Adaptive Team Coordination

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It is hypothesized that highly effective teams adapt to stressful situations by using effective coordination strategies. Such teams draw on shared mental models of the situation and the task environment as well as mutual mental models of interacting team members' tasks and abilities to shift to modes of implicit coordination, and thereby reduce coordination overhead. To test this hypothesis, we developed and implemented a team-training procedure designed to train teams to adapt by shifting from explicit to implicit modes of coordination and choosing strategies that are appropriate during periods of high stress and workload conditions. Results showed that the adaptation training significantly improved performance from pre- to posttraining and when compared with a control group. Results also showed that several underlying team process measures exhibited patterns indicating that adaptive training improved various team processes, including efficient use of mental models, which in turn improved performance. The implication of these findings for team adaptive training is discussed. This research spawned the adaptive architectures for a command and control project investigating adaptive models that focus on changes in the structural and process architecture of large organizations. The research also produced a cadre of integrated performance assessment tools that have been used in training and diagnostic settings, and new components for a team training package focused on effective coordination in high-performance teams.

INTRODUCTION

A ubiquitous factor that teams have to confront and adapt to is stress induced by uncertainty, ambiguity, and time pressure. Stress reduces an individual's or team's flexibility and causes errors (e.g., the *Vincennes* incident). Janis and Mann (1977) stated that under stress, particularly high stress, team members may experience such an inordinate amount of cognitive constriction and perseveration that their thought processes are disrupted. Not all teams, however, appear to be equally affected. Serfaty, Entin, and Deckert (1993) found that an increase in the level of stress did not necessarily result in a decrease in the team's outcome performance. For example, increasing target uncertainty did not have a direct effect on the identification error-rate of the team; team members simply increased their information-seeking rate. In other words, team members coped by altering their information-seeking strategy, a characteristic that LaPorte and Consolini (1988) attributed to highly reliable teams. The most striking evidence of team adaptation to stress in the experiment conducted by Serfaty, Entin, and Deckert (1993), however, came from the observation that teams were able to maintain the same level of performance with one-third of the time available to make decisions.

We maintain, as did Serfaty, Entin, and Deckert (1993), that the primary adaptation mechanism that allowed these teams and teams in general to maintain and improve their performance under a high level of time pressure was a switch from explicit to implicit coordination, a special mode of coordination (Kleinman &

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Serfaty, 1989; Orasanu, 1990; Wang, Luh, Serfaty, & Kleinman, 1991).

Cannon-Bowers and Salas (1990), Orasanu (1990), and others have effectively argued that implicit coordination involves the use of shared or mutual mental models among team members. It is hypothesized that shared mental models are made up of two principal components: a common or consistent model of the tactical situation among team members and a set of mutual mental models about the other team-member functions. It is the mutual mental models that team members have of one another that allow one team member to preempt the actions and needs of another so that actions can be coordinated and needs met in the absence of explicit communication. In this way implicit coordination reduces communication and coordination overhead. For example, in a study to observe how teams cope and adapt to high levels of stress, Entin, Serfaty, Entin, and Deckert (1993) reported that there was a strong correlation (.79) between the use of implicit coordination and the performance levels of the six teams that participated in the experiment. Moreover, the use of implicit coordination was adaptive to time-pressure-induced stress. The three higher-performing teams in the experiment increased their use of implicit coordination as time pressure increased, whereas the three lower-performing teams did not. Presumably some teams are able to employ their mutual mental models and shift to implicit communication modes under high stress, thereby reducing their communication and coordination load so that more attention can be focused on their mission tasks.

Orasanu's (1990) study of communication strategies used by airline pilots to cope with emergencies suggests that effective shared mental models are developed during periods of low workload and implemented during periods of high workload. To the extent that team members have accurate mental models, implicit coordination allows the team to maintain an effective level of performance under stress. To the extent that the mental models are lacking or inaccurate, high stress will lead to degraded performance.

We believe there is ample evidence that understanding superior team performance and coordination in terms of shared mental models is a promising approach to team training (Cannon-Bowers, Salas, & Converse, 1991; Kleinman & Serfaty, 1989; MacIntyre, Morgan, Salas, & Glickman, 1988). Moreover, researchers (e.g., Morris, Rouse, & Zee, 1987) hypothesize that training fostering the development of accurate mental models of a system will improve the performance of operators controlling those systems. This viewpoint can be extended to the team environment, where the development of a system model can be complemented by the development of mutual mental models of each team member's tasks and abilities. The importance of implicit coordination strategies used by effective teams in high-stress situations suggests that shared mental models are useful constructs to explain the anticipatory behavior of team members in the absence or scarcity of communications.

Decision makers have other means of reducing high cognitive loads (e.g., stress) confronting them. Payne, Bettman, and Johnson (1986) have argued that individual decision makers faced with increasing time pressure or task complexity will turn to various heuristics to lower the cognitive effort required to perform the task. Payne et al. noted that although some heuristics may be detrimental (Tversky, 1969), many prove to be adaptive to the increases in task demands. It is their contention that people's selection among strategies is adaptive; a decision maker will select strategies that are relatively efficient in terms of effort and accuracy as task demands escalate.

Decision makers operating as a team have a richer repertoire of alternative adaptive strategies available to them than does a single decision maker working alone. Extending the Payne et al. (1986) findings to the team environment, Kleinman and his colleagues (Kleinman, Luh, Pattipati, & Serfaty, 1992; Kleinman & Serfaty, 1989; Serfaty & Kleinman, 1985) hypothesized that high-performing teams will employ adaptive strategies in conditions of high workload/task complexity. Moreover, they will do so in a highly efficient manner that minimizes team errors and maintains performance. Indeed, experimental results reported by Kleinman and Serfaty (1989) and Wang et al. (1991) show that in conditions of high workload, higher performing teams adopt communication and coordination strategies that reduce the effort needed to meet task demands while maintaining performance levels.

Clearly, teams that perform well in high-stress conditions employ different strategies than do teams that perform poorly under stress (Entin et al., 1993; Entin & Serfaty, 1990; LaPorte & Consolini, 1988; Serfaty, Entin, & Deckert, 1993). LaPorte and Consolini identified three characteristics of highly reliable teams: The team structure is *adaptive* to changes in the task environment; the team maintains *open and flexible communication* lines; and team members are extremely *sensitive to other members' workload and performance* in high-tempo situations. High-performing teams possess the ability to adapt not only their decision-making and coordination strategies, but also their structure in order to maintain their performance in the presence of escalating workload and stress (LaPorte & Consolini, 1988; see also Pfeiffer, 1989, and Reason, 1990a, 1990b). We maintain that an important mechanism that highly effective teams use in the adaptation process is to develop a shared mental model of the task environment and the task itself, as well as a mutual mental model of interacting team members' tasks and abilities. These models are used to generate expectations about how other team members will behave (Cannon-Bowers & Salas, 1990; MacIntyre et al., 1988; Orasanu, 1990; Serfaty, Entin, & Volpe, 1993).

Research has shown that high-performing teams make use of such models (particularly when timely, error-free, and unambiguous information is at a premium) to anticipate both the developments of the situation and the needs of the other team members (Entin et al., