. A control group of subject matter experts would have made it possible to check this. In Study 3, the novelty of the situation and the cross-training itself could have had the same effect on arousal. In Study 3, however, the familiar teams decreased their HR from the first cross-training to the high intensity simulation. This indicates that familiar teams developed resilience towards higher workloads compared to unfamiliar teams. The faster learning by familiar teams as shown by better performance (i.e., improved number of hits) strengthens this notion. A control group not participating in the cross-training would have enabled us to establish this.

Looking at HR patterns over all conditions in Studies 2 and 3, differences emerged between familiar and unfamiliar teams. In Study 2, familiar teams increased their HR significantly from baseline to low workload. Recovery of HR in Studies 2 and 3 was only found in the familiar teams, indicating higher adaptability of the organism to environmental demands.

This ability to regulate physiological activity is associated with Situational Awareness (SA). Saus, Johnsen, Eid, Riisem, Andersen and Thayer (2006), for instance, reported an association between Heart Rate Variability (HRV) and SA measured during the recovery phase. Furthermore, Saus et al. (submitted) have shown that naval cadets who displayed a high degree of SA in a navigation simulator were also able to modulate their

internal environment in order to match external demands. This was found with suppression of HRV from baseline to simulation and a recovery effect. In contrast, in the low SA group, there was no differentiation of HRV from rest to simulation and recovery.

This indicates that familiar teams, initially and over time, display a more adaptive and resilient response to change in the environment (e. g., higher workload) compared to unfamiliar teams. This is understood as increased sensitivity to external demands and a key element of the importance of a shared mental model of team members.

4.6 Shared mental models of team members make a difference

Study 1 demonstrated that knowledge about team members (i.e., a shared mental model of team members) adds to performance over and above the contribution of operational skills (Aim 1). Study 2 confirmed Study 1 (within teams) and provided empirical evidence for the effect of shared mental models of team members in distributed teams (Aim 2). The findings in Study 3 suggest that shared mental models of team members are transferable across tasks and enhance the effects of cross-training (Aim 3). All studies extend previous research, but Study 3 in particular indicates that a shared mental model of team members is distinctly different from a transactive memory system (Aim 3). Hence, a shared mental model of team members represents an independent, adaptive asset at team level that enhances team performance, efficiency, and resilience.

These studies are the first to provide empirical evidence that supports the notion that a shared mental model of team members is a mechanism that improves efficiency and coordination in teams. It thus expands previous knowledge, where the focus has been on equipment, tasks and team interaction. The findings represent a contribution to and fill a vital gap in the Shared Mental Model literature.

The findings from these three studies are strong indications that a shared mental model of team members contributes to resilience and coping. The superior performance and efficiency shown by familiar teams in all three studies supports this proposition. A shared mental model of team members seems to enable the team to choose coordination strategies that fit the team and the situation. A model is therefore proposed to put the findings into a context that shows how shared mental models of team members seem to operate.

4.7 *The ShipMate Model*

One way of understanding the findings is to look at what can happen when a team member becomes aware of a change in the environment (outer world). The other team members sense a change in his/her behavior –“something has happened” – (e.g., the team member appears to be more concentrated, uncertain). This is in line with the proposed property of shared mental models that they enable the team to identify changes in the team and in team-mates (Salas et al., 2005). This suggests that a shared mental model of team members enhances a team’s sensitivity to change, enabling it to act accordingly (see Figure 2).

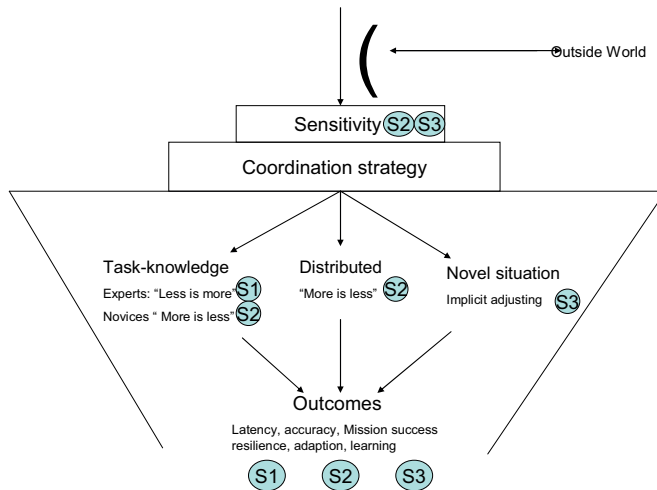


Figure 2: The ShipMate mode: The symbols S1/S2/S3 are understood as findings from Study 1, Study 2 and study 3. The logic is explained to be that when a change takes place in the outer world this is sensed (discovered) by on or two members in the team. Then the teams choose three different ways to coordinate based on what knowledge and skill they have on own task, if they are separated, or face a novel situation. This then give better outcomes (e.g., more hits).

4.7.1 Sensitivity

The ability to detect deviancies, shortcomings, and unfamiliarity in members of the team was enhanced in familiar teams, and they focused on rectifying the situation. As a result, familiar teams put more effort into understanding and coping, even in situations where there was no immediate need for action (e.g., low workload). This, in turn, could result in an immediate increase in the observed heart rate during low workload in Study 2 and initial cross-training in Study 3. This could also help to explain why familiar teams performed better than unfamiliar teams in Study 2 during low workload. Another argument in this connection is provided by the finding made when looking at heart rate during recovery, where only familiar teams in Studies 2 and 3 decreased their heart rates, indicating higher

sensitivity and thereby adaptability of the organism to environmental demands. (Saus et al., 2006)

Increased sensibility in familiar teams has at least two implications. First, the whole team implicitly shares within the team that a change has occurred, and they therefore become aware of changes more quickly and can cope with the reality of the change in the environment. Less irrelevant communication by the familiar teams in Study 2 can be understood as better awareness and, consequently, a more appropriate strategy and an indication of a shared mental model of team members.

Second, familiar teams are able to adjust implicitly to the coordinating strategy that best fits the situation and the team. The second implication is in line with the theoretical framework for shared mental models, where Salas et al. (2005) define the ability to implicitly anticipate what your team-mates need and, accordingly, what (i.e., information, action) they need from you. Thus, a shared mental model of team members enables the team to choose the coordination strategy that is best suited to coping with the situation and/or to the abilities of the team. These three studies indicate that the (implicit) choice of coordination strategy depends on three factors/questions: do we know the task, are we separated from other team members, and are we facing a novel situation (a learning situation)?

4.7.2 Task knowledge coordination

If the team knows the task (are subject matter experts), as was the case in Study 1, then the coordination seems to be straightforward and in accordance with the original theoretical framework for shared mental models. The teams have a general shared mental model (of equipment, task, interaction, and team members) and are able to immediately start

communicating implicitly. The appropriate coordination is “less is more”, i.e., less communication (statements per minute) and less control (requests).

When facing a task they are not experts in, as was the case in Study 2 (within teams), teams are forced to communicate more in order to learn the new elements in the task they as a team must adapt to. In such cases, familiar teams implicitly know that team-mates need more information and thus start to push it or display what Entin and Serfaty (1999) call a higher global anticipation ratio to meet high workload. Thus, a shared mental model of team members enables them to choose a coordination strategy that can be characterized as “more is less”, i.e., more transfer, task-oriented communication and monitoring (non-verbal).

4.7.3 Distributed coordination

When teams are separated physically, this puts even more strain on the coordination process. The solution to the obstacle to communication seems to be implicitly understood by familiar teams. Study 2 indicates that, given physical separation, the strategy for familiar teams seems to be “more is less”. As was the case within the teams in Study 2, a shared mental model of team members enables familiar teams to push information, increase the number of transfers and, contrary to within teams on the same vessel, enhance the overall communication strategy by communicating more when the workload increases.

4.7.4 Coordination in novel situations

When teams that have a shared mental model of team members (Study 3) face a novel situation, they implicitly understand there is a need to learn, and they act accordingly. (“we do not know and have to learn - together”). In such situations, teams that have a shared mental model of team members have two parallel communication strategies. Initially, when the uncertainty is greatest, it is crucial to create a common understanding of the

surroundings. Hence, they adjust (implicitly) and become more explicit, make more statements per minute and use closed loop communication to develop a shared mental model of the equipment, task and interaction. The need to be explicit is reduced as the team learns the task. The second strategy seems to be to dynamically allocate task-relevant resources to team members to take care of workload distribution problems by giving more backup and engaging in adaptive behavior.

4.7.5 Outcomes

The Shipmate Model suggests that familiar teams approach a dynamic environment differently from unfamiliar teams. First, familiar teams seem to be more attentive (higher heart rate during low workload in Studies 2 and 3), more resilient (lower heart rate during high workload in Study 1), and adaptive (decreasing heart rate during cross-training sessions in Study 3 and recovery in Studies 2 and 3). A shared mental model of team members seems to enable familiar teams to act more quickly and more thoroughly and to achieve greater mission success (e.g., more hits).

4.8 Limitations and weaknesses

Despite the possible contribution of the present thesis, several potential limitations should be noted.

4.8.1 Design of the studies

Studies 2 and 3 can be considered experiments since the cadets were randomly assigned to groups, even though they were not randomly sampled from a population. Study 1 comprised

the total submarine crew population of the Norwegian Royal Navy. Generalizing the findings to other kinds of personnel or types of teams involves several complications. First, the participants are selected Norwegian, military personnel and caution should be displayed when generalizing these findings to other cultures and a more diverse group of people. The type of teams is also distinct, but it is reasonable to expect that the findings apply to teams that consist of domain experts with interdependent tasks working towards a common goal in a high workload environment. However, Yang, Kang, & Mason (2008) among others (e.g., Kellermanns, Floyd, Pearson, & Spencer, 2008) have shown that other type of teams (e.g., project teams, software development teams, university teams) benefit from knowledge about the SMM concept in general. It is reasonable, therefore, to assume that other types of teams will experience similar effects of shared mental models of team members.

4.8.2 Control variables

Other possible limitations not controlled for in the present thesis are learning effects, trust, cohesion, self-efficacy, and motivation.

First, the results could have been influenced by learning effects. In Study 1, the runs were administered in balanced order to meet this challenge. In Studies 2 and 3, however, the experience of being a cadet for a year at the Royal Naval Academy may have resulted in more knowledge about how to cooperate in teams. Thus, a group of four teams of older cadets (third year) was put together. A 2x2 ANOVA showed no differences between third-year cadets and first-year cadets in the unfamiliar group on any dependent variable. This suggests that learning effects did not explain the results obtained.

Furthermore, the literature shows that increasing attention is being devoted to trust as a precursor of team performance (Bandow, 2001). However, trust may have been present in

both the familiar and unfamiliar teams in Study 2. This is based on Bandow (2001), who states that 12 to 18 hours of face-to-face contact is required to instill the appropriate trust in a team. When the unfamiliar teams started Studies 2 and 3, they came straight from the introduction week at the Royal Norwegian Naval academy. This week is an intensive team-building period involving extensive face-to-face interaction with the aim of instilling trust in the naval cadets. It is reasonable to expect that they were confident in each other and that the differences found in the present studies can be attributed to shared mental models of team members and not to the level of trust. This is further supported by another study of cadets from the Royal Norwegian Naval Academy. According to Nissestad (2007), there were no differences after the first week and after the first year in terms of group climate or group dynamics in the teams. He also showed that cadets are a homogeneous group, referring to personality factors measured by the NEO-PI. The Nissestad study was conducted on five cohorts between 2001 and 2005, and it is reasonable to expect that this would also apply to the participants in the present studies. Concepts such as self-efficacy and cohesion could also have biased the findings in Studies 2 and 3. However, as these phenomena were not explicitly controlled for, they could have influenced the result of the present study. Not measuring the cohorts in Studies 2 and 3 and the officers in Study 1 could possibly be a limitation on the findings.

Moreover, there may be differences in the level of motivation between the different groups that could have influenced performance and efficiency. Studies 2 and 3 were conducted as a part of an exercise in the leadership program for cadets. The participants were told that the best team would take the lead in the next period, which they actually did. This probably increased motivation in all the teams. One indication that supports this notion is the low number of communications unrelated to the task observed in Study 3 and, more

importantly, the fact that there were no differences between familiar or unfamiliar teams. Motivation may still differ between familiar and unfamiliar teams, however.

4.8.3 Measurement challenges

Another possible weakness that has to be taken into consideration when interpreting and discussing the findings is the challenge relating to measurement. This thesis was based on inferring from team members' behaviors the presence of a shared mental model of team members. Systematic observation of behavior of this kind can provide insight into cognition and, in particular, mechanistic theories of cognition (e.g., shared mental models; Cooke et al. 2004). Mohammed et al. (2010) recommend that researchers move from referring to shared mental models in the abstract to specifying content domain and property. However, they also underline the diversity, complexity, and number of measurement methods (Mohammed et al., 2010). In the same vein, they concur that shared mental models of team members have been a greater empirical challenge relative to shared mental models of task, equipment and interaction, which by their nature tend to be more straightforward to assess. Another related problem is the operationalization and definition of shared mental models as a construct. Shared mental models of teams members are largely unexamined and broadly (unclear) defined (Salas & Fiore, 2004). This thesis has provided empirical support for the hypothesis that it is an important determinant of team functioning and team performance, but it does not provide a more firm and robust definition or operationalization of what shared mental models of team members are than the one already proposed (Cannon-Bowers et al., 1993). Thus, a proposal for future research in this field would be to examine the nature of the mental models each team member has of each other, and to subsequently investigate whether they are shared in successful teams.

4.8.4 Future research

The proposed enhanced performance during uncertain high workload situations is at the core of the SMM approach. The next step might therefore be to investigate how team members perceive each others' behavior during uncertainty and high workload. One way of addressing this is to use facial recognition (Ekman & Friesen, 2003) and voice interpretation (Busso & Narayanan, 2007) in teams. It is proposed to investigate a possible shared awareness and ability to understand how own team members express emotions by facial expression and/or tone of voice (i.e., aggression caused by uncertainty) during high workload. This would make it possible to confirm and elaborate on the findings of this thesis. More importantly, however, this would have a potential to narrow down the present definition of a shared mental model of team members (i.e., knowledge, preferences, tendencies, abilities) that can be understood as a broad concept.

4.9 Implications

This thesis concludes that teams that have a shared mental model of team members display superior coordination and efficiency. This indicates that a shared mental model of team members plays an important role in team functioning and performance. The taxonomy (shared mental model of equipment, task, interaction, and team) proposed by Cannon-Bowers et al. (1993) has not been empirically validated (Salas 2009), and, more specifically, this thesis indicates that a shared mental model of team members is a vital contribution to team performance in expert or novice teams (Aim 1), distributed teams (Aim 2), and teams facing a novel situation (Aim 3). It also concludes that the concept is distinctly different from TMS. This thesis thereby confirms that a shared mental model of team members is an

important and independent concept with an added value in relation to team performance and efficiency.

4.9.1 Transactive memory systems

As a valid training strategy relating to TMS, Moreland et al. (1999) propose to simply state (give) each team member's individual knowledge and skills about the task ahead before the team is supposed to execute a task. While it is important in terms of enhancing performance, TMS is no more than a personification of ordinary task work or stating what expertise each member has. This line of thinking implies that team members understand each other as more or less skilful or knowledgeable in their own tasks, as tools, not a human beings. If the operating theater is used as an example, each team member is an expert (in his or her own task) and everybody knows this or else they would not be allowed to cut open or sedate the patient. But the findings of all these three studies question whether the coordination between team members is distorted by the fact that they do not know each other as human beings. The TMS perspective offers no solution besides better procedures and expertise, which, while important in itself, is not the entire answer. The TMS perspective underlines the importance, in relation to performing the overall task, of distributed knowledge of team members' skills and knowledge, but it does not add to performance when the workload is high, interdependence between roles is high, the situation is new, time is limited, and coordination is crucial. The cost of distributed knowledge may be that it hampers performance (Kozlowski & Ilgen 2006). Study 3 shows that a shared mental model of team members enables familiar teams to adapt to and learn a changing situation more quickly and more accurately. Thus, if an organization relies exclusively on distributed knowledge in accordance with the TMS perspective, teams will need more time

to obtain new knowledge and skills or to adapt to a new situation than teams with a shared mental model of team members.

4.9.2 Staffing

The findings in this thesis have implications for the rotation of personnel in expert teams. Mastery of rules, procedures, and skills is not enough for high performance by a team. Personnel need to develop a shared mental model of the other team members. Keeping teams intact during training and operations could be a way of achieving this.

Consequently, there are implications for staffing. The findings indicate a policy of promoting stable team membership. When the question of replacing a team member arises, one solution could be to choose between potential candidates based on their familiarity with the team in question. Training (e.g., a simulator) should also be conducted collectively as a team prior to actual performance, and not individually as is the case in many organizations.

4.9.3 Safety

It is obvious that it is almost impossible to avoid rotation. Unfamiliarity will therefore always be present to a greater or lesser extent. But the findings can contribute to a higher level of safety. This thesis indicates that organizations should avoid putting together unfamiliar teams in situations where a possible novel and critical situation may occur before they have had time to operate together for some time. If this is impossible, one recommendation would be to use the first occasion on which they are assembled to obtain vital information about each other and to spread it throughout the team. The findings indicate that a shared mental model of team members enhances a team's sensitivity to change (ref. the proposed Shipmate model). A crucial issue for a newly formed team to attend to would therefore seem to be to increase and share awareness of how each team

member reacts to a high workload and uncertainty. Second, knowing when to use closed loop communication will be crucial in relation to making sure that everybody understands and learns as a situation unfolds and develops. Similarly, each team member must understand and engage in behavior such as mutual performance monitoring, backup, and adaptability. By following the logic of Salas et al. (2005) and the findings of this thesis, a newly formed team will be able to learn more quickly and adapt better to high workload situations.

5. Conclusion

The scope of the present thesis was to investigate whether and how familiarity influences coordination, resilience, and efficiency in high performance teams in safety-critical organizations.

The findings from these three studies suggest that a shared mental model of team members is a mechanism that improves efficiency, resilience, and coordination in teams. Study 1 demonstrated that knowledge about team members (i.e. a shared mental model of the team members) adds to performance (implicit communication), efficiency (more hits), and resilience (lower HR) over and above the contribution of operational skills. Study 2 provided empirical evidence for the effect of a shared mental model of team members on distributed teams (i.e., global anticipation ratio, mission success). The findings from Study 3, suggest that a shared mental model of team members is transferable across tasks and that it enhances the effects of cross-training (i.e., more hits, closed loop, adaptability, and backup) and are distinctly different from the concept of transactive memory systems.

This thesis confirms shared mental models of team members as an important and independent construct with an added value in relation to team performance and efficiency. It

thereby expands previous knowledge, where the focus has been on equipment, tasks, and team interaction. The findings represent a contribution to and fill in a vital gap in the Shared Mental Model literature and they have implications for training, staffing, and safety issues for teams in safety-critical organizations.

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Shared Mental Models and Operational Effectiveness: Effects on Performance and Team Processes in Submarine Attack Teams

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In this study submarine attack crews were studied during simulated attack operations. The aim of the study was to test whether knowledge about team members had an effect on performance and team processes. The design controlled for skills of the different operators. Briefly, this study demonstrated that knowledge about team members adds to performance, over and above the contribution from operational skills. This was evident for number of hits on target, amount of information exchange, and the type of information changed to a more controlling type of interaction when the attack teams operated. In addition, the data indicated less physiological arousal in teams with known team members. We attributed this effect to the shared mental models of team members when the attack teams operated under a condition of known team members.

In military organizations critical decisions are made every day by teams of individuals who must coordinate their activities to achieve optimal effectiveness. Decisions are often made under the strain of time pressure, uncertainty, and threat of fatal consequences. Complex high-tech systems and equipment have been introduced to facilitate meeting the challenges of command and control in operational environments. One consequence of this increasingly complex man-machine interface is the need to carefully coordinate and synchronize input from individual team members. Submarines constitute a specialized environment, characterized by careful selection and training of personnel, highly complex technology, and a unique organizational culture (Schrier, 1989).

The ultimate challenge for a submarine crew is to function effectively when it must defend itself and attack enemy vessels. The submarine crew must be able to operate sophisticated equipment, integrate and exchange vital situational assessments, and execute actions against hostile contacts. Complex decisions must be made despite high workload, time pressure, uncertainty, and external threat. In addition salient stressors such as extremely limited work and living space, absence of day-night cues, confinement, isolation from all interactions with the external world, monotony in routine, and extended separation from family members constitute internal demands that submarine crews must master.

Research into team effectiveness has shown that effective teams can maintain performance even under conditions of high workload when communication opportunities are reduced (Kleiman & Serfaty, 1989). This has been labeled *implicit coordination* and depends on the teams' ability to draw on a common understanding of the task. Several authors have hypothesized that the mechanisms that allow this type of performance are shared mental models (SMMs; Cannon-Bowers, Salas, & Converse, 1993). Mental models involve mechanisms that humans use to describe the purpose and form of a system as well as its functioning in the present and future state (Rouse & Morris, 1986). Recently, researchers have emphasized the shared aspects of mental models in expert teams (Driskell & Salas, 1998). SMMs are assumed to enable the team members to predict task needs and actions of other team members. SMM offers an understanding of how team members coordinate behavior and choose different actions without explicit demands to coordinate (Cannon-Bowers & Salas, 1998).

The significance of SMMs and team coordination was emphasized in the research project Tactical Decision Making Under Stress (TADMUS), initiated after the *USS Vincennes* shot down an Iranian Airbus in 1988. TADMUS is an applied research program in U.S. Department of Defense parlance. Briefly, the goal of the TADMUS program was to develop training, simulation, decision support, and display principles that would help to mitigate the impact of stress on decision making (Cannon-Bowers & Salas, 1998). The program had a special emphasis on information processing and tactical decision making by shipboard command teams in air defense operations under conditions of short decision times, high operational

workload, and ambiguous incomplete information. One of the conclusions from the TADMUS project was the importance of swift and accurate coordination of information and behavior to successfully cope with the demands of emergency combat situations. This implies the need for team coordination strategies that must be implicit and automatic (Kleinman & Serfaty, 1989). SMMs constitute a core aspect of a successful coordination of information and behavior in expert teams (Cannon-Bowers et al., 1993). Highly effective operational teams have multiple SMMs of different types and levels of complexity that enhance effective coordination and problem solving. Following the TADMUS project, a number of studies have indicated that SMM may contribute to increased team effectiveness (Volpe, Cannon-Bowers, Salas, & Spector, 1996).

Another significant outcome from the TADMUS project was its emphasis on naturalistic decision making (NDM) to study aspects of real-life decision making. NDM implies a focus on the individual decision maker and the decision process. Lipshitz and Ben Shaul (1996) stated that a common view in the different NDM models is the focus on recognition of situations and reflection processes as a continuous shift between thought and action. The actual situation at hand is compared to similar situations, actions, and outcomes. The decision maker focuses not on a particular problem, but uses his or her experience with similar situations to implement different solutions to a series of problems. The dominating model in NDM is recognition primed decision making (RPD; Klein, 1998). In RPD an expert decision maker is believed to make use of previous experience and expertise to detect familiar elements and information patterns that can be used to assess the situation and solve the problem at hand.

The TADMUS project also focused on team performance. Team output gives a good indication of team efficiency. However, team performance is also related to information sharing, implicit and explicit coordination, and team-member exchange to solve operational tasks. In other words, team performance hinges on several underlying processes occurring in the team during task executing. The TADMUS project identified supporting behavior, team initiative, information exchange, and communication as significant aspects of team performance (Smith-Jentsch, Zeisig, Acton, & McPherson, 1998).

Research in the TADMUS project was largely performed on teams operating on antiair warfare in U.S. Navy vessels (Combat Information Centre Anti-Air Warfare teams [CiC team]). The environments these teams must master are characterized by dependence of team effort, proficiency of specific and shared tasks, and distinct roles among the team members (see Duncan et al., 1996, for an overview). Through in-depth interviews, observations, and comparison of errors between experts and novices in expert teams, a number of core characteristics of SMMs were extracted. These characteristics of the high-performing, high-SMM teams were summarized in six hypotheses. First the team members will be more accurate in predicting the actions of their teammates. Second, team members will require less

overt planning time to accomplish their mission. Third, teams will spend less time communicating. Fourth, the frequency of requests to repeat information or ask why a team member is taking some action will be reduced. Fifth, activities will be better sequenced, without discussion, because team members will know what and when to communicate to whom. Finally, teams will be more resilient to stress effects. Although stressors normally reduce the amount of information flow through the CiC, thereby limiting the tasks they can perform, an SMM will allow them to coordinate implicitly using an internal model of the team (Duncan et al., 1996, p. 185).

Orasanu (1990, cited in Stout, Cannon-Bowers, Salas, & Milanovich, 1999) showed that effective aircrews met difficult situations with an increased amount of unasked information. At the same time the captains reduced requests for information. Less effective teams showed the opposite information exchange strategies. In the TADMUS project, the information exchange strategies used by effective teams were interpreted as an index of the presence of an SMM in the team. It was stated that an SMM made it possible for the team to give each other vital information in a proper and orderly manner without the receiver asking for it. This enabled the team to focus on the essentials in the task they were facing. Thus the number of times unsolicited information was offered was seen as a vital confirmation of the presence of an SMM (Duncan et al., 1996).

An SMM is based on the assumption that the team must be able to simulate future events to create good and plausible explanations of future outcomes. To make this possible, some researchers have suggested that multiple shared models must be in action at the same time. Rouse and Morris (1986) suggested a taxonomy of mental models where every level or type of model has different importance depending on which task one wants to solve. Some problems are solved through one type of mental model, and other problems are solved by integrating several mental models.

The TADMUS study identified four levels or types of SMM: (a) the equipment, (b) task at hand, (c) team interaction, and (d) type of team (Cannon-Bowers et al., 1993). The SMMs related to the equipment, task, and team interaction are particularly emphasized in the TADMUS project. Some empirical studies have focused on the importance of knowledge about tasks, need of information, and the entire team (Duncan et al., 1996). The fourth type of SMM is related to knowledge about individual differences in competencies, skills, abilities, preferences, and tendencies (Cannon-Bowers & Salas, 1993). In spite of repeated statements of the importance of SMM of team members, few if any empirical studies of this factor have been published.

Thus, it is still an open issue if the SMM of the team influences team performance and resilience toward stress. This could lead to a hypothesis that both knowledge about how to act and knowledge about individual team members will influence team performance and effectiveness. One way to explore the effect of

an SMM of team members would be to study seasoned and well-established military teams, such as submarine attack crews. These teams are relatively small, well trained, and have a high degree of both operational skill and personal knowledge. To study team performance in a realistic and true-to-life operational setting, a full-scale submarine simulator provides several advantages. First, these simulators are exact copies of operational submarines. Second, simulators offer several options for monitoring performance and tracking individual performance over time.

The aim of this study was to investigate whether knowledge about individual team members would augment the effect of operational skills in predicting operational effectiveness in trained expert teams. More specifically, would an SMM of team members add to the performance of the team, over and above that explained by operational skills? We hypothesized that known team members—those familiar with one another—would show better performance and less cardiovascular reactivity to a simulated tactical situation compared to unknown team members.

METHOD

Participants

The total population of attack teams on the Norwegian ULA class submarines participated in the study. Twenty-four active duty officers composed four attack teams (six members per team). The officers were ranked from lieutenant commander to submarine lieutenant. The purpose of the attack team was to discover, classify, and eventually attack when operating against an imaginary or real enemy.

The participants' mean age was 26.3 years (range = 24–33) and experience ranged from 4 to 12 years. All members of the attack teams had worked together as teams for more than 3 months.

Outcome Variables

Interpositional knowledge. A questionnaire was developed to evaluate operational knowledge in the teams. The questionnaire was based on *interpositional knowledge* (IPK; Volpe et al., 1996). This IPK was developed in cooperation with expert personnel in the submarine service. IPK refers to the amount of knowledge a team member has of others, their own, and the team's tasks, roles and proper responses in different situations. The IPK was divided into two parts. Part 1 deals with the member's knowledge about different positions in the attack teams, their roles, tasks, responsibilities, and duties. Part 2 concerns knowledge about the system and what to do given different situations or system status. The IPK consisted of 17 items. Here is an example of an item: "The submarine has 8 torpedoes on the

way. Sonar reports compressed cavitation. What can and should each position in the attack team contribute in this situation?" The items were scored by expert raters and given scores from 1 to 3 based on the quality of their answers. Each person and subsequently each attack team was given a total score.

Performance variables. The attack teams and their reactions were observed during two different war games in a ULA-class tactical trainer. This simulator is a replica of the submarine central, the natural work space of an attack team. The simulator presented information about own speed and depth as well as all information available about other ships that would be present for the attack team on board a real ULA-class submarine. Computer software in the simulator recorded target solutions, firing range, hits, and course and speed of own and other vessels. Criteria-based evaluation of efficiency consisted of accuracy, latency, and mission effectiveness (Cannon-Bowers & Salas, 1998). Latency was measured as distance in meters to targets at the moment of firing and when it was actually hit. Mission effectiveness was the number of torpedoes hitting the target.

Process variables. Teamwork was evaluated on four dimensions: information exchange, communication, supporting behavior, and team initiative (based on ATOM; Smith-Jentsch et al., 1998).

Verbal processes were examined using video and audio tape recordings (Sony TCM-459V) and video (Sony Super Steady Shot Handycam video HI8 CCD TR2200E PAL; Serfaty, Entin, & Johnston, 1998). The number of statements was registered as total amount (statements per minute) and separated into three categories: request, transfer, and confirmation. Request and transfer were divided into information, actions, and problem solving (see Serfaty et al., 1998). In addition, statements confirming request and transfer were registered. Every statement was also registered with respect to the sender and the receiver.

Psychophysiological arousal. Cardiovascular responses were measured by using the Ambulatory Monitoring System V. 3. 6. (AMS; Klaver, de Geus, & de Vries, 1994). The cardiac responses were measured with 8 mm Ag/AgCl ECG electrodes (Cleartrode, Disposable Pregelled Electrodes, 150, Standard Silver). One electrode was placed over the jugular notch of the sternum, between the collarbones; another was placed 4 cm under the left ribs; and the third electrode was placed at the right lateral side between the two lower ribs. Heart rate was recorded as beats per minute (bpm).

Procedure

The study was conducted in the tactical submarine simulator for the ULA-class submarine situated at Haakonsværn Naval Base in Bergen, Norway. Norwegian

submarine crews use the tactical simulator as part of their normal enhancement training. The training program follows established demands and progression levels. All four attack teams were experienced users of the simulator at the time of this study. The head of submarine simulator training noted that the teams were equivalent in terms of performance. All four attack teams were rated as operational and approved by their superiors to be functioning on the highest level within 2 months prior to this study.

The two war game scenarios used in this study were consistent with the training program the attack teams normally go through and identical for all teams. The scenarios were event based (Johnston, Payne, & Smith-Jentsch, 1998), following the same design used in the studies of the TADMUS project. The war games were comprised of realistic stressors that gave the teams an increasing amount of workload and need for coordination. An experienced submarine expert evaluated both war games as realistic and consisting of the necessary stress level.

The participants completed the IPK questionnaire and were then equipped with the AMS before entering the simulator. Ten minutes before each war game started, the commanding officer got a description of the situation his team was supposed to handle. Each of the two war games lasted 50 min. One game was run with an intact original team (known team). The second run was performed with a second in command (2iC) from a different team (unknown team). The runs were administered in balanced order.

To look at stress reactivity, each run was separated into two distinct phases. The low-stress phase involved classification and calculations of bearings of opponents. The last 10 min (high-stress phase) involved a high-stress situation in which the attack teams had several torpedoes in the water and a manipulated problem with the torpedoes. The problem was identical for all teams and both conditions. In addition, the submarine was attacked by a hostile submarine.

Statistical Analyses

T tests for independent samples were used to test differences in IPK between the different attack teams. Analyses of performance during the simulator run were based on a repeated measures design (Ferguson, 1981), and *t* tests for dependent samples were used to test differences between the two conditions. Due to the specific predictions about the directions of the means, one-tailed tests were used (Ferguson, 1982). Analyses of physiological arousal were performed using a 2 (known vs. unknown teams) \times 2 (low-stress vs. high-stress phase) factorial design (Ferguson, 1982), using a two-way analysis of variance (ANOVA); both factors were treated as repeated measures. Preplanned simple effects and contrasts were performed by means of one-tailed *t* tests due to the clear predictions of the direction of the means (Wilcox, 1997).

RESULTS

Preconditions

No differences between the teams on IPK were found. Examination of the scores on the IPK of the four 2iC teams indicated that the four scores were almost identical.

Performance

Better performance measured as number of hits on target was found for known teams compared to unknown teams, $t(3) = 2.45, p < .05$. This can be seen in Figure 1, where known teams shows better performance than unknown teams.

The criteria-based measurement of performance also showed a nonsignificant tendency toward superior behavior of known teams. Although not significant, there was a trend for known teams to discover, classify, attack, and hit targets at a longer distance than unknown teams. Known teams fired their weapons at a mean distance of 59,657 m compared to a distance of 55,200 m for unknown teams. Known teams also hit their targets from longer distance ($M = 30,325$ m) compared to unknown teams ($M = 21,625$ m).

Team Processes

Rate of information exchange was significantly different between the two groups (see Figure 2). A higher volume of verbal statements occurred in the unknown team member group compared to the known group, $t(23) = 1.78, p < .05$.

When looking at types of information exchange, unknown teams showed higher frequencies of requests, $t(23) = 1.81, p < .05$. These requests were separated

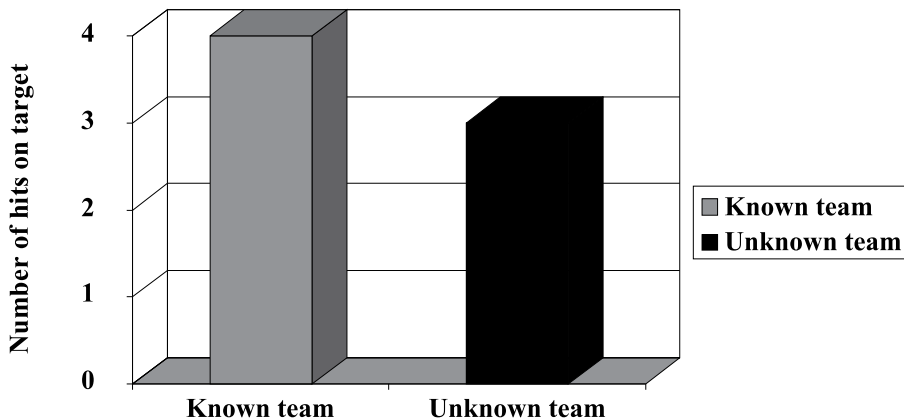


FIGURE 1 Mean number of hits on target for the unknown and the known team.

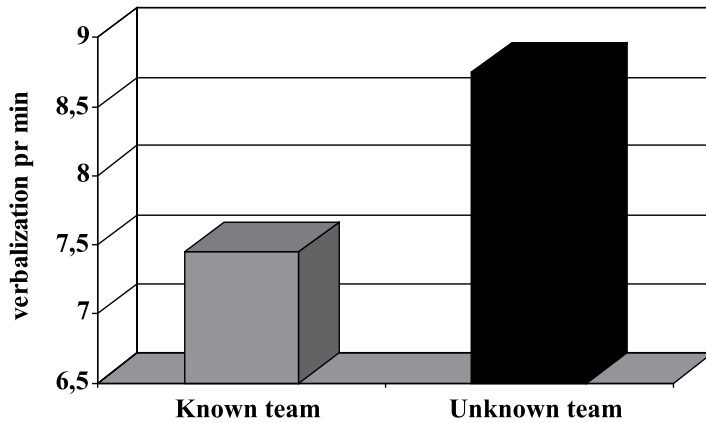


FIGURE 2 Mean number of verbalizations per minute.

into request for information, request for action, and request for solving a problem. Unknown teams showed higher frequencies on all these measures: $t(3) = 2.24, p < .05$; $t(3) = 3.36, p < .05$; and $t(3) = 2.35, p < .05$, respectively (see Figure 3).

An indication of a similar pattern was discovered for the analyses of transfer of information, transfer of action, and transfer of problem solving. There was a trend toward higher level of information transfer in the unknown group compared to the known group, $t(3) = 1.84, p < .08$ (one-tailed). There were also nonsignificant tendencies toward higher numbers of transfer of actions and problem solving for the unknown compared to the known teams.

When investigating which position contributed most to the increase in information exchange between the two conditions, a clear picture emerged. The command-

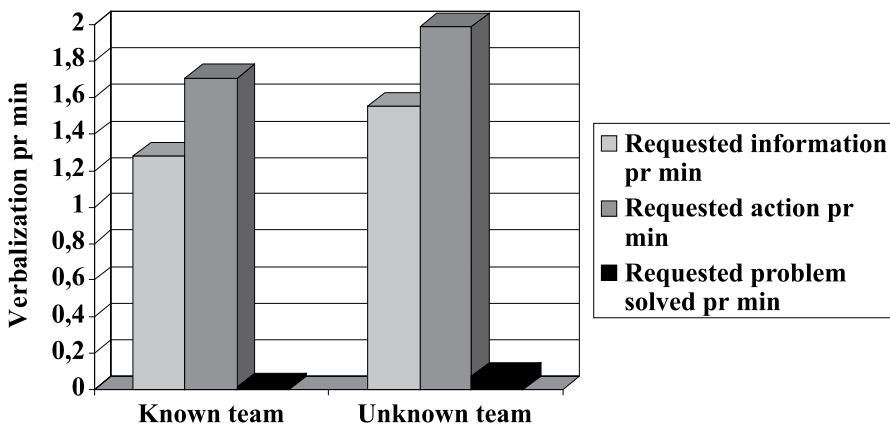


FIGURE 3 Mean number of verbalizations per minute in three information categories.

TABLE 1
Quantity of Information Exchange Separated for Different Positions
in the Attack Team

Information Exchange	Known 2iC		Unknown 2iC	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Commanding Officer–Crew–2iC				
Commanding officer–crew	2.90	0.47	3.25	0.82
Crew–commanding officer	2.30	0.41	2.63	1.03
Commanding officer–2iC*	1.12	0.75	1.63	0.65
2iC–commanding officer	1.04	0.60	1.52	0.61

Note. 2iC = second in command.

* $p < .05$.

ing officer verbalized significantly more to the unknown 2iC, $t(3) = 2.67, p < .05$, and the unknown 2iC's verbalization to the commanding officer tended to be higher compared to that of the known 2iC, $t(3) = 2.02, p < .07$. As can be seen in Table 1, all exchange of information in the triad, commanding officer—the rest of the crew—2iC, increased when the 2iC was unknown.

When positional information exchange was paired with type of information it showed that the commanding officer had significantly more requests to his unknown 2iC, $t(3) = 5.8, p < .05$, compared to the known 2iC. Unknown 2iCs made significantly more requests to the commanding officer compared to known 2iCs, $t(3) = 3.45, p < .05$. The categories of transfer and confirmation were significantly higher from unknown 2iC to commanding officer compared to known 2iC, $t(3) = 2.29, p < .05$ and $t(3) = 1.68, p < .05$ (one-tailed), respectively. No other significant effects were found.

Psychophysiological Arousal

Analyses of cardiovascular activity showed a borderline significant main effect of groups, $F(1, 22) = 3.62, p < .07$, with higher heart rate (HR) during the unknown team condition. Furthermore, a borderline main effect was found for the high-stress compared to the low-stress phase, resulting in higher HR in the high-stress phase, $F(1, 22) = 3.4, p < .07$.

Preplanned contrasts showed that the only significant difference found was an increase in HR from low-stress to high-stress phase in unknown teams ($p < .05$; see Figure 4).

DISCUSSION

This study showed superior performance in known submarine attack teams compared to unknown teams. When expert teams changed from an unknown 2iC to a

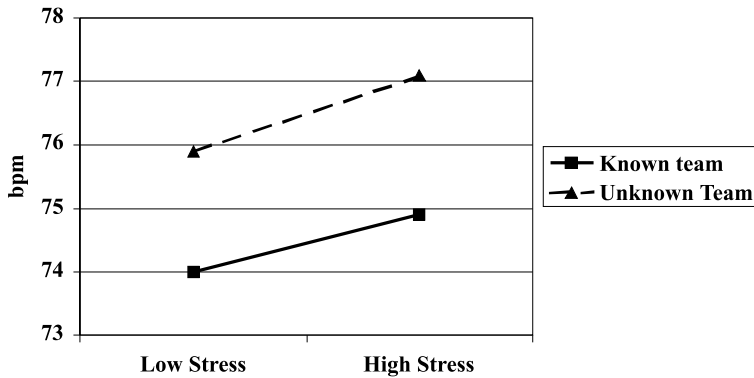


FIGURE 4 Heart rate, beats per minute (Bpm) for known and unknown teams, in high-stress and low-stress phases.

well-known 2iC, the number of torpedoes on target increased, information exchange decreased, and members showed less physiological stress reaction.

The main purpose of a submarine attack team is to sink enemy ships with torpedoes. This study showed that attack teams composed of well-known team members had more hits by torpedoes compared to teams with an unknown 2iC. This was found although the teams and the officers had equal knowledge and experience about the system they operated. It could be argued that teams with a well-known 2iC had an SMM that facilitated performance.

This expands previous knowledge about SMMs, where the focus has been on equipment, task, and team interaction (Cannon-Bowers et al., 1993). Performance data were further supported by a pattern of nonsignificant results that all pointed in the same direction. This was the case, for example, with the variable of distance to target when firing and correct classifications. Thus, disrupting the SMM of expert members, while keeping the level of knowledge of equipment, tasks, and roles constant, decreased performance on crucial aspects of the submarine's performance.

The analyses of team processes showed that the amount of information was higher in the unknown group. It has been assumed that well-developed SMMs enable teams to coordinate their activities in a way that increases their ability to cope with external threats (Kleinman & Serfaty, 1989). Through SMMs, team members have better capability to predict other team members' actions and need for information (Cannon-Bowers et al., 1993). Thus, the need for explicit coordination of information transfer will be lower in teams with a highly developed SMM (Kleinman & Serfaty, 1989). In this study, it could be argued that the increased exchange of information seen in the unknown team was an indication of a lack of an SMM of the team members. This argument could be valid because all teams had similar operational SMMs (equipment, task, and roles).

The significance of an SMM of team members also became evident in the analyses of types of information exchanged. In this study, the types of information were categorized in two major categories: requests and transfers. These categories were further divided into information (need to know), actions (demanding the execution of an order), and solving a problem (need something to be done; Serfaty et al., 1998). The results of this study showed higher levels of all measures of request and a borderline difference in transfer. The unknown attack teams exchanged information to a greater degree and the information was more controlling. This was a change in coordination strategy from a more implicit strategy in the known attack teams, to an explicit controlling strategy when the teams changed from a well-known 2iC to an unknown 2iC. The substance of the statements used in the explicit strategy was dominated by a need for increased control over the team members. Significantly more requests and transfers give a clear indication that unknown teams needed to coordinate their activity verbally through checking that something was done in a proper manner. This shows that teams without an SMM of the team members coordinate their activity differently and less efficiently than those with such an SMM. This is in line with Urban, Bowers, Monday, and Morgan (1995), who claimed in a study of hierarchical and nonhierarchical teams that efficient teams are characterized by minimized use of question–answer sequences. Our study also showed that teams with an SMM of the team members showed reduced question–answer sequences.

Further analyses of the information exchange within the attack teams revealed an interesting pattern. This pattern showed that more information was exchanged between the commanding officer and the 2iC in the unknown teams. There was also more information exchange from the 2iC to the commanding officer in the unknown teams. This gives further support to the notion that the information structure in the unknown team was distorted, and it was characterized by the need for the commanding officer and the 2iC to coordinate and control each orders needs, intentions, and actions. The commanding officer and the 2iC were the team members that made most of the decisions. Thus, the lack of an SMM among team members results in an increase in the need for explicit coordination among the team's senior decision makers.

One aspect of the TADMUS project was the extensive use of randomly composed teams of experts (Duncan et al., 1996). Expert teams are not just an aggregate of highly skilled operators working together. It could be argued that an expert team also consists of members with extensive knowledge about each team member and that they have trained and served together over a prolonged period of time. This study supports the importance of this notion and shows that not only will expert teams with an SMM of the team members show improved performance, but also show increased stress resilience. This is based on the findings that only the unknown teams showed a significant increase in HR from low-intensity to high-intensity scenarios. HR is often used as a measure of a stress response (Kudielka,

Buske-Kirschbaum, Hellhammer, & Kirschbaum, 2004) and Schommer, Hellhammer, and Kirschbaum (2004) showed a decrease in HR during the stress response over time. As can be seen from this study, the groups without an SMM of the team members showed an increase in HR over time as the workload increased, but only when they were exposed to a condition with an unknown 2iC.

The research described in the TADMUS project was based on studies performed on participants recruited from the U.S. Navy or U.S. colleges (Cannon-Bowers & Salas, 1998). Although there are cultural differences between the U.S. Navy and the Norwegian Navy, the theoretical framework of SMMs appears quite applicable to teamwork in the Norwegian Navy.

In summary, this study demonstrated that knowledge about team members (i.e., SMM of the team members) adds to performance over and above the contribution of operational skills. This was evident for performance evaluations like number of hits on target, as well as team processes like information exchange. The need for controlling types of information was higher when teams changed from a known 2iC to an unknown 2iC. Stress reactivity, measured by HR, increased from a low-stress to a high-stress situation only in the teams without a highly developed SMM of the team members. This study has implications for training and rotation of personnel in expert teams. Mastery of rules, procedures, and skills is not enough for high performance in a crew. Personnel need to develop an SMM of the other team members. Keeping crews intact during training and operations could do this. Rotation of personnel among different vessels and expert teams may result in decreased efficiency. Although the effects of known team members add to the performance of knowledge in expert teams, well-known teams could be more negatively affected by negative group processes like groupthink and other socially induced biases (Janis, 1972).

In addition, a need for further studies on the effects of SMMs of team members is called for. This is especially true because there is an increased emphasis on networkcentric warfare, where different expert teams must coordinate their activities. These teams are often located apart and SMMs of team members could influence the performance of these teams.

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Running head: SHARED MENTAL MODELS IN DISTRIBUTED TEAMS

Do shared mental models of team members influence performance in distributed teams?

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Abstract

The aim of the present study was to test whether the Shared Mental Models of team members have an effect on team performance, communication and physical arousal when distributed teams are forced to coordinate their activities in pursuit of a common goal. A sample (N = 15) of newly formed navy teams was compared with a sample (N = 13) of seasoned navy teams who had received extensive training as a team. All teams were exposed to a novel naval scenario they had no previous experience from or knowledge about, i.e. close support of a civilian tanker operating in littoral waters in a naval simulator (tactical trainer). The results showed that familiar teams displayed higher performance levels, faster reaction times, more accuracy, and greater mission success compared to unfamiliar teams. A significant shift in communication strategy was observed between unfamiliar and familiar teams, in that the latter increased “push” of information during times of high workload. From baseline to low workload, the familiar teams increased HR significantly, while the unfamiliar teams showed no differences. Recovery of hearth rate was only found in the familiar teams. Implications for team training and shared mental models of team members in the familiar teams are discussed.

Do shared mental models of team members influence performance in distributed teams?

In safety critical organisations (SCOs) such as the military, operational decisions are most often made by designated individuals who are dependent on timely information and coordination with fellow team members in order to achieve desired outcomes (Cebrowski & Garstka, 1998). Decisions are often made under the strain of time pressure, uncertainty, and threat of fatal consequences. Technological developments in information-communication technology and command and control systems add to the complexity even if the purpose is to facilitate the challenges of command and control in operational environments. One consequence of this increasingly complex man- machine interface is the need to carefully coordinate and synchronize between teams separated physically, so called distributed teams. In addition, most SCOs such as the military, rotate personnel through 24/7 shift-work schedule which makes it difficult to maintain stable person/role expectations in the operational teams over time.

This lack of face-to-face interaction and familiarity with fellow team members are two major issues that might affect team coordination, communication, efficiency and outcomes. To examine the consequences of familiarity between teams this study investigates the differences in outcomes (communication, stress and efficiency) between familiar and unfamiliar teams who are forced to coordinate their activities towards a shared goal in a distributed team setting (i.e. separated by geographic distance).

A recurring question in team research has been to identify factors that constitute good teamwork and how excellence in teamwork is manifested in actual behaviour (Koslowski & Ilgen, 2006). One promising theoretical perspective that has attracted considerable attention in recent years is the Shared Mental Model approach (SMM; Cannon-Bowers & Salas, 2001). Salas, Sims, and Burke (2005) proposed five core components that promote team effectiveness. These components include team leadership, mutual performance monitoring,

backup behaviour, adaptability and team orientation. Salas et al. (2005) suggest SMM are the supporting and coordinating mechanism that melds together the value of each of the five. This stems from the notion that teams working in high-intensity environments coordinate their activities efficiently when the team members are able to anticipate and predict each others' needs and are able to identify changes in the team, task or teammates and adjusting strategy as needed. To make this possible, the team members must have similar or shared mental models of the system with which they are interacting. If the mental models are shared, then this allows team members to draw on their own mental models as the basis for choosing actions that are consistent and coordinated with other team members. In high performing teams this is done even without coordination or actions being explicitly required. According to the theoretical framework, SMMs are proposed to explain why high performance teams often coordinate their behaviour without explicit communication (Cannon-Bowers, Salas & Converse, 1993). Duncan, Rouse, Johnston, Cannon-Bowers, Salas, & Burns (1996) suggest that teams with shared mental models also will be more resilient to stress effects, due to their redundancy and ability to supply, substitute, or select information based on a superior understanding of team-role needs.

Research into team effectiveness has shown that some teams can maintain performance over time under conditions of high workload even when opportunities to communication are limited (Kleiman & Serfaty, 1989). Wittenbaum, Vaughan & Stasser (1998) argue that coordination is an essential component of successful team performance. However, they suggest that successful groups coordinate their efforts by communicating implicitly. To coordinate implicitly saves time but may also increase the possibility of failure (Wittenbaum et.al. 1998). It is therefore suggested that successful implicit coordination rests on the team's ability to share a common understanding of the situation, which constitutes a core element of the SMM approach (Cannon-Bowers et.al. 1993). More specifically, in order to coordinate

their activity, teams with SMMs will not only reduce the amount of communication they use (implicitly), they will also change their communication patterns from pulling (requesting) to pushing (presenting) information when the workload increases. According to Entin and Serfaty (1999), this shift in communication pattern is reflected in the ratio that results when transfers are divided by requests for information ('the global anticipation ratio'). An increase in 'the global anticipation ratio' is seen to represent a strong indication of SMM (Entin & Serfaty, 1999). As an example, Orasanu (1990) reported that superior teams increasing the push of information from team members and reducing requests for information from the team leader during high workload periods.

Cannon-Bowers, Tannenbaum, Salas & Volpe (1995) propose four types of SMMs. In addition to SMM of equipment, task and interaction, an SMM of the team members (team) is suggested. This model contains information that is specific to the team and constitutes an SMM of the individual team members' knowledge, skills, attitudes, preferences, and tendencies. SMMs related to technology/equipment, the task at hand and team interaction have frequently been emphasised in previous research (Stout, Cannon-Bowers, Salas & Milanovich, 1999).

In spite of repeated statements concerning the importance of the fourth type, SMM of team members, few empirical studies of this factor have been published to date. This is surprising and indicates a vital gap in the knowledge base, given the widespread occurrence of work teams that are unfamiliar with each other even in SCOs. One notable exception is Woody, Mckinney, Barker and Clothier (1994) who analyzed 74 major airline accidents and found that newly formed (unknown) crews flew more safely than fixed (known) crews. On the other hand, Kanki and Foushee (1989) reported that if the captain and first officer had recently flown together, they committed fewer errors and engaged in more open communication with respect to information exchange. Furthermore, a study of submarine

attack teams showed that familiar crews performed better, showed more efficient communication patterns and had lower cardiovascular activity during high workload situations than a crew with one unfamiliar crewmember (Espevik, Johnson, Eid, & Thayer, 2006). This result emerged after controlling for knowledge about tasks and equipment, as well as the roles and responsibilities of the team (i.e. the three other types proposed SMM). Although findings from aviation and maritime industries emphasise the importance of shared mental models of team members, the results so far are not conclusive. The present study provides new information by exploring the limits of shared mental models of team members in familiar and unfamiliar distributed teams facing an operational task.

The lack of face-to-face interaction in distributed teams results in new challenges in terms of team coordination and communication that could influence team efficiency and outcomes. It is therefore necessary to generate more empirical knowledge about mechanisms that influence coordination and performance outcomes in distributed teams. Recent research suggests that face to face teams and distributed teams manifest communication and other teamwork processes differently (Priest, Stagl, Klein, Salas & Burke, 2006). To our knowledge, the present study is unique in that both face-to-face contacts within the teams and distributed team processes are investigated in the same study.

On the basis of emerging, although limited, research on teams in SCOs, it is reasonable to assume that knowledge about other team members will influence team processes and outcome in high workload situations. From previous research it is reasonable to assume that teams with SMM of each other will coordinate their activities differently (better), showing more teamwork behaviour made possible by their SMM of each other (e.g. backup and monitoring, Salas et al., 2005). The result is enhanced performance (e.g. fewer errors, mission success, more accuracy, latency) (Stout, Cannon-Bowers, Salas, & Milanovich, 1999).

From the above discussion, we hypothesised that familiar teams would show enhanced performance and better coordinating skills compared to unfamiliar teams. More specifically, in the present study we predict that familiar, compared to the unfamiliar teams will:

H1: *show higher mission success measured as reaction time as well as accuracy, both in the low and high workload scenario.*

A second prediction is that familiar teams will be better in identifying changes in the team, task or team mates and eventually anticipate team members future actions (Salas et.al, 2005). This will enable familiar teams to adjust strategies as needed and we expected familiar teams to:

H2: *communicate less during a high workload situation compared to unfamiliar teams (Espevik et al., 2006).*

H3: *enhance global anticipation ratio (more “push” of information) from low to high workload condition (Entin & Serfaty, 1999),*

H4: *have a higher rate of monitoring behaviour (Salas et.al. 2005).*

It was also predicted that the familiar teams will be less involved in:

H5: *task-irrelevant communication (Kanki & Foushee, 1989).*

Although stressors (e.g. physical distance, workload) may reduce the amount of information flow, and teammembers may become more limited as to the tasks they can perform we expected familiar teams to be able to coordinate more implicitly when needed because of their knowledge of the teammembers. We expected this to put lower cognitive load on familiar teams compared unfamiliar, thus we anticipated that familiar teams would be

H6: *less aroused (i.e. lower heart rate) during high workload condition.*

Methods

Subjects

A total of 108 cadets from the Royal Norwegian Naval Academy (mean age 24, 2 years, range 21-32) were recruited to the present study. The subjects' military service background ranged from two to 10 years, 9.2% were female officers, and the subjects' ranks ranged from Sub-Lieutenant to Lieutenant. Although the training was mandatory, participation in the research project was voluntary and seven declined to take part in the study, leaving a total of 101 subjects that had their heart rate measured. Due to equipment failure there were 84 subjects who completed the full video recording. None of the subjects had previous experience of the simulator or other forms of simulator training in general.

Procedure

Subjects were categorised as members of familiar or unfamiliar teams. To be included in the familiar teams group, the team members had to have completed the first year of basic officer training together at the Norwegian Naval Academy. During this first year, the cadets are organised into permanent teams of six persons that stay together for eight months. During this period, the fixed teams share as a team the hardship of a number of extensive exercises as well as a nine-week period on a tall-masted ship on a transatlantic crossing. This results in extended knowledge about individual differences in competencies, skills, abilities, preferences and tendencies (Cannon-Bowers et al., 1993). The present study included 13 familiar teams.

The other category, the unfamiliar teams group, consisted of cadets from another cohort at the Royal Norwegian Naval Academy. The participants had no previous history together, either as individuals or as members of other teams, except for a one-week getting acquainted period at the start of the semester. To control for any learning effects of being a cadet at the Royal Norwegian Naval Academy, 8 teams of third-year cadets were formed. They had no

experience of each other as members of the same team during their own first year nor any history of attending the same classes during the second or third year. No differences between third-year cadets and the group that had just started were found on any measures. Hence, in the following, they were treated as one category, unfamiliar teams. Together, these subjects formed a total of 15 unfamiliar teams.

The study was carried out in a high fidelity simulator that is a replica of a naval operations room. Expert instructors from the Royal Norwegian Navy developed the scenario used in the present study. The scenario was event-based (Johnston, Payne & Smith-Jentsch, 1998, Espevik et. al., 2006), with four events in the low and four events in the high workload condition.

During the simulation, each of the original six-member teams was randomly divided into two three-member teams. The two (sub) teams then manned two different simulator cubicles (i.e. naval vessels) with a common goal of providing close protection to an oil tanker in littoral waters. The tanker was sailing to an oil refinery. The two (sub) teams/vessels were faced with the challenge of coordinating their activities and controlling the area close to the tanker. This involved surveillance and coordination of air and surface traffic in the area and subsequent military actions to protect the tanker and prevent hostile actions. The scenario was designed to include realistic stressors that gave the teams an increasing workload and a greater need for coordination and communication both within and between the teams.

In order to look at the effects of workload, the scenario was separated into two phases. The low workload phase lasted for 40 minutes and included four distinct events. The first phase involved surveillance of two vessels at long distance, followed by two vessels at close range, which required active communication to establish their identity and mission. The next 15 minutes (the high workload phase) also consisted of four distinct events, including an enemy warship, an unknown helicopter, equipment failure on the team's own ship and a

merchant vessel moving in too close to the oil tanker. The high workload phase took place when the oil tanker was in littoral waters, which restricted navigation and gave the naval protection teams little time to react. All the teams were presented with the same scenarios.

Team members were randomly assigned to one of two identical vessels and randomly assigned to three different positions in the operations room. Those positions were electro-optical surveillance and firing, commanding officer and overall picture.

The study started with a 30-minute briefing on the scenario, consisting of setting, order, intelligence information, the outline of the simulator and function of the equipment. This was followed by 30 minutes' on-hands training on the designated position in the simulator. After this, the personnel were equipped with ambulatory cardiac recording equipment before entering a 30-minute planning phase. Baseline Heart Rate was recorded for five minutes before entering the simulator. Continuous recordings were obtained during the scenario in the simulator. After completion, another five minutes was recorded during recovery. All recordings were obtained while the subjects were seated.

Two paid, independent raters categorised the information exchange in the teams. They were unfamiliar with the SMM theory, the scenario and experimental set-up. Both raters were introduced to and trained in the use of the Noldus program (Noldus, Trienes, Hendriksen, Jansen, & Jansen, 1991, 2000). The two raters established a common understanding of the categories by rating several videos together before the actual recording of the videos. The inter-rater reliability showed an intra-class correlation of .98 ($p < .00$). This was based on the average of the two raters' evaluations of three teams.

Instruments

Performance. Performance measures were based on transcripts from the simulator, video and voice recording. They were examined using criteria-based evaluation of efficiency, consisting of mission success, accuracy and latency (Cannon-Bowers & Salas, 1997).

Insert table 1

Mission success was defined according to the specific objective of the mission – i.e. to avoid or minimise hostile threat to the oil tanker. To assess this outcome measure, a scoring system was developed, whereby high scores indicated a high level of mission success (i.e. safe escort of the oil tanker). For each event except for weapon malfunction, which had its own estimate, performance scores were defined and accumulated as follows (maximum of three points):

a) Positioning own vessel between the threat and oil tanker (one point), b) establishing voice contact with the threat (one point), c) own weapon system in a ready status pointing towards the threat (one point).

One event, weapon malfunctioning, was treated separately and assigned an accumulated score of maximum four points as follows: a) ready to fire (one point), b) firing warning shot across the bow to stop the enemy vessel (one point), c) firing after the lookout had reported activity around the canon on the enemy ship (one point), and d) transferring information about the incident to the other vessel (one point).

Each of the eight events in the scenario was measured for accuracy. The accuracy score was computed as a composite score based on observation (observed = one point / not observed = zero points) of the following operational factors: discovered, monitored, made verbal contact, evaluated, made plans for handling the situation, informed (friendly vessel), and classification (the identity of the contact). Each team could score a total of 54 points, 28 during the low workload period and 28 during the high workload period.

Latency was measured as an accumulated score based on reaction times (in seconds). To obtain this accumulated score, each of the eight events in the scenario was scored for how quickly the team responded. Firstly, the latency to sharing the information within the team, secondly the time taken to make an assessment (based on this information) and, thirdly, how rapidly they made a decision about action. Since these three responses are sequential in nature, three points were earned if the response was performed within a timeframe of 10 seconds from the previous response (i.e. evaluating after sharing and decisions after evaluation). Two points were earned if the response was performed within 10 to 20 seconds, one point between 20 and 30 seconds and zero points if over 30 seconds. Within each of these responses – from sharing, evaluation and action – a total of nine points was attainable for each event.

Team processes. The number of statements was registered as the total number of statements per minute. In line with Entin, Johnston & Serfaty (1998), each statement was classified as a request for information, a transfer of information, an action or problem solving.

The global anticipation ratio was calculated by dividing the total number of transfers by the total number of requests (Entin & Serfaty, 1999). The index was computed within teams as well as between teams separated physically. Thus, a change (increase) in the global anticipation ratio from low to high workload may be taken as a strong indication of SMMs of team members (Entin & Serfaty, 1999).

The non-verbal behaviour was examined on the basis of the video and labelled monitoring behaviour (Salas et.al., 2005). The number of glances at other positions, equipment and other team members was registered. This resulted in a quantification of monitoring behaviour, thus serving as an indicator of SMMs of team members.

Physiological arousal. Cardiovascular responses were measured using an Ambulatory Monitoring System V. 3. 6. (AMS, Klaver, de Geus & de Vries, 1994). The Inter Beat Intervals were measured using 8 mm Ag/AgCl ECG electrodes (Cleartrode, Disposable Pregelled Electrodes, 150, Standard Silver). One electrode was placed over the jugular notch of the sternum, between the collarbones, another was placed four centimetres under the left ribs, and the third electrode was placed on the right lateral side between the two lower ribs. Heart rate (HR) was recorded as beats per minute (bpm).

Design and statistics

The study was carried out using a 2 (Familiar teams vs. Unfamiliar teams) x 2 (high vs. low workload phase) factorial design. Analyses of HR were performed as a manipulation check for the different phases of the simulation. Thus, a 2 (Familiar teams vs. Unfamiliar teams) x 4 (baseline vs. low workload vs. high workload vs. recovery) factorial design (Ferguson, 1982) was used. The first factor was treated as a between-group factor and the second factor as a within-group factor in all analyses. When hypotheses based on specific predictions of the directions of the means were tested, non-significant interaction effects were followed up. (See Wilcox, 1987 for a discussion.) Stoline and Spjotvoll HSD tests for unequal sample sizes were used as post-hoc tests.

Results

Performance scores

 Insert table 2

A main effect of group was found for mission success, $F(1, 26) = 22.96, p < .001$, with the familiar teams scoring higher than the unfamiliar teams. A main effect of workload was

found, with higher scores for mission success in the high workload condition $F(1, 26) = 21.57, p < .001$.

A main effect of factor group was also found on accuracy, with familiar teams scoring higher than the unfamiliar teams, $F(1,26) = 22.83, p < .001$. A main effect of workload was also found, with higher accuracy in the high workload condition, $F(1, 26) = 12.97, p < .001$. A borderline significant interaction $F(1, 26) = 3.86, p < .06$ was followed up using the Stoline and Spjotvoll HSD test. The result revealed higher accuracy in the familiar teams compared with the unfamiliar teams in both low and high workload conditions (both $p < .01$). However, the unfamiliar teams improved its performance from low to high workload ($p < .001$), while the familiar teams showed higher scores in both conditions.

For latency, a main effect of groups was found $F(1, 26) = 129.13$, with the familiar teams showing a higher (shorter reaction times) latency score than the unfamiliar teams. No other comparisons reached significance level.

Team processes within each vessel

Amount of information exchange. Results from the analyses of information exchange within each vessel showed no differences between groups or conditions.

Global Anticipation ratio. A main effect of workload condition was found, $F(1, 26) = 5.04, p < .03$. This was caused by a higher anticipation of information ratio (more push) during the high stress condition. Furthermore, a borderline interaction of group by workload condition, $F(1, 26) = 3.6, p < .07$, was followed up. The results only showed an increase in anticipation ratio only for the familiar teams ($p < .04$) from low to high workload condition.

 Insert figure 1

Non-task-relevant information. A main effect of group was found, with unfamiliar teams relaying more irrelevant information than familiar teams, $F(1, 26) = 9.23, p < .05$. An interaction of group by workload condition reached significance level, $F(1, 26) = 4.1, p < .05$. HSD tests only revealed an increase in irrelevant information relay for unfamiliar teams ($p < .05$) from low to high workload condition. The unfamiliar teams also had higher numbers of irrelevant information relays during the high workload condition compared to the familiar teams ($p < .01$).

Monitoring behaviour. A main effect of workload condition was found, with reduced monitoring during high compared to low workload condition, $F(1, 26) = 7.19, p < .01$. Because of the specific hypothesis proposed, a non-significant interaction was followed up. A decrease in monitoring behaviour from low to high stress condition was found only for the unfamiliar teams ($p < .03$).

Team processes between the cooperating vessels

Amount of information exchange. Results from the analyses of information exchange between vessels showed a main effect of workload condition, $F(1, 26) = 10.4, p < .003$. This was caused by increased communication between vessels during the high workload condition. The non-significant interaction of groups by workload condition was followed up. This was done because of the hypothesised direction of change. The results revealed an increase in communication for familiar teams from low to high workload condition ($p < .05$). No difference was found for unfamiliar teams.

Global Anticipation ratio. A main effect of workload condition was found, $F(1, 26) = 52.146, p < .01$. This was caused by a higher Global anticipation ratio (more push) during the high workload condition. There were no differences between the familiar teams and unfamiliar teams.

Insert figure 2

Since the global anticipation ratio consists of several different processes, the findings were followed up by looking at differences in specific communication patterns

Information transfer. A main effect of groups was found, with familiar teams showing higher numbers of transfers than unfamiliar teams, $F(1,26) = 12.61, p < .001$. A main effect of workload condition revealed higher numbers of transfers during the high workload condition compared with the low workload condition, $F(1, 26) = 93.28, p < .001$. Furthermore, the interaction of groups by workload condition reached significance level, $F(1, 26) = 8.83, p < .001$. A Stoline and Spjotvoll HSD test showed that both groups enhanced their transfer scores from low to high workload condition (both p 's $< .001$). In addition, a group difference was found for the high workload condition with the familiar teams showing higher numbers of transfers compared to the unfamiliar teams ($p < .001$). No such difference occurred during the low workload condition.

Physiological arousal

Analyses of cardiovascular activity showed a main effect of workload condition, $F(3,297) = 13.31, p < .01$. A follow-up HSD test revealed an increase in HR from baseline to low workload period (first 10 min; $p < .001$) and further to the high workload period (last 15 minutes; $p < .001$). The recovery phase was also significantly higher than the baseline ($p < .001$). Furthermore, an interaction of groups by condition was found, $F(3,294) = 6.20, p < .01$. (The trajectories of mean HR responses over time in the two groups are shown in Figure 4.) The Stoline and Spjotvoll post-hoc test revealed that familiar teams increased HR significantly from baseline to the low ($p < .001$) and high workload periods ($p < .001$). There was no difference between baseline and recovery. For unfamiliar teams, the pattern was

different, with no differences between baseline and low workload, followed by a significant increase in the high workload phase ($p < 0.001$). In addition, no recovery was found, since unfamiliar teams had higher recovery HR compared with their baseline ($p < .001$).

 Insert figure 3

Discussion

In this simulated naval threat scenario, familiar teams outperformed unfamiliar teams on all outcome measures, higher mission success, higher accuracy and shorter response latencies. Statements per minute showed no differences between familiar and unfamiliar. Familiar teams changed its global anticipation ratio from low to high workload. Only unfamiliar teams decreased its monitoring behaviour from low to high workload and were more involved in task-irrelevant communication. Investigating the communication between the vessels, contrary to what we expected only familiar teams increased statements per minute from low to high workload. There were no differences in global anticipation ratio, even though the overall effect was an increase from low to high workload. But only familiar teams increased transfer from low to high workload. The familiar teams were more aroused (heart rate per minute) during low workload. During recovery only familiar teams decreased arousal.

We argue that the mechanism that explains these findings could be a more developed SMM of the team members in the familiar teams compared to the unfamiliar teams (Cannon-Bowers et.al. 1993). It also both replicates and extends the findings of Espevik et al. (2006). Espevik et al (2006) studied teams of experts, submarine crews, and they were able to show significantly more torpedo hits when the team was intact compared with situations where the team included one new member(replaced one “old” teammember).

The present study indicates that, if a team faces a totally new and unfamiliar situation (the tactical trainer), familiar teams outperforms unfamiliar teams. We suggest that these differences in performance are caused by a better communication/coordination process enabled by SMMs of team members in the familiar teams. Orasanu (1990) showed that airline pilots used low workload periods to develop SMM, which in turn made it possible to employ different communication strategies during high workload, thus enabling them to communicate more implicitly. In our view, the change of communication strategy that takes place within the familiar teams when they go from the low to the high workload phase is a strong indication of SMMs in action. Entin and Serfaty (1999) suggest that an increase in global anticipation rate (total transfers/total requests) is a strong indication that a team transforms its communication from explicit to implicit and that this change shows that SMMs are operating. Unfamiliar teams met the high workload without any change of communication strategy, which means that there was no difference in terms of transfers of and requests for information. On the other hand, familiar teams altered significantly from pulling (request) to pushing (transfer) information when in the high workload condition.

Another indication of SMM is proposed by Salas et.al. (2005). They suggested a strong connection between monitoring behaviour and SMM. They proposed that mutual performance monitoring only occurs in teams with adequate SMMs. Thus, the decrease in monitoring behaviour shown in the unfamiliar teams indicate a lack of an adequate SMM of team members and thereby that team members engage less in behaviour such as identifying mistakes or providing feedback and helping team members with a heavier workload than themselves. Eventually, this may have a detrimental effect on the effectiveness of the team. We argue that when unfamiliar teams were more involved in task-irrelevant communication, which increased during the high workload condition they to lesser degree were able to

understand that other team members were uncertain and needed help (Kanki & Foushee, 1989).

Although differences were not prevalent in relation to communication pattern between the two vessels (distributed teams), there were indications that familiar teams engaged in more implicit communication. This argument is based on an increase in the frequency of transfers of information from low to high workload condition found in this group. This is especially interesting since unfamiliar teams showed no such increase. This may indicate that familiar teams verged on being more implicit in their communication. This further strengthens the impact of SMMs of team members, also in distributed teams.

Contrary to what we expected, there were no differences in the amount of communication within each vessel, neither during low nor high workload. However, between vessels the familiar teams increased statements per minute from low to high workload compared with unfamiliar teams. One explanation could be that familiar teams adjusted their communication based on what Salas et. al. (2005) describe as an ability to identify changes in the team, task or teammates and implicitly adjust strategies as needed. Hence when the situation is new, the team members are not subject matter experts but hold shared mental models of each others then they will be able to sense that other team members are struggling and need help (e.g. information). If this is correct then it implies that novices on the task use their familiarity to enhance communication, be more implicit by pushing information (more transfer), to keep every team member up to speed with a new and inexperienced situation. It is also possible that familiar teams monitored each other more efficiently through verbal clues, like tone of voice indicating that help was needed and acted accordingly. The last argument is supported by the differences in transfer, when familiar teams initiated more unsolicited communications during high workload compared to unfamiliar teams. Thus familiar teams may have been more able to anticipate that the other teams (vessel) needed to share

information or something done and acted accordingly. It may indicate a learning strategy that is adaptable to a new situation when the team consists of task novices and only connected through verbal clues. To our view additional studies are called for to address this.

To our knowledge, there are no studies besides Espevik et al. (2006) of SMMs of team members where physiological recordings have been applied. Although cardiovascular responses were used as a manipulation check for the high vs. low workload conditions, some aspects are worth mentioning. We anticipated that unfamiliar teams would be more physiologically aroused than familiar teams when facing a high workload condition, as shown in the Espevik et al. (2006) study. Contrary to our hypothesis, no differences were found. However, looking at HR patterns over all conditions, differences emerged between the two groups. From baseline to low workload, the familiar teams increased HR significantly, while the unfamiliar teams showed no differences. One explanation could be that having SMMs of teammates enabled familiar teams to detect deviancies, shortcomings and uncertainty among other teammembers. They thus focused on rectifying these matters and subsequently put more effort into understanding and coping with the situation even though there was no immediate need for action. This, in turn, could result in the immediate increase in HR observed in the present study. Again, this could also be related to familiar teams performing better than unfamiliar teams.

Recovery of HR was only found in the familiar teams, indicating higher adaptability of the organism to environmental demands. This ability to regulate physiological activity is associated with Situational Awareness (SA). For instance, Saus, Johnsen, Eid, Riisem, Andersen and Thayer (2006) reported an association between Heart Rate Variability (HRV) and SA measured during the recovery phase. Furthermore, Saus et al. (submitted) have showed that naval cadets who show a high degree of SA in a navigation simulator were also able to modulate their internal environment in order to match external demands. This was

found with suppression of HRV from baseline to simulation and a recovery effect. In contrast, the low SA group showed no differentiation of their HRV from rest to simulation and recovery.

There are other possible explanations for why familiar teams outperformed unfamiliar teams. One factor that could have influenced the results was a possible learning effect of being a cadet for a year at the Royal Naval Academy compared with one week. Since there were no differences between third-year cadets and first-year cadets in the unfamiliar teams on any dependent variable, it is unlikely that learning effects could explain the results of the present study. Recent literature shows increasing attention being devoted to trust as a precursor of team performance (Bandow, 2001). However, we argue that trust was equally present in familiar as unfamiliar teams. This is based on Bandow (2001), who states that 12 to 18 hours of face-to-face contact is required to instil the appropriate trust in a team. When the unfamiliar teams started the study, they came straight from the introduction week at the Royal Norwegian Naval academy. This week involves intensive face-to-face interaction. It is reasonable to expect that they trusted each other. In a study on from the Norwegian Naval Academy, Nissestad (2007) found no differences from the first week and after the first year, on group climate or groups dynamics in the teams. He also showed that cadets are a homogeneous group, referring to personality factors measured by the NEOPi. The Nissestad study was conducted on five cohorts between 2001 and 2005, and it is reasonable to expect that this would be the case for the participants in the present study. However, future studies should include measures of trust.

Another theoretical perspective that has tried to explain effects of familiarity in teams is the theory of transactive memory system (Wegner, 1986). In contrast to the concept of SMMs, transactive memory systems(TMS) is conceptualised as a set of distributed, individual memory systems that combines the knowledge possessed by particular team members with a

shared awareness of who knows what (Moreland 1999). According to transactive memory theory each team member will use the other team members as an external memory aid, thereby creating a compatible and distributed memory system (Koslowski & Ilgen. 2006). Kanawattanachai and Yoo (2007) demonstrated that TMS can be formed in distributed teams and enhance efficiency. Thus, the transactive memory system theory and findings connected to it, offers insightful and important knowledge about team processes.

However research based on the TMS approach has been concentrated on knowledge about the task the team is meant to solve and the team's ability to draw on different memories of it held by different team members. We argue that this raise two complications that differentiate TMS from SMMs of team members; the task must be familiar to the team and are not transferrable to other tasks. This implies that a team with a well developed transactive memory faces challenges when a novel and or critical situation arise. In the present study the situation and the task was novel and none of the team had any predisposition in form of knowledge about the task that needed to be done. When the teams that were familiar met the new and to them unknown simulation situation they performed better in the low and high workload situation. It is reasonable that they were able to benefit from the shared knowledge they had on each other. We argue that SMMs of team members enabled the familiar teams to identify changes in the team and team members and implicitly adjust strategies needed (e.g. more push of information when the workload increases). The present study indicates that SMMs of teammates are transferrable across tasks and functional even if the teams are separated physically and distinctly different for transactive memory systems. Further investigations are needed to study if this also implies that familiar teams learn a new task faster compared to unfamiliar teams.

To sum up, the present study is the first study to provide empirical evidence for the effect of SMMs of teammates distributed teams. It gives further support to the notion that SMMs

of teammates is a mechanism that improves performance and communication in teams, and it expands previous knowledge, where the focus has been on equipment, tasks and team interaction, by demonstrating the importance in distributed teams. We contend that SMMs of teammates enable teams to coordinate activities more effectively and more implicitly even if separated physically and connected only by verbal communication. A team with SMMs of teammates seems to regulate their physical arousal more adaptively and cope better with high workload.

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SHARED MENTAL MODELS IN DISTRIBUTED TEAMS

Table 1. The eight events in the scenario with maximum points for mission success, accuracy and latency.

<i>Workload</i>	<i>Event</i>	<i>Mission success</i>	<i>Accuracy</i>	<i>Latency</i>
Low	1. Friendly tanker	3	7	9
	2. Friendly tanker	3	7	9
	3. Fishing vessel	3	7	9
	4. Local passenger boat	3	7	9
	Total low Workload	12	28	36
Event1 – 4				
High	5. Helicopter	2	7	9
	6. Hostile warship	3	7	9
	7. Friendly tanker	3	7	9
	8. Malfunction firing	4	7	9
	9. Activity on hostile Warship	0	0	9
Total high workload		12	28	45
Event5-8				

Table 2: *Performance scores, Mission success, accuracy and Latency*

	Mission success Max.: 12				Accuracy Max.: 28				Latency Max.: 36 (Low workload) Max.: 45 (High workload)			
	Familiar		Unfamiliar		Familiar		Unfamiliar		Familiar		Unfamiliar	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Low Workload	6.38	2.6	2.87	1.81	22.84	4.93	15	3.1	29.7	3.57	14.2	4.46
High Workload	8.46	2.6	4.6	2.16	23.92	3.64	18.67	4.24	37.46	4.89	19.47	6.85

Figure captions

Figure 1. *Global Anticipation ratio in the low and high workload condition for the Familiar and Unfamiliar teams. Error bars indicate 0.95 confidence intervals.*

Figure 2. *Transfer of information, for the Familiar and Unfamiliar teams in the low and high workload conditions. Error bars indicate 0.95 confidence intervals.*

Figure 3. *Heart rate in beats per minute (bpm) for the Familiar and the Unfamiliar teams during baseline, low workload, high workload and recovery. Error bars indicate 0.95 confidence intervals.*

Figure 1

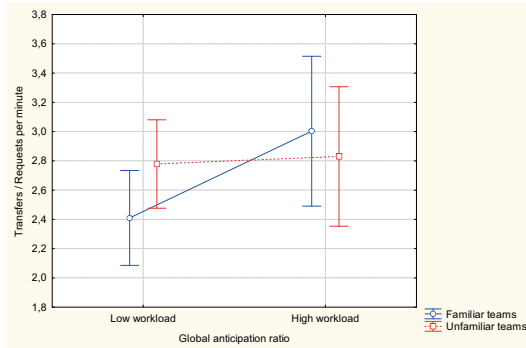


Figure 2

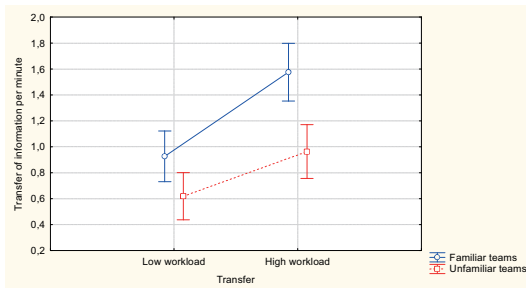
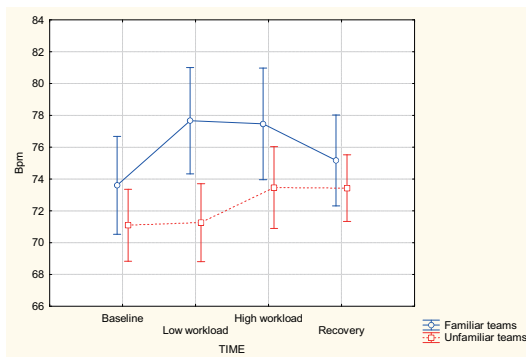


Figure 3



Outcomes of shared mental models of team members in cross training and high intensity
simulations

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Key words: shared mental models, Transactive memory systems, cross training, team efficiency, teamwork, communication, Navy

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Abstract

The present study examined whether shared mental models of team members characteristics were associated with team outcomes (i.e. performance, communication, and physical arousal) in cross-training and a high intensity simulation requiring coordinated team action. In a quasi experimental design 36 Navy officer cadets were randomly assigned to 12 newly formed tactical teams in the no shared mental modal condition (NoSMM). In contrast, 33 Navy officer cadets in 11 seasoned teams were included in the shared mental model condition (TMSMM). All teams were exposed to the same naval scenarios in their cross training and simulation exercise. The results showed that teams with TMSMM had superior performance and communication patterns characterized by updates and confirmations compared to the NoSMM teams during cross training and simulation. During cross training TMSMM teams provided more updates and backup than NoSMM teams. These findings suggest that shared mental models of team member are transferable through tasks and enhance the effects of cross training. The present study extends previous research indicating that shared mental models is distinctly different from transactive memory systems and represents an independent, adaptive asset at the group level, that may enhance team efficiency.

Outcomes of shared mental models of team members in cross training and high intensity simulations

The 26th of November 1999, MS "Sleipner" ran aground on the Norwegian west coast. 16 people died in the worst shipping disaster of its kind in Norway since World War II. At the morning of the accident, the on duty captain had to be replaced by a qualified stand in. Although both the new captain and the chief officer (the bridge team) were formally very well qualified – they were unfamiliar with each other. Seconds before grounding the new captain instead of stopping the vessel felt it necessary to turn on the lights to check the chief officer's statement about a suspected navigational error. The investigation report suggested that the bridge team failed to detect important critical cues and suffered from a lack of common understanding of the situation (NOU: 31, 2000).

The MS Sleipner accident is unfortunately not unique in that failures of team leadership, coordination, and communication are frequent causes of air accidents, medical errors, and industrial disasters (Kozlowski & Ilgen, 2006). The ability to adapt to a novel situation is vital for team performance in high intensity situations. In safety critical organizations (SCOs) such as aviation, emergency services, and the military rotation of personnel through 24/7 shift-work schedule makes it difficult if not impossible to maintain stable person/role expectations over time. In addition, many SCO's require domain experts to work together in a team context (e.g. emergency services and security forces). One way to determine the best practice in team management is to examine historical data. After analyzing 74 major accidents in the airline industry Woody, McKinney, Barker and Clothier (1994) concluded that newly formed (unknown) crews flew more safely than fixed (known) crews. This prompted a policy in several airlines to rotate crewmembers in order to ensure compliance with procedures, arguing that this results in increased safety. However, this view is challenged by Kanki and Foushee (1989) who found empirical evidence that, if the captain and first officer had recently flown together, they committed fewer errors and engaged in more open communication with respect to information exchange. Thus, a critical issue in

SCOs is how team member familiarity and precise person/role expectations will inform effective command, control, and communication (C³) to solve safety critical issues.

Interestingly, the literature on team processes offers two theoretical perspectives that seem to take quite different views to explain the outcome of team unfamiliarity. In their concept of shared mental model (SMM), Cannon-Bowers, Salas, & Converse (1993) suggest that more effective teams share similar mental models and understanding of the situation at hand. On the other hand Wegner (1986) proposes that effective team work is based on a transactive memory system where team members compartmentalize and specialize in different work segments. These apparently different perspectives inspired our quest to examine if transactive memory systems and shared mental models of team members are distinctly different and how these differences eventually might impact team performance in SCO's.

To our knowledge only studies within the transactive memory system framework have examined issues of familiarity and learning in teams (for an overview see, Moreland, 1999). However, if shared mental models are transferrable over different tasks (Salas et. al., 2005), then teams with shared mental models of team members should be able to adapt better to a new team performance situation or learn faster over time. Thus, one important aim of the present study is to examine if shared mental models of team members will transfer across new tasks or situations and result in improved performance. A better understanding of how person/role requirements influence team outcomes could also give better directions for how and when new training should be imposed on a team. In the following sections these issues are laid out in more detail.

Shared mental models

Salas et. al. (2005) reviewed 138 models from the team literature and proposed five factors that promote team effectiveness. These factors consist of team leadership, mutual performance monitoring, backup behaviour, adaptability, and team orientation. Salas et. al. (2005) suggest that shared mental models are the supporting and coordinating mechanism that

melds together the value of each of the five factors. This stems from the notion that teams working in high-intensity environments coordinate their activities efficiently when the team members are able to anticipate and predict each others' needs. Knowledge about other team members enables the team to identify changes in the task or team and implicitly adjust strategies as needed to meet external demands. To facilitate coordination, Salas et al. (2005) emphasize that team members must have similar or shared mental models of the system with which they are interacting. Cannon-Bowers et al. (1993) proposed four types of shared mental models. In addition to shared mental models of *equipment*, *task*, and *interaction*, they also suggest a shared mental model of *team members*. The shared mental model of team members holds team specific information about each team members' knowledge, skills, attitudes, preferences, and tendencies. Previous research on shared mental models has confirmed that technology/equipment models, task models, and team interaction models are important for team performance (Volpe, Cannon-Bowers, Salas & Spector, 1996; Urban, Bowers, Monday & Morgan 1995; Stout, Cannon-Bowers, Salas & Milanovich, 1999). Despite a wide spread assumption that shared mental models of team members will facilitate team behaviours and outcomes, few empirical studies have examined this factor within the shared mental models theoretical framework. In one study, Smith-Jentsch, Kraiger, Cannon-Bowers, & Salas (2009) found that commercial air traffic control teams with a history as teams were positively associated with requests for backup on the job. Furthermore, in a study of submarine attack teams our research group showed that crews with shared mental models of team members revealed higher levels of performance, showed more efficient communication patterns, and had lower cardiovascular arousal during high workload situations compared to crews without (Espevik, Johnson, Eid, & Thayer, 2006). This result emerged after controlling for knowledge about tasks and equipment, as well as the roles and responsibilities of the team (i.e. other elements of shared mental models). Findings are mixed, and the present study attempts to fill

this gap in the literature, given the frequent personnel rotation and reliance on team work in safety critical organizations.

Transactive memory systems

A theoretical perspective that has tried to explain effects of familiarity in teams is the transactive memory system Wegner (1986). In contrast to the concept of shared mental models, transactive memory systems is conceptualised as a set of distributed, individual memory systems that combines the knowledge possessed by particular team members with a shared awareness of who knows what. According to transactive memory theory each team member will use the other team members as an external memory aid, thereby creating a compatible and distributed memory system. Thus, team effectiveness depends on team specialization and increased capacity. Moreland (1999) posits that this will enable the team to plan their work more sensibly; assigning tasks to the people who will perform them best, and finally improving coordination because the team members can anticipate rather than simply react to each others behaviour. From laboratory experiments where small groups were trained to perform complex tasks (assembly radios); these researchers assessed the impact of various types of individual and group training on group performance. Their findings indicated that groups performed better when their members were trained together rather than apart and they suggest that the benefits of group training depended heavily on the operation of transaction memory systems (Moreland, 1999). The transactive memory system theory and findings connected to it, offers insightful and important knowledge about team processes. However it is still an open question if transactive memory system represents the fourth content domain in the shared mental model theory, i.e. shared mental model of team members proposed by Cannon-Bowers et al. (1993). The present study aims to address this issue and examine if transactive memory systems and shared mental models of team members are distinctly different and eventually where the boundaries between them are. One way to explore this question is to examine the learning process in teams over time.

Cross training

One training strategy that is shown to foster shared mental models is cross training (Volpe et al, 1996, Cannon-Bowers and Salas 1998, McCann, Baranski, Thompson, Pigeau 2000, Marks, Sabella, Burke, Zaccaro, 2002). Kozlowski and Ilgen (2006) suggest that one outcome of cross training will be to develop transactive memory system. Cross training refers to a strategy in which each member is trained on the specific tasks, duties and responsibilities of his or her fellow team members. In most cases, cross training is seen as a way to ensure a robust and redundant system, where team members can fill in or replace each other if needed. Thus, in order for crosstraining to be optimally efficient, every team member must have complete mastery of all team roles. A welcome side effect is that this training will provide team members with a clear understanding of how the entire team functions and how one's particular responsibilities interrelate with other team members'. In essence, cross training can close the gap in team member's person/role expectation, by enabling team members to anticipate the sorts of information and assistance that other team members need, increasing coordination and reduce the need for communication among teams. By rotating team roles, cross training will represent intense new learning opportunities for all team members. In the present study we were particularly interested in how shared mental models of team members would influence team performance and adaptation to a radically changed context represented by cross training and a high fidelity simulation exercise. To our knowledge, few previous studies have assessed differences in outcomes of shared mental models of team members when team members confront a series of new and unfamiliar training sessions represented by cross training and a high fidelity simulation exercise.

The aim of this study is to isolate the effects of shared mental models of team members, while controlling for knowledge about the scenario and the technical aspects of the situation. One way to achieve this is to introduce all participants to a totally new situation, where they are left with little more than the knowledge they have of each other. In a situation

where all team members are unfamiliar with the task, there is little or no pre-existing knowledge in the teams of who knows what. Thus, with no specific transactive memory system, one is left with shared mental models of team members. On the basis of emerging, although limited, research on consequences of familiarity for teams in SCO's, it is reasonable to assume that knowledge about other team members will positively influence the team's performance and outcome (e.g. fewer errors, higher mission success, better accuracy, and latency; Griepentrog & Flemming, 2003, Mohammed, Klimoski, & Rentsch, 2000, Stout, Cannon-Bowers, Salas, & Milanovich, 1999). Salas et al. 2005 propose that all four types of shared mental models enable the team to be more efficient. Based on the assumption that shared mental models of team members play an important part in team problem solving and are transferrable across tasks, we expect that teams with a shared mental model of team members will be increasingly efficient in cross training and more efficient in a complex high fidelity simulation, compared to teams with no shared mental model of team members. Thus, our first hypothesis will be:

H 1: Teams with shared mental models of team members will learn faster and perform better (i.e. fewer errors, higher mission success, better accuracy, and latency) over crosstraining sessions and in a high fidelity simulation situation.

Research into team effectiveness has shown that effective teams can maintain performance over time under conditions of high workload and when opportunities to communicate are limited (Kleiman & Serfaty, 1989). Effective teams are more effective at coordinating their activities using less explicit communication than less successful teams. Implicit coordination rests on the team's ability to share a common understanding of the situation, which constitutes a core element of the shared mental model approach (Cannon-Bowers et.al., 1993). However, previous studies have focused on how teams perform in familiar rather than unfamiliar tasks. Little empirical evidence is available to shed light on communication and team coordination when teams with differences in shared mental models

of team members who are confronted with unfamiliar situations. In new and unfamiliar situations we expect that shared mental models of team members will facilitate explicit communication and coordination processes during initial learning sessions. After successful acquisition of new skills, the explicit coordination will be replaced by more implicit coordination as an index of team performance and learning.

Based on this we expect to observe systematic differences in communication and coordination strategy between teams with and without shared mental models of team members. From this our second hypotheses are as follows:

H 2: Teams with shared mental models of team members will communicate more explicitly and implicitly compared to less experienced teams when confronting new and unfamiliar tasks.

The explicit adjusting strategies that will take place will manifest itself in different ways if shared mental models of team members are to play a role in team coordination. A seemingly paradoxical effect will be that in order to coordinate their activity, teams with shared mental models of team members will increase the amount of communication they use when confronted with unfamiliar situations. Based on this assumption H2 could be operationalized as follows:

H2 a: Teams with shared mental models of team members will have a higher rate of statements per minute compared to those starting with less experience as a team when confronting an unfamiliar situation.

Salas et al. (2005) emphasize the presence of closed loop communication as a coordinating mechanism to avoid misunderstandings in communication and facilitate the continuous updating of the teams shared mental models. Closed loop communication implies team members confirms and repeats vital information such as time, place, geographical coordinates etc. Thus we expect that H2 could also result in:

H 2 b: Teams with shared mental models of team members will show more closed loop communication.

Salas et al. (2005) emphasize that three out of five teamwork behaviours are closely connected to the shared mental model concept, that is adaptability, backup behaviour and mutual monitoring behaviour. Adaptability is defined as the ability to adjust strategies based on information gathered from the environment, which is dependent on backup behaviour, or the team's ability to anticipate other teammembers needs and carry out actions to shift workload among members to achieve balance during high workload. Mutual performance monitoring is proposed as the ability to develop common understanding of the team environment and apply appropriate task strategies to accurately monitor other team members performance. We expect that shared mental models of fellow team members will facilitate adaptive communication and coordination processes when team members confront unfamiliar situations. From this follows that H2 also could manifest itself as follow:

H 2 c: Teams with shared mental models of team members will show more adaptability, backup behaviour, and mutual performance monitoring behaviour over training sessions and in the high fidelity simulation scenario.

In line with the shared mental model logic, all teams will increase their shared mental models of equipment, task and interrelations move towards a more implicit communication as the crosstraining evolves. Hence we expect the relative difference between the TMSMM and NoSMM groups in adaptability, backup, and mutual performance monitoring will be reduced over crosstraining sessions.

The importance of shared mental models is proposed to increase as teams must perform in stressful conditions (Salas et. al., 2005). Team performance in ambiguous high fidelity situations will depend heavily on executive functions in team members such as attention, memory, and planning. Cognitive flexibility is seen as a particularly important asset when confronted with a rapidly changing and hostile environment. Adaptive team functioning

involves using and combining team role/resources in a flexible manner in order to cope with a rapidly changing dynamic environment. Teams with shared mental models will be more resilient to stress effects, due to their redundancy and ability to supply, substitute, or select information based on a superior understanding of team-role needs. Although stressors may reduce the amount of information flow, and team members may become more limited as to the tasks they can perform, teams with shared mental models of team members will be able to coordinate explicitly and implicitly when needed because of their knowledge of the person/role expectations in the team (Duncan, Rouse, Johnston, Cannon-Bowers, Salas, & Burns 1996). This will put lower cognitive load on teams with shared mental models of team members compared to those without it. Knowing the other team members and that they will be able to provide support if needed will reduce perceived risk of failure and increase positive outcome expectancies. Gradual mastery of new tasks will result in fewer errors and more positive outcome expectancies over time. From this follows our last hypothesis:

H 3: Teams with shared mental models of team members will be less aroused (i.e. lower heart rate) over time as performance increases and the need for explicit communication and coordination decreases.

Methods

Subjects

A total of 69 cadets from the Royal Norwegian Naval Academy (mean age 24 years, range 21-32) were recruited to the present study. The subjects' military service background ranged from two to 10 years, 10% were female officers, and the subjects' ranks ranged from Sub-Lieutenant to Lieutenant. Although the training was mandatory, participation in the research project was voluntary. Six of the cadets declined to participate in the part that involved HR measurement. 5 subjects were lost due to equipment failure leaving a total of 59

for the HR measurement. None of the subjects had previous experience of the simulator or other forms of simulator training in general.

Instruments

Three consoles operating firing of missiles and receiving detected radar transmission were arranged in a triangular position facing each other. Computer software in the simulator recorded target solutions, firing range, hits, and course and speed of all aircrafts

Verbal processes were examined using video and audio tape recordings (Sony TCM-459V) and video (Sony Super Steady Shot Handycam video HI8 CCD TR2200E PAL)

Physiological arousal

Cardiovascular responses were measured using Polar pulse watches. Heart rate (HR) was recorded as beats per minute (bpm).

Performance

Performance measures were based on transcripts from the simulator, and examined using criteria-based evaluation of efficiency and mission success (Cannon-Bowers & Salas, 1997).

Performance scores were defined according to the specific objective of the mission, that is shoot down enemy aircraft and letting friendly through. To assess this outcome measure, a scoring system was developed, whereby high performance scores indicated a high level of mission success (see table 1).

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Insert table 1

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In each of the training sessions, cross1, cross2, and cross3 there were 4 hostile and 2 friendly. Total score obtainable was 18 points in each cross training session. In the high fidelity simulation there were 9 hostile and 2 friendly. Total score obtainable was 33 points.

Team processes.

The number of statements was registered as the total number of statements per minute. To categorize information further each statement was scored in accordance with Salas et. al. (2005) to mimic team behaviour indicating a shared mental model concept, i. e. adaptability, backup behaviour, and mutual monitoring behaviour. The present study focus on statements that are proposed to be connected to implicit communication, hence statements that were offered or carried through *without* being asked for by another team member. Thus each statement was categorized into:

- a. updates/priorities labelled as adaptability, (e.g. "we lost contact with contact" or "that target is our main focus now"):
- b. Presenting information, actions, solutions, labelled as backup, (e.g.: "the correct course is" or "I have given the target the correct bearing").
- c. Offered information, actions, solutions labelled as mutual performance monitoring. (e.g.: "I can give you the bearing now" or "Do you need a classification").

In addition closed loop communication was quantified as indicators of an underlying mechanism to update team members TMSMM and shared mental models in general. Closed-loop refers to communication involving the sender initiating a message, the receiver receiving the message, interpreting it, and acknowledges its receipt and the sender following up to insure the intended message was received.

- d. confirmation, labelled as closed loop (e.g. "received" or "did you get the bearing I sent you?").

Procedure

Subjects were categorised as members of teams with shared mental models of team members (TMSMM) or without it (NoSMM). To be included in the TMSMM group, the team members had to have completed the first year of basic officer training together at the Norwegian Naval Academy. During this first year, the cadets are organised into permanent teams of six persons that stay together for eight months. During this period, the fixed teams share as a team the hardship of a number of extensive exercises as well as an eleven-week period on a tall-masted ship on a transatlantic crossing. This results in extended knowledge about individual differences in competencies, skills, abilities, preferences and tendencies in their fellow cadets (Cannon-Bowers et al., 1993). Due to the outline of the simulator the original six member teams were randomly divided to two which gave 11 three member teams with TMSMM.

The other category, the NoSMM group, consisted of cadets from another cohort at the Royal Norwegian Naval Academy. The participants had no previous history together, either as individuals or as members of other teams, except for a one-week getting acquainted period at the start of the semester. Together, these subjects randomly formed a total of 12 three members' teams with NoSMM.

The study was carried out in a high fidelity simulator that is a replica of a naval operations room. Expert instructors from the Royal Norwegian Navy developed the scenarios used in the present study.

Insert figure 1

The participants were informed about the study and invited to sign an informed consent. Pulse watches were administered and baseline HR was recorded while the

participants were seated. HR was recorded through baseline, crosstraining sessions, high fidelity simulation and recovery. The subjects were told that the intention with the exercise was to discover how fast they were able to learn and cooperate. The officer cadets were not given monetary rewards, and were informed that the outcome of the exercise was not going to influence their military leadership grads. Each team was told that the team which, after training, would perform best at the final test would be given the next high profile mission in the ongoing exercise they all were taking part in.

During the training scenarios, the three member teams had to work interdependently towards a common goal of providing protection for an aircraft carrier in littoral waters. The aircraft carrier was at anchor and its protection (safety) depended on the team's ability to shoot down unfriendly aircrafts and allow friendly aircrafts to operate in the area. This involved surveillance and coordination of air traffic in the area and subsequent military actions to protect the aircraft carrier. This put great constraints on the team effort to coordinate their activities with limited time at their disposal. The scenario was designed to include realistic stressors that gave the teams an increasing workload and a greater need for coordination and communication between the team members.

Team members were randomly assigned to three different positions (team roles) in the operations room. These were: Early Warning (EW), Classification (CL), and Weapons control (WE). The main task of EW was to detect and get the bearing of unknown radar transmission. EW was then assigned to discover potential targets early and send the data (radar characteristics) to CL who then was able to classify them (from the checklist s/he solemnly held) as friendly or hostile. EW was also tasked to calculate speed and course on potential targets based on own and CL bearings. The main task of WE was to update the overall picture. The WE had a map of the area on the consol but no sensor to give him/her a bearing or radar characteristics. Thus, WE's ability to fire missiles totally depended on the

cooperative work of all positions. All team roles depended heavily on the performance of the other two.

The study started with a 30-minute briefing on the scenario, consisting of setting, order, intelligence information, the outline of the simulator and functional demonstration of the equipment. This was followed by 30 minutes' hands-on training on the designated position in the simulator.

In order to examine effects of cross training, each team went through an identical training period consisting of three similar 20 minute scenarios; C1, C2, and C3. All team members rotated through each of the team roles in scenarios C1, C2, and C3. In the final scenario team members were again assigned their original role – the same as in C1. The high fidelity simulation scenario(S) was more intense, with more contacts from different directions, and higher workload.

After completion, a five minute HR recovery period was recorded. All recordings were obtained while the subjects were seated.

Two paid, independent raters categorised the information exchange in the teams. They were unfamiliar with the shared mental model theory, the scenario and blind to the experimental set-up. Both raters were introduced to and trained in the use of the Noldus program (Noldus, 1991, Noldus, Trienes, Hendriksen, Jansen, Jansen, 2000). The raters established a common understanding of the categories (adaptability, backup behaviour, mutual performance monitoring and closed loop communication) by rating three videos together before the actual recording of the videos. The inter-rater reliability showed an intra-class correlation of .98 ($p < .00$).

Results

Descriptive statistics on performance and team process scores over test conditions for the TMSMM and NoSMM groups follows from Table 2

Insert Table 2

Performance scores

The first hypothesis on systematic group differences in performance and learning over cross training sessions was explored by a 2(TMSMM vs. NoSMM) x 3(C1 vs. C2 vs. C3) factorial design (Ferguson, 1982), with independent ratings of mission specific success criteria as outcome variable. The first factor (groups) was treated as a between-group factor and the second factor (sessions) as a within-group factor in all analyses. Our findings revealed a main effect of groups during cross training sessions, $F(1, 21) = 17.49, p < .001$, with TMSMM scoring highest. In addition, a main effect of cross training was found, $F(2, 42) = 12.81, p < .00$. A post hoc Tukey test revealed a steady increase in mission success over time from C1 to C2 and C3 (all $p < .001$). An interaction of groups by cross training sessions was also found, $F(2, 42) = 3.34, p < .04$. A follow-up Tukey test revealed that the TMSMM group scored borderline higher from C1 to C2 ($p < .07$) and to C3 ($p < .01$) and significantly higher from C2 to C3 ($p < .01$). The NoSMM group showed no differences across sessions. The TMSMM group scored higher than the NoSMM group on C2 ($p < .01$) and C3 ($p < .01$) (se Figure 2).

Insert Figure 2

Performance scores in the high fidelity simulation scenario (S) after cross training were examined using an unrelated t test. In line with hypothesis 1 our results revealed that the TMSMM teams ($M = 17.78, SD = 5.93$) showed significantly higher performance scores than

the NoSMM teams ($M = 8.42$, $SD = 5.07$, $t(19) = 3.89$, $p < .001$) during high fidelity simulations.

Team processes

Team processes scores were studied using a 2(TMSMM vs. NoSMM) x 3(C1 vs. C2 vs. C3) factorial design (Ferguson, 1982) with outcome variables (team processes) as suggested in H2 a, b, c. The first factor (groups) was treated as a between-group factor and the second factor (sessions) as a within-group factor in all analyses. An independent-samples t -test was conducted to compare team process differences between TMSMM and NoSMM teams during the high fidelity simulation.

Total information exchange.

In order to assess H-2 a total information exchange was analyzed as outcome variable. The results revealed that total statements per minute showed a main effect of groups, $F(1, 18) = 18.7$, $p = .004$ were TMSMM teams scored higher than NoSMM teams.

An independent-samples t -test was conducted to compare total amount of information exchange (communication per min) for teams with TMSMM and NoSMM. Teams with TMSMM showed more communication ($M = 18.54$, $SD = 2.37$) than the NoSMM teams ($M = 15.83$, $SD = 3.06$, $t(18) = 2.11$, $p < 0.05$ during the high fidelity simulation.

Closed loop

In order to assess H-2 c indicators of closed loop communication (confirmation per minute) were used as outcome variable. Analyses of confirmations per minute showed a main effect of groups, $F(1, 18) = 18.17$, $p < .001$, with the TMSMM group showing more confirmations compared to the NoSMM group.

Furthermore, an interaction of groups by sessions was found, $F(2, 36) = 4.81, p = .01$. The Tukey post hoc test revealed that teams with TMSMM decreased from C1 to C3 ($p < .001$). For NoSMM teams no difference found (see Figure 3). TMSMM teams were higher ($p < .001$) at C1 and C2.

Insert Figure 3

No differences on closed loop communication in the high fidelity simulation (Borderline $p < 0.99$)

Adaptability

In order to assess H-2 b indicators of adaptability (updates) were used as outcome variable. Analyses of updates per minute showed a main effect of groups, $F(1, 18) = 12.95, p < .002$, with the TMSMM group showing more updates compared to the NoSMM group.

Analysis of updates per minutes showed a main effect through sessions, $F(2, 36) = 19.92, p = .001$. A Tukey post hoc test showed increase in adaptability for from C1 to C2 and C3 (all p 's $< .001$).

Furthermore, an interaction of groups by sessions was found, $F(2, 36) = 3.18, p = .05$. The Tukey post hoc test revealed that teams with TMSMM increased from C1 to C2 and C3 (both $p < .001$). For NoSMM teams no differences were found (see Figure 4).

Insert Figure 4

An independent -samples t-test was conducted to compare how often a priority or intention was voiced in the team (per minute). There was a statistic difference where

TMSMM teams ($M = 2.19$, $SD = 0.47$) showed significantly higher compared to NoSMM ($M = 1.22$, $SD = 0.57$, $t(18) = 3.998$, $p < 0.01$) teams during the high fidelity simulation.

Backup

In order to assess H-2 b indicators of backup (unsolicited help provided per minute) were used as outcome variable. Analyses of unsolicited help (information, solution to a problem or action) per minute showed a main effect of groups, $F(1, 18) = 4.3$, $p < .005$, with the TMSMM group showing more backup compared to the NoSMM group.

Following up on H-2 b, indicators of backup behaviour were analyzed. An effect through sessions were found $F(2, 36) = 7.94$, $p < .01$. A Tukey post hoc test showed an increase from C2 to C3 ($p < .001$). No effect of interaction effects was found.

Mutual performance monitoring

No systematic differences emerged between groups and/or over time for scores on monitoring behaviour.

Physiological arousal

In order to examine H-3 indicators of arousal (HR) were used as outcome variable. Analyses of HR were performed using a 2 (TMSMM vs. NoSMM) x 6 (baseline vs. C1 vs. C2 vs. C3 vs. S vs. recovery) factorial design (Ferguson, 1982). The first factor was treated as a between-group factor and the second factor as a within-group factor in all analyses. Tukey post hoc test were used as post hoc tests. Analyses of cardiovascular activity showed a main effect of all Sessions, $F(5, 28) = 11.191$, $p < .001$. A Tukey test revealed a decrease in HR from baseline to C3 ($p < .03$), and to high fidelity simulation (S) ($p < .04$), and to recovery ($p < .001$). There was also a decrease from C1 to C3 and to S ($p < .001$). Furthermore, an interaction of groups by sessions was found, $F(5, 275) = 3.86$, $p < .002$ (see Figure 3). Tukey post hoc test revealed that teams with TMSMM decreased HR from baseline to C3 ($p < .03$) and S ($p < .04$), and to recovery ($p < .00$). Finally, a Tukey post hoc test revealed that teams

with TMSMM decreased HR from C1 to C3 ($p < .03$) and S ($p < .04$), and to recovery ($p < .001$). For NoSMM teams no differences in HR were found over time (see Figure 5).

Insert Figure 5

Discussion

In the present study TMSMM teams performed significantly better, hitting more targets than NoSMM teams at cross training sessions two and three, as well as in the high intensity simulation. The TMSMM teams increased performance over time, while no improvement in performance score was found for the NoSMM teams. The TMSMM teams also showed more process behaviour indicating higher adaptability and backup behaviour as well as more closed loop communication and confirmation during cross training and in the high fidelity simulation. Only the TMSMM teams revealed a marked decrease in physical arousal over training sessions.

The present study extends previous research by presenting new empirical findings on the significance of shared mental models of team members in a naturalistic true to life setting. Salas et al (2005) proposed that the shared mental concept made a team more able to anticipate and predict other team member's needs and identify changes in the team, task or teammates that would facilitate an implicit adjustment of strategies as needed. To explore this issue, the present study focused on a series of situations (i.e. cross training and the high intensity simulation) where team performance was dependant on team members ability to "identify changes in the team and teammates." Thus, all teams confronted a novel situation at the start of crosstraining and the high fidelity simulation.

In this simulated naval threat scenario, our results showed that teams with TMSMM outperformed teams with NoSMM. When the team was faced with a new and unfamiliar

challenge, an interesting pattern in performance emerged over time. While there was no difference in performance scores during the first cross training session, only TMSMM teams improved over subsequent sessions and outperformed NoSMM teams after only one training session. These findings support our first hypothesis and could be interpreted as a strong indication that shared mental models of team members enables teams to learn an unfamiliar task faster. One possible explanation could be that the team members in the TMSMM group have a more developed shared mental model of person/role expectations compared to the NoSMM group (Cannon-Bowers & Salas and Converse, 1993). This is supported by previous research and evaluations of the leadership training program at the Royal Naval Academy, which indicated that cohesion, interpersonal relations and perceptions of colleagues are shaped and heightened during basic officer training (Eid, Johnsen, Bartone, & Nissestad, 2008). The leadership training exposes the teams to several demanding situations, allowing them to gain first-hand knowledge of each team member's characteristics, abilities and tendencies (Polley, & Eid, 1990). Over a year, it is therefore reasonable to assume that the cadets have developed shared mental models of team members that will enable them to coordinate more effectively during cross training and high intensity simulations.

The present study replicates and extends the findings of Espevik et al., (2006) where submarine crews showed better performance when the team was intact compared to situations where one team member was substituted with a member from another submarine crew. The present study indicates that, if a team faces cross training, TMSMM teams benefit more from cross training and outperforms the NoSMM group after a short crosstraining period. This implies that teams with TMSMM learn faster, although all teams started with no knowledge about the task or this type of training. Since the NoSMM did not show an improvement of performance scores over the training sessions, crosstraining strategy for newly formed teams must contain extended time to gain learning. When a novel situation arises it is therefore possible that TMSMM team will have an advantage to understand and consequently adapt to

the situation. Our study suggests that these differences in performance may be explained by marked differences in communication/coordination process between the TMSMM and NoSMM teams.

According to our second hypothesis, we assumed that the TMSMM teams would apply other adaptive strategies to enhance team communication and coordination when faced with a new and unfamiliar task compared to the NoSMM teams. First when the situation was new and unfamiliar to the team members, the TMSMM teams were more explicit in their initial communication to make sure that every team member got the proper information through more communication (i.e. statements per minutes) and more closed loop communication (confirmations) to ensure that every aspect of the situation was received and understood. Thus in contrast to the less successful NoSMM teams, the TMSMM teams developed and updated their shared mental models while they were engaged in problem solving and task work during the initial training scenarios. This finding may indicate an important distinction between task experts and task novices. In that subject matter expert explicitly attend to team process and information exchange during initial training and preparations. This study also shows differences in communication strategy when compared to the Espevik et al, 2006 study of seasoned submarine teams. The present study indicates that teams (TMSMM) with little prior knowledge of the task, equipment, interaction approach high workload with higher amount of explicit communication in contrast to subject matter experts with TMSMM who decrease explicit communication (Espevik et al., 2006).

Over time a notable difference in communication pattern revealed that TMSMM teams over time changed to more implicit communication compared to the NoSMM teams. This gives some support to the suggestion that the TMSMM teams were more attuned to changes in team and team mates and anticipated the needs of fellow team members. Salas et. al. (2005) proposed a strong connection between, adaptability, backup and mutual performance monitoring behaviour and SMM. They proposed that mutual performance monitoring, backup

behaviour and adaptability occurs more often in teams with adequate shared mental models. Teams with TMSMM showed as predicted (H-2 b) higher frequency than NoSMM teams on adaptability and backup behaviour.

Contrary to what we expected, there were no differences between TMSMM and NoSMM teams in mutual performance monitoring. One explanation could be that the heavy workload reduced the opportunities for a team member to watch another team member due to time constraints. It is also possible that the TMSMM teams monitored each other more efficiently through verbal clues, like tone of voice indicating that help was needed and acted accordingly (e.g. offering action which was significantly higher for the TMSMM teams). The last argument is supported by the differences in adaptability, when TMSMM teams initiated more updates than NoSMM teams and backup where help (information, action, problem solving) was provided more often. Thus they anticipated more often than NoSMM teams that the team needed to share information or get something done and acted accordingly. This may be the most important difference connected to the availability of shared mental models and taken together with the results that the TMSMM teams showed higher rate of confirmations as well as outperformed NoSMM we advocate that this is the case.

To our knowledge very few studies (Espevik et al 2006, 2010) have combined physiology together with SMM approach. This is somewhat surprising since several authors (Kleinman and Serfaty, 1989; Orasanu and Salas 1993; Salas et al, 2005) suggest that the importance of shared mental models as a coordinating mechanism increases in teams that must perform in stressful conditions. It is therefore interesting to measure physiological outcomes in high workload situations where shared mental models are most called upon and may increase resilience to stress (Salas et. al. 2005). In the present study only the TMSMM teams decreased HR from first cross training (C1) session to the high fidelity simulation (S). This implies that the TMSMM teams over time revealed a more adaptive and resilient response to higher workload when compared to the NoSMM teams. The superior performance

by the TMSMM teams strengthens this notion. We anticipated that the NoSMM group would be more physiologically aroused than the TMSMM teams when facing a high workload situation, as shown in the Espevik et al. (2006) study. Contrary to our hypothesis, no differences were found between the TMSMM and NoSMM teams. It is possible that in the present study the cross training itself affected and thus mediated the physiological arousal. A control group not participating in the cross training would have had the ability to uncover this.

Another explanation of the results is offered by the transactive memory system (TMS) theory. Research based on the TMS approach has been concentrated on knowledge about the task the team is meant to solve and the team's ability to draw on different memories of it held by different team members. This implies that a team with a well developed transactive memory may face challenges when a novel and or critical situation arise. The knowledge about how a team member behaves when he or she is almost overwhelmed by workload is not salient in this research and this knowledge may be vital for how they as a team coordinate and cope. Moreland (1999) suggests as a strategy to confront unfamiliarity were every team member gives each other information of their own knowledge and skills pertaining to the task. This could be viewed as a personification of ordinary task work or shared mental models of people's knowledge about equipment/task/interaction. However, if TMS caused the observed effect all teams would show an increased performance score since knowledge would be accumulated and shared. This would have been manifested as only a main effect of training sessions. This was not the case, since an interaction of Group by Sessions was observed. We suggest that the differences found in this study indicate that TMSMM is distinct and different from TMS, with an independent and added value to the coordination processes that explain the superior performance of the TMSMM teams in the final test situation.

Limitations

There are other possible explanations for why TMSMM teams outperformed the NoSMM teams. One factor that could have influenced the results was a possible learning effect of

being a cadet for a year at the Royal Naval Academy compared to one week. Espevik et. al. (2010) found no differences in performance when studying two different cohorts of cadets in a simulator between first and the third year cadets. It is reasonable to believe that this also would be the case in the present study.

Another explanation to the findings could be a difference in trust between the two groups. Recent literature shows increasing attention being devoted to trust as a precursor of team performance (Bandow, 2001). However, we argue that trust was adequately present in both the TMSMM teams and the NoSMM teams. This is based on Bandow (2001), who states that 12 to 18 hours of face-to-face contact is required to instil the appropriate trust in a team. When the No SMM group started the study, they came straight from the introduction week at the Royal Norwegian Naval academy. This week involves an intensive teambuilding period with extensively face-to-face interaction with an aim of installing trust in the naval cadets. It is reasonable to expect that they were confident in each other and that the differences found in the present studies between the TMSMM group and the NoSMM group were attributed to a shared mental model of team members and not in the level of trust. This is further supported by another study of cadets from the Royal Norwegian Naval Academy. According to Nissestad (2007), there were no differences from the first week and after the first year, on group climate or groups dynamics in the teams. He also showed that cadets are a homogeneous group, referring to personality factors measured by the NEOPi. The Nissestad study was conducted on five cohorts between 2001 and 2005, and it is still reasonable to expect that this would be the case for the participants in the present study.

To sum up, the present study is the first study to provide empirical evidence for the effect of TMSMM during crosstraining. We conclude that teams that start with TMSMM will benefit more than NoSMM teams when performing cross training. It also implies that TMSMM is transferable across different tasks. Finally, TMSMM is distinctly different and with an added value to teamwork and subsequently to outcomes, than transactive memory

systems as it is proposed by Moreland (1999). The present study extends and replicates Espevik et al (2006, 2010) and gives further evidence to the proposed significance of TMSMM. We conclude that TMSMM is a mechanism that improves coordination evidenced by better communication strategies and resulting in enhanced learning of a new task, better performance, and outcomes in high workload conditions. Taken together, this knowledge expands previous knowledge, where the focus has been on equipment, tasks and team interaction, by demonstrating the importance of TMSMM in teamwork.

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Figure captions

Figure 1. Design for the study, TMSMM and NoSMM groups from baseline, through three crosstraining sessions (C1, C2, and C3), High fidelity simulation (S) and recovery.

Figure 2. Performance scores during the three (C1, C2, and C3) crosstraining sessions, for the TMSMM and NoSMM groups. Error bars indicate 0.95 confidence intervals.

Figure 3. Closed loop, confirmation per minute during the three (C1, C2, and C3) crosstraining sessions, for the TMSMM and NoSMM groups. Error bars indicate 0.95 confidence intervals.

Figure 4. Adaptability, (updates per minute) during the three (C1, C2, and C3) crosstraining sessions, for the TMSMM and NoSMM groups. Error bars indicate 0.95 confidence intervals.

Figure 5. Heart rate in beats per minute (bpm) for the TMSMM and NoSMM groups during baseline, crosstraining session 1 (C1), crosstraining session 2 (C2), crosstraining session 3 (C3), High fidelity simulation (S) and recovery. Error bars indicate 0.95 confidence intervals.

Table 1: Presents events and weights composing the Performance score.

Event	Score
Hit hostile aircraft	+3
Fire, not hitting hostile	+1
Friendly aircraft through	+3
Hostile aircraft penetrate screen	-1
Friendly aircraft hit	-3

Table 2: Performance scores as mission success. Communication indicated as statements per minute for total amount, adaptability, backup, mutual performance monitoring and closed loop communication. Physical arousal indicated as beats per minute.

Variables			H1 Mission Success	H2 a Total Amount	H2 b Adapt-Ability	H2 b Backup	H2 b Monitor	H2 c Closed Loop	H3 Physical Arousal
Point of measures									
Baseline	TMSMM	Mean							78.47
		SD							12.45
	NoSMM	Mean							74.72
		SD							9.91
C1 Cross-Training session 1	TMSMM	Mean	5	18.09	0.35	0.16	0.31	3.35 ⁶	79.79
		SD	2.45	3.08	0.31	0.12	0.17	0.74	12.86
	NoSMM	Mean	4.64	14.79	0.34	0.04	0.28	2.24	75.71
		SD	2.2	3.14	0.44	0.05	0.23	0.3	8.76
C2 Cross-Training session 2	TMSMM	Mean	8.11 ¹	16.77	1.57 ⁴	0.24	0.24	3.02 ⁷	76.06
		SD	2.67	2.52	0.47	0.13	0.12	0.56	12.2
	NoSMM	Mean	5	16.36	0.8	0.1	0.19	2.11	75.53
		SD	1.35	3.82	0.48	0.09	0.14	0.48	9.01
C3 Cross-Training session 3	TMSMM	Mean	11.44 ²	16.59	1.57	0.22	0.14	2.6	73.39
		SD	3.8	3.13	0.55	0.12	0.11	0.69	11.5
	NoSMM	Mean	6.75	15.84	0.89	0.14	0.25	2.1	74.25
		SD	4.25	2.81	0.59	0.16	0.32	0.59	8.87
S High fidelity scenario	TMSMM	Mean	17.78 ³	18.54	2.19 ⁵	0.14	0.25	2.98	73.47
		SD	5.9	2.37	0.47	0.08	0.14	0.64	10.92
	NoSMM	Mean	8.41	15.83	1.22	0.14	0.18	2.45	75.13
		SD	5.07	3.06	0.56	0.32	0.16	0.69	9.51
Recovery	TMSMM	Mean							70.15
		SD							9.4
	NoSMM	Mean							72.24
		SD							8.9

1. TMSMM higher than NoSMM ($p < .001$). 2. TMSMM higher than NoSMM ($p < .001$). 3. TMSMM higher than NoSMM ($p < .001$).
 4. TMSMM higher than NoSMM ($p < .001$). 5. TMSMM higher than NoSMM ($p < .001$). 6. TMSMM higher than NoSMM ($p < .001$).
 7. TMSMM higher than NoSMM ($p < .001$).

Figure 1,

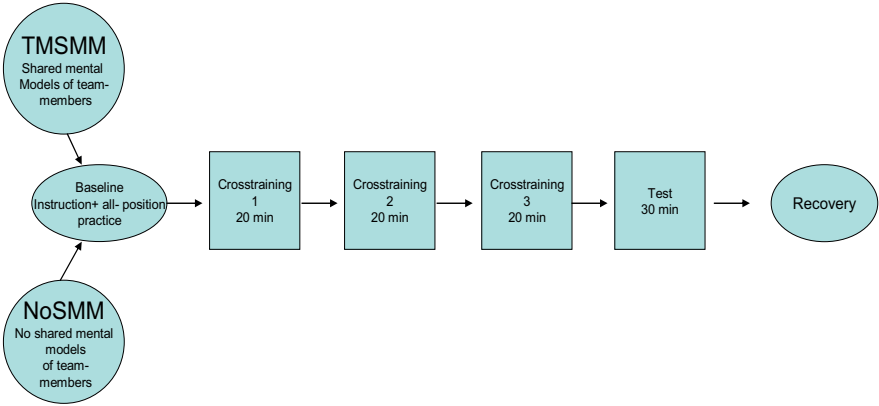


Figure 2.

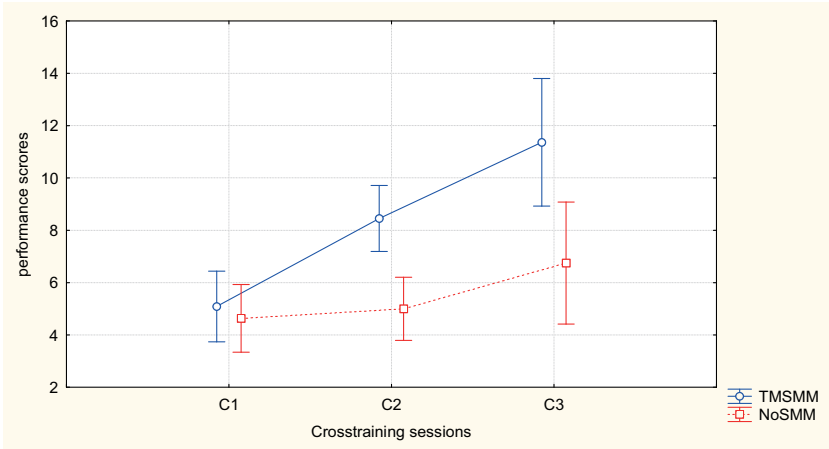


Figure 3.

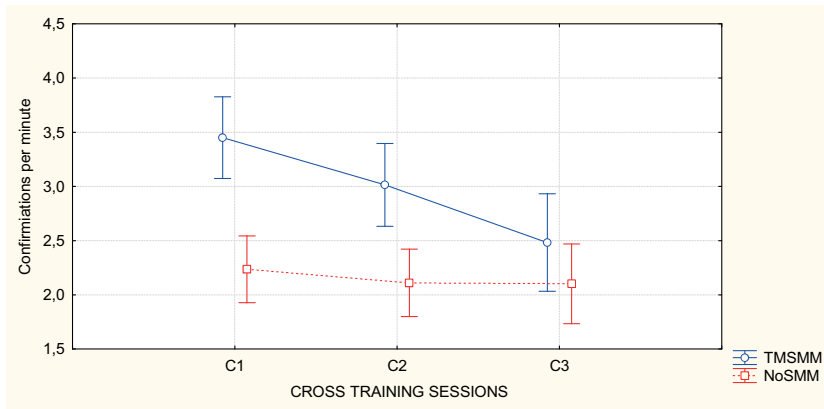


Figure 4

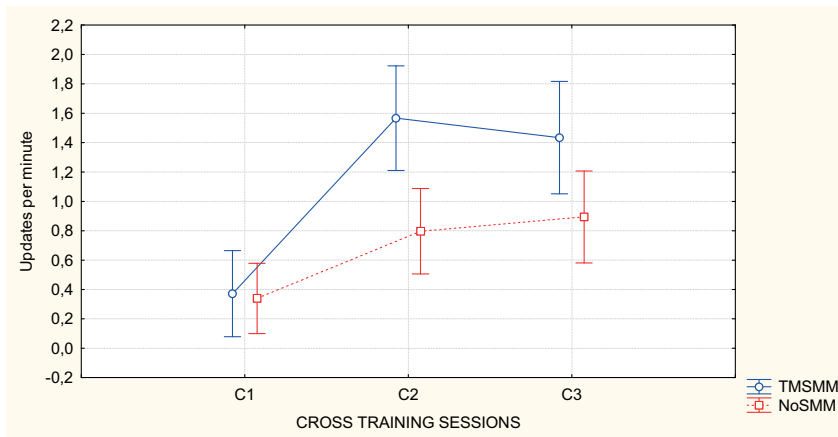
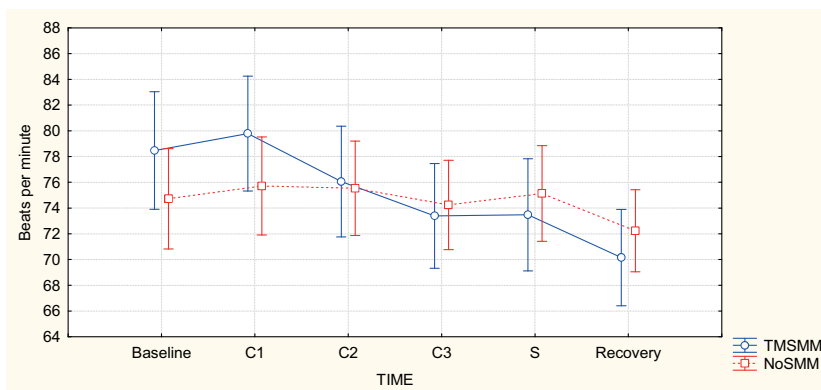


Figure 5.



Biographies

Roar Espevik

Cand.Polit, NLA University College, 2001. PhD student, Faculty of Psychology, University of Bergen, Norway

Professor Bjørn Helge Johnsen

Dr. Psychol., Department of biological and medical psychology, 1993. Faculty of Psychology, University of Bergen, Norway

Associate Dean, Professor Jarle Eid

Dr. Psychol., Department of clinical psychology, 2000. Faculty of Psychology, University of Bergen, Norway.

Doctoral Theses at The Faculty of Psychology,
University of Bergen

1980	Allen, H.M., Dr. philos.	Parent-offspring interactions in willow grouse (<i>Lagopus L. Lagopus</i>).
1981	Myhrer, T., Dr. philos.	Behavioral Studies after selective disruption of hippocampal inputs in albino rats.
1982	Svebak, S., Dr. philos.	The significance of motivation for task-induced tonic physiological changes.
1983	Myhre, G., Dr. philos.	The Biopsychology of behavior in captive Willow ptarmigan.
	Eide, R., Dr. philos.	PSYCHOSOCIAL FACTORS AND INDICES OF HEALTH RISKS. The relationship of psychosocial conditions to subjective complaints, arterial blood pressure, serum cholesterol, serum triglycerides and urinary catecholamines in middle aged populations in Western Norway.
	Værnes, R.J., Dr. philos.	Neuropsychological effects of diving.
1984	Kolstad, A., Dr. philos.	Til diskusjonen om sammenhengen mellom sosiale forhold og psykiske strukturer. En epidemiologisk undersøkelse blant barn og unge.
	Løberg, T., Dr. philos.	Neuropsychological assessment in alcohol dependence.
1985	Hellesnes, T., Dr. philos.	Læring og problemløsning. En studie av den perseptuelle analysens betydning for verbal læring.
	Håland, W., Dr. philos.	Psykoterapi: relasjon, utviklingsprosess og effekt.
1986	Hagtvet, K.A., Dr. philos.	The construct of test anxiety: Conceptual and methodological issues.
	Jellestad, F.K., Dr. philos.	Effects of neuron specific amygdala lesions on fear-motivated behavior in rats.
1987	Aarø, L.E., Dr. philos.	Health behaviour and socioeconomic Status. A survey among the adult population in Norway.
	Underlid, K., Dr. philos.	Arbeidsløse i psykososialt perspektiv.
	Laberg, J.C., Dr. philos.	Expectancy and classical conditioning in alcoholics' craving.
	Vollmer, F.C., Dr. philos.	Essays on explanation in psychology.
	Ellertsen, B., Dr. philos.	Migraine and tension headache: Psychophysiology, personality and therapy.
1988	Kaufmann, A., Dr. philos.	Antisocial atferd hos ungdom. En studie av psykologiske determinanter.

	Mykletun, R.J., Dr. philos.	Teacher stress: personality, work-load and health.
	Havik, O.E., Dr. philos.	After the myocardial infarction: A medical and psychological study with special emphasis on perceived illness.
1989	Bråten, S., Dr. philos.	Menneskedyaden. En teoretisk tese om sinnets dialogiske natur med informasjons- og utviklingspsykologiske implikasjoner sammenholdt med utvalgte spedbarnsstudier.
	Wold, B., Dr. psychol.	Lifestyles and physical activity. A theoretical and empirical analysis of socialization among children and adolescents.
1990	Flaten, M.A., Dr. psychol.	The role of habituation and learning in reflex modification.
1991	Alsaker, F.D., Dr. philos.	Global negative self-evaluations in early adolescence.
	Kraft, P., Dr. philos.	AIDS prevention in Norway. Empirical studies on diffusion of knowledge, public opinion, and sexual behaviour.
	Endresen, I.M., Dr. philos.	Psychoimmunological stress markers in working life.
	Faleide, A.O., Dr. philos.	Asthma and allergy in childhood. Psychosocial and psychotherapeutic problems.
1992	Dalen, K., Dr. philos.	Hemispheric asymmetry and the Dual-Task Paradigm: An experimental approach.
	Bø, I.B., Dr. philos.	Ungdoms sosiale økologi. En undersøkelse av 14-16 åringers sosiale nettverk.
	Nivison, M.E., Dr. philos.	The relationship between noise as an experimental and environmental stressor, physiological changes and psychological factors.
	Torgersen, A.M., Dr. philos.	Genetic and environmental influence on temperamental behaviour. A longitudinal study of twins from infancy to adolescence.
1993	Larsen, S., Dr. philos.	Cultural background and problem drinking.
	Nordhus, I.H., Dr. philos.	Family caregiving. A community psychological study with special emphasis on clinical interventions.
	Thuen, F., Dr. psychol.	Accident-related behaviour among children and young adolescents: Prediction and prevention.
	Solheim, R., Dr. philos.	Spesifikke lærevansker. Diskrepanskriteriet anvendt i seleksjonsmetodikk.
	Johnsen, B.H., Dr. psychol.	Brain asymmetry and facial emotional expressions: Conditioning experiments.
1994	Tønnessen, F.E., Dr. philos.	The etiology of Dyslexia.
	Kvale, G., Dr. psychol.	Psychological factors in anticipatory nausea and vomiting in cancer chemotherapy.

	Asbjørnsen, A.E., Dr. psychol.	Structural and dynamic factors in dichotic listening: An interactional model.
	Bru, E., Dr. philos.	The role of psychological factors in neck, shoulder and low back pain among female hospitale staff.
	Braathen, E.T., Dr. psychol.	Prediction of exellence and discontinuation in different types of sport: The significance of motivation and EMG.
	Johannessen, B.F., Dr. philos.	Det flytende kjønnet. Om lederskap, politikk og identitet.
1995	Sam, D.L., Dr. psychol.	Acculturation of young immigrants in Norway: A psychological and socio-cultural adaptation.
	Bjaalid, I.-K., Dr. philos	Component processes in word recognition.
	Martinsen, Ø., Dr. philos.	Cognitive style and insight.
	Nordby, H., Dr. philos.	Processing of auditory deviant events: Mismatch negativity of event-related brain potentials.
	Raaheim, A., Dr. philos.	Health perception and health behaviour, theoretical considerations, empirical studies, and practical implications.
	Seltzer, W.J., Dr.philos.	Studies of Psychocultural Approach to Families in Therapy.
	Brun, W., Dr.philos.	Subjective conceptions of uncertainty and risk.
	Aas, H.N., Dr. psychol.	Alcohol expectancies and socialization: Adolescents learning to drink.
	Bjørkly, S., Dr. psychol.	Diagnosis and prediction of intra-institutional aggressive behaviour in psychotic patients
1996	Anderssen, N., Dr. psychol.	Physical activity of young people in a health perspective: Stability, change and social influences.
	Sandal, Gro Mjeldheim, Dr. psychol.	Coping in extreme environments: The role of personality.
	Strumse, Einar, Dr. philos.	The psychology of aesthetics: explaining visual preferences for agrarian landscapes in Western Norway.
	Hestad, Knut, Dr. philos.	Neuropsychological deficits in HIV-1 infection.
	Lugoe, L.Wycliffe, Dr. philos.	Prediction of Tanzanian students' HIV risk and preventive behaviours
	Sandvik, B. Gunnhild, Dr. philos.	Fra distriktsjordmor til institusjonsjordmor. Fremveksten av en profesjon og en profesjonsutdanning
	Lie, Gro Therese, Dr. psychol.	The disease that dares not speak its name: Studies on factors of importance for coping with HIV/AIDS in Northern Tanzania
	Øygard, Lisbet, Dr. philos.	Health behaviors among young adults. A psychological and sociological approach
	Stormark, Kjell Morten, Dr. psychol.	Emotional modulation of selective attention: Experimental and clinical evidence.

- Einarsen, Ståle, Dr. psychol. Bullying and harassment at work: epidemiological and psychosocial aspects.
- 1997**
- Knivsberg, Ann-Mari, Dr. philos. Behavioural abnormalities and childhood psychopathology: Urinary peptide patterns as a potential tool in diagnosis and remediation.
- Eide, Arne H., Dr. philos. Adolescent drug use in Zimbabwe. Cultural orientation in a global-local perspective and use of psychoactive substances among secondary school students.
- Sørensen, Marit, Dr. philos. The psychology of initiating and maintaining exercise and diet behaviour.
- Skjæveland, Oddvar, Dr. psychol. Relationships between spatial-physical neighborhood attributes and social relations among neighbors.
- Zewdie, Teka, Dr. philos. Mother-child relational patterns in Ethiopia. Issues of developmental theories and intervention programs.
- Wilhelmsen, Britt Unni, Dr. philos. Development and evaluation of two educational programmes designed to prevent alcohol use among adolescents.
- Manger, Terje, Dr. philos. Gender differences in mathematical achievement among Norwegian elementary school students.
- 1998**
- V Lindstrøm, Torill Christine, Dr. philos. «Good Grief»: Adapting to Bereavement.
- Skogstad, Anders, Dr. philos. Effects of leadership behaviour on job satisfaction, health and efficiency.
- Haldorsen, Ellen M. Håland, Dr. psychol. Return to work in low back pain patients.
- Besemer, Susan P., Dr. philos. Creative Product Analysis: The Search for a Valid Model for Understanding Creativity in Products.
- H Winje, Dagfinn, Dr. psychol. Psychological adjustment after severe trauma. A longitudinal study of adults' and children's posttraumatic reactions and coping after the bus accident in Måbødalen, Norway 1988.
- Vosburg, Suzanne K., Dr. philos. The effects of mood on creative problem solving.
- Eriksen, Hege R., Dr. philos. Stress and coping: Does it really matter for subjective health complaints?
- Jakobsen, Reidar, Dr. psychol. Empiriske studier av kunnskap og holdninger om hiv/aids og den normative seksuelle utvikling i ungdomsårene.
- 1999**
- V Mikkelsen, Aslaug, Dr. philos. Effects of learning opportunities and learning climate on occupational health.
- Samdal, Oddrun, Dr. philos. The school environment as a risk or resource for students' health-related behaviours and subjective well-being.
- Friestad, Christine, Dr. philos. Social psychological approaches to smoking.

	Ekeland, Tor-Johan, Dr. philos.	Meining som medisin. Ein analyse av placebofenomenet og implikasjoner for terapi og terapeutiske teoriar.
H	Saban, Sara, Dr. psychol.	Brain Asymmetry and Attention: Classical Conditioning Experiments.
	Carlsten, Carl Thomas, Dr. philos.	God lesing – God læring. En aksjonsrettet studie av undervisning i fagtekstlesing.
	Dundas, Ingrid, Dr. psychol.	Functional and dysfunctional closeness. Family interaction and children's adjustment.
	Engen, Liv, Dr. philos.	Kartlegging av leseferdighet på småskoletrinnet og vurdering av faktorer som kan være av betydning for optimal leseutvikling.
2000		
V	Hovland, Ole Johan, Dr. philos.	Transforming a self-preserving "alarm" reaction into a self-defeating emotional response: Toward an integrative approach to anxiety as a human phenomenon.
	Lillejord, Sølvi, Dr. philos.	Handlingsrasjonalitet og spesialundervisning. En analyse av aktørperspektiver.
	Sandell, Ove, Dr. philos.	Den varme kunnskapen.
	Oftedal, Marit Petersen, Dr. philos.	Diagnostisering av ordavkodingsvansker: En prosessanalytisk tilnæringsmåte.
H	Sandbak, Tone, Dr. psychol.	Alcohol consumption and preference in the rat: The significance of individual differences and relationships to stress pathology
	Eid, Jarle, Dr. psychol.	Early predictors of PTSD symptom reporting; The significance of contextual and individual factors.
2001		
V	Skinstad, Anne Helene, Dr. philos.	Substance dependence and borderline personality disorders.
	Binder, Per-Einar, Dr. psychol.	Individet og den meningsbærende andre. En teoretisk undersøkelse av de mellommenneskelige forutsetningene for psykisk liv og utvikling med utgangspunkt i Donald Winnicotts teori.
	Roald, Ingvild K., Dr. philos.	Building of concepts. A study of Physics concepts of Norwegian deaf students.
H	Fekadu, Zelalem W., Dr. philos.	Predicting contraceptive use and intention among a sample of adolescent girls. An application of the theory of planned behaviour in Ethiopian context.
	Melesse, Fantu, Dr. philos.	The more intelligent and sensitive child (MISC) mediational intervention in an Ethiopian context: An evaluation study.
	Råheim, Målfrid, Dr. philos.	Kvinnens kroppserfaring og livssammenheng. En fenomenologisk – hermeneutisk studie av friske kvinner og kvinner med kroniske muskelsmerter.
	Engelsen, Birthe Kari, Dr. psychol.	Measurement of the eating problem construct.

	Lau, Bjørn, Dr. philos.	Weight and eating concerns in adolescence.
2002		
V	Ihlebak, Camilla, Dr. philos.	Epidemiological studies of subjective health complaints.
	Rosén, Gunnar O. R., Dr. philos.	The phantom limb experience. Models for understanding and treatment of pain with hypnosis.
	Høines, Marit Johnsen, Dr. philos.	Fleksible språkrom. Matematikklæring som tekstutvikling.
	Anthun, Roald Andor, Dr. philos.	School psychology service quality. Consumer appraisal, quality dimensions, and collaborative improvement potential
	Pallesen, Ståle, Dr. psychol.	Insomnia in the elderly. Epidemiology, psychological characteristics and treatment.
	Midthassel, Unni Vere, Dr. philos.	Teacher involvement in school development activity. A study of teachers in Norwegian compulsory schools
	Kallestad, Jan Helge, Dr. philos.	Teachers, schools and implementation of the Olweus Bullying Prevention Program.
H	Ofte, Sonja Helgesen, Dr. psychol.	Right-left discrimination in adults and children.
	Netland, Marit, Dr. psychol.	Exposure to political violence. The need to estimate our estimations.
	Diseth, Åge, Dr. psychol.	Approaches to learning: Validity and prediction of academic performance.
	Bjuland, Raymond, Dr. philos.	Problem solving in geometry. Reasoning processes of student teachers working in small groups: A dialogical approach.
2003		
V	Arefjord, Kjersti, Dr. psychol.	After the myocardial infarction – the wives' view. Short- and long-term adjustment in wives of myocardial infarction patients.
	Ingjaldsson, Jón Þorvaldur, Dr. psychol.	Unconscious Processes and Vagal Activity in Alcohol Dependency.
	Holden, Børge, Dr. philos.	Følger av atferdsanalytiske forklaringer for atferdsanalysens tilnærming til utforming av behandling.
	Holsen, Ingrid, Dr. philos.	Depressed mood from adolescence to 'emerging adulthood'. Course and longitudinal influences of body image and parent-adolescent relationship.
	Hammar, Åsa Karin, Dr. psychol.	Major depression and cognitive dysfunction- An experimental study of the cognitive effort hypothesis.
	Sprugevica, Ieva, Dr. philos.	The impact of enabling skills on early reading acquisition.
	Gabrielsen, Egil, Dr. philos.	LESE FOR LIVET. Lesekompetansen i den norske voksenbefolkningen sett i lys av visjonen om en enhetsskole.
H	Hansen, Anita Lill, Dr. psychol.	The influence of heart rate variability in the regulation of attentional and memory processes.

	Dyregrov, Kari, Dr. philos.	The loss of child by suicide, SIDS, and accidents: Consequences, needs and provisions of help.
2004		
V	Torsheim, Torbjørn, Dr. psychol.	Student role strain and subjective health complaints: Individual, contextual, and longitudinal perspectives.
	Haugland, Bente Storm Mowatt Dr. psychol.	Parental alcohol abuse. Family functioning and child adjustment.
	Milde, Anne Marita, Dr. psychol.	Ulcerative colitis and the role of stress. Animal studies of psychobiological factors in relationship to experimentally induced colitis.
	Stornes, Tor, Dr. philos.	Socio-moral behaviour in sport. An investigation of perceptions of sportspersonship in handball related to important factors of socio-moral influence.
	Mæhle, Magne, Dr. philos.	Re-inventing the child in family therapy: An investigation of the relevance and applicability of theory and research in child development for family therapy involving children.
	Kobbeltvedt, Therese, Dr. psychol.	Risk and feelings: A field approach.
2004		
H	Thomsen, Tormod, Dr. psychol.	Localization of attention in the brain.
	Løberg, Else-Marie, Dr. psychol.	Functional laterality and attention modulation in schizophrenia: Effects of clinical variables.
	Kyrkjebø, Jane Mikkelsen, Dr. philos.	Learning to improve: Integrating continuous quality improvement learning into nursing education.
	Laumann, Karin, Dr. psychol.	Restorative and stress-reducing effects of natural environments: Experiential, behavioural and cardiovascular indices.
	Holgersen, Helge, PhD	Mellom oss - Essay i relasjonell psykoanalyse.
2005		
V	Hetland, Hilde, Dr. psychol.	Leading to the extraordinary? Antecedents and outcomes of transformational leadership.
	Iversen, Anette Christine, Dr. philos.	Social differences in health behaviour: the motivational role of perceived control and coping.
2005		
H	Mathisen, Gro Ellen, PhD	Climates for creativity and innovation: Definitions, measurement, predictors and consequences.
	Sævi, Tone, Dr. philos.	Seeing disability pedagogically – The lived experience of disability in the pedagogical encounter.
	Wiium, Nora, PhD	Intrapersonal factors, family and school norms: combined and interactive influence on adolescent smoking behaviour.
	Kanagaratnam, Pushpa, PhD	Subjective and objective correlates of Posttraumatic Stress in immigrants/refugees exposed to political violence.

	Larsen, Torill M. B. , PhD	Evaluating principals` and teachers` implementation of Second Step. A case study of four Norwegian primary schools.
	Bancila, Delia, PhD	Psychosocial stress and distress among Romanian adolescents and adults.
2006		
V	Hillestad, Torgeir Martin, Dr. philos.	Normalitet og avvik. Forutsetninger for et objektivt psykopatologisk avviksbegrep. En psykologisk, sosial, erkjennelsesteoretisk og teoriehistorisk framstilling.
	Nordanger, Dag Øystein, Dr. psychol.	Psychosocial discourses and responses to political violence in post-war Tigray, Ethiopia.
	Rimol, Lars Morten, PhD	Behavioral and fMRI studies of auditory laterality and speech sound processing.
	Krumsvik, Rune Johan, Dr. philos.	ICT in the school. ICT-initiated school development in lower secondary school.
	Norman, Elisabeth, Dr. psychol.	Gut feelings and unconscious thought: An exploration of fringe consciousness in implicit cognition.
	Israel, K Pravin, Dr. psychol.	Parent involvement in the mental health care of children and adolescents. Emperical studies from clinical care setting.
	Glasø, Lars, PhD	Affects and emotional regulation in leader-subordinate relationships.
	Knutsen, Ketil, Dr. philos.	HISTORIER UNGDOM LEVER – En studie av hvordan ungdommer bruker historie for å gjøre livet meningsfullt.
	Matthiesen, Stig Berge, PhD	Bullying at work. Antecedents and outcomes.
2006		
H	Gramstad, Arne, PhD	Neuropsychological assessment of cognitive and emotional functioning in patients with epilepsy.
	Bendixen, Mons, PhD	Antisocial behaviour in early adolescence: Methodological and substantive issues.
	Mrumbi, Khalifa Maulid, PhD	Parental illness and loss to HIV/AIDS as experienced by AIDS orphans aged between 12-17 years from Temeke District, Dar es Salaam, Tanzania: A study of the children's psychosocial health and coping responses.
	Hetland, Jørn, Dr. psychol.	The nature of subjective health complaints in adolescence: Dimensionality, stability, and psychosocial predictors
	Kakoko, Deodatus Conatus Vitalis, PhD	Voluntary HIV counselling and testing service uptake among primary school teachers in Mwanza, Tanzania: assessment of socio-demographic, psychosocial and socio-cognitive aspects
	Mykletun, Arnstein, Dr. psychol.	Mortality and work-related disability as long-term consequences of anxiety and depression: Historical cohort designs based on the HUNT-2 study
	Sivertsen, Børge, PhD	Insomnia in older adults. Consequences, assessment and treatment.

2007

- V Singhammer, John, Dr. philos. Social conditions from before birth to early adulthood – the influence on health and health behaviour
- Janvin, Carmen Ani Cristea, PhD Cognitive impairment in patients with Parkinson's disease: profiles and implications for prognosis
- Braarud, Hanne Cecilie, Dr.psychol. Infant regulation of distress: A longitudinal study of transactions between mothers and infants
- Tveito, Torill Helene, PhD Sick Leave and Subjective Health Complaints
- Magnussen, Liv Heide, PhD Returning disability pensioners with back pain to work
- Thuen, Elin Marie, Dr.philos. Learning environment, students' coping styles and emotional and behavioural problems. A study of Norwegian secondary school students.
- Solberg, Ole Asbjørn, PhD Peacekeeping warriors – A longitudinal study of Norwegian peacekeepers in Kosovo

2007

- H Søreide, Gunn Elisabeth, Dr.philos. Narrative construction of teacher identity
- Svensen, Erling, PhD WORK & HEALTH. Cognitive Activation Theory of Stress applied in an organisational setting.
- Øverland, Simon Nygaard, PhD Mental health and impairment in disability benefits. Studies applying linkages between health surveys and administrative registries.
- Eichele, Tom, PhD Electrophysiological and Hemodynamic Correlates of Expectancy in Target Processing
- Børhaug, Kjetil, Dr.philos. Oppseding til demokrati. Ein studie av politisk oppseding i norsk skule.
- Eikeland, Thorleif, Dr.philos. Om å vokse opp på barnehjem og på sykehus. En undersøkelse av barnehjemsbarns opplevelser på barnehjem sammenholdt med sanatoriebarns beskrivelse av langvarige sykehusopphold – og et forsøk på forklaring.
- Wadel, Carl Cato, Dr.philos. Medarbeidersamhandling og medarbeiderledelse i en lagbasert organisasjon
- Vinje, Hege Forbech, PhD Thriving despite adversity: Job engagement and self-care among community nurses
- Noort, Maurits van den, PhD Working memory capacity and foreign language acquisition

2008

- V Breivik, Kyrre, Dr.psychol. The Adjustment of Children and Adolescents in Different Post-Divorce Family Structures. A Norwegian Study of Risks and Mechanisms.
- Johnsen, Grethe E., PhD Memory impairment in patients with posttraumatic stress disorder
- Sætrevik, Bjørn, PhD Cognitive Control in Auditory Processing

	Carvalhosa, Susana Fonseca, PhD	Prevention of bullying in schools: an ecological model
2008		
H	Brønnick, Kolbjørn Selvåg	Attentional dysfunction in dementia associated with Parkinson's disease.
	Posserud, Maj-Britt Rocio	Epidemiology of autism spectrum disorders
	Haug, Ellen	Multilevel correlates of physical activity in the school setting
	Skjerve, Arvid	Assessing mild dementia – a study of brief cognitive tests.
	Kjønniksen, Lise	The association between adolescent experiences in physical activity and leisure time physical activity in adulthood: a ten year longitudinal study
	Gundersen, Hilde	The effects of alcohol and expectancy on brain function
	Omvik, Siri	Insomnia – a night and day problem
2009		
V	Molde, Helge	Pathological gambling: prevalence, mechanisms and treatment outcome.
	Foss, Else	Den omsorgsfulle væremåte. En studie av voksnes væremåte i forhold til barn i barnehagen.
	Westrheim, Kariane	Education in a Political Context: A study of Knowledge Processes and Learning Sites in the PKK.
	Wehling, Eike	Cognitive and olfactory changes in aging
	Wangberg, Silje C.	Internet based interventions to support health behaviours: The role of self-efficacy.
	Nielsen, Morten B.	Methodological issues in research on workplace bullying. Operationalisations, measurements and samples.
	Sandu, Anca Larisa	MRI measures of brain volume and cortical complexity in clinical groups and during development.
	Guribye, Eugene	Refugees and mental health interventions
	Sørensen, Lin	Emotional problems in inattentive children – effects on cognitive control functions.
	Tjomsland, Hege E.	Health promotion with teachers. Evaluation of the Norwegian Network of Health Promoting Schools: Quantitative and qualitative analyses of predisposing, reinforcing and enabling conditions related to teacher participation and program sustainability.
	Helleve, Ingrid	Productive interactions in ICT supported communities of learners
2009		
H	Skorpen, Aina Øye, Christine	Dagliglivet i en psykiatrisk institusjon: En analyse av miljøterapeutiske praksiser
	Andreassen, Cecilie Schou	WORKAHOLISM – Antecedents and Outcomes

	Stang, Ingun	Being in the same boat: An empowerment intervention in breast cancer self-help groups
	Sequeira, Sarah Dorothee Dos Santos	The effects of background noise on asymmetrical speech perception
	Kleiven, Jo, dr.philos.	The Lillehammer scales: Measuring common motives for vacation and leisure behavior
	Jónsdóttir, Guðrún	Dubito ergo sum? Ni jenter møter naturfaglig kunnskap.
	Hove, Oddbjørn	Mental health disorders in adults with intellectual disabilities - Methods of assessment and prevalence of mental health disorders and problem behaviour
	Wageningen, Heidi Karin van	The role of glutamate on brain function
	Bjørkvik, Jofrid	God nok? Selvaktelse og interpersonlig fungering hos pasienter innen psykisk helsevern: Forholdet til diagnoser, symptomer og behandlingsutbytte
	Andersson, Martin	A study of attention control in children and elderly using a forced-attention dichotic listening paradigm
	Almås, Aslaug Grov	Teachers in the Digital Network Society: Visions and Realities. A study of teachers' experiences with the use of ICT in teaching and learning.
	Ulvik, Marit	Lærerutdanning som danning? Tre stemmer i diskusjonen
2010		
V	Skår, Randi	Læringsprosesser i sykepleieres profesjonsutøvelse. En studie av sykepleieres læringserfaringer.
	Roald, Knut	Kvalitetsvurdering som organisasjonslæring mellom skole og skoleeigar
	Lunde, Linn-Heidi	Chronic pain in older adults. Consequences, assessment and treatment.
	Danielsen, Anne Grete	Perceived psychosocial support, students' self-reported academic initiative and perceived life satisfaction
	Hysing, Mari	Mental health in children with chronic illness
	Olsen, Olav Kjellevoid	Are good leaders moral leaders? The relationship between effective military operational leadership and morals
	Riese, Hanne	Friendship and learning. Entrepreneurship education through mini-enterprises.
	Holthe, Asle	Evaluating the implementation of the Norwegian guidelines for healthy school meals: A case study involving three secondary schools
H	Hauge, Lars Johan	Environmental antecedents of workplace bullying: A multi-design approach
	Bjørkelo, Brita	Whistleblowing at work: Antecedents and consequences

Reme, Silje Endresen	Common Complaints – Common Cure? Psychiatric comorbidity and predictors of treatment outcome in low back pain and irritable bowel syndrome
Andersen, Wenche Helland	Communication difficulties in children identified with psychiatric problems
Beneventi, Harald	Neuronal correlates of working memory in dyslexia
Thygesen, Elin	Subjective health and coping in care-dependent old persons living at home
Aanes, Mette Marthinussen	Poor social relationships as a threat to belongingness needs. Interpersonal stress and subjective health complaints: Mediating and moderating factors.
Anker, Morten Gustav	Client directed outcome informed couple therapy
Bull, Torill	Combining employment and child care: The subjective well-being of single women in Scandinavia and in Southern Europe
Viig, Nina Grieg	Tilrettelegging for læreres deltakelse i helsefremmende arbeid. En kvalitativ og kvantitativ analyse av sammenhengen mellom organisatoriske forhold og læreres deltakelse i utvikling og implementering av Europeisk Nettverk av Helsefremmende Skoler i Norge
Wolff, Katharina	To know or not to know? Attitudes towards receiving genetic information among patients and the general public.
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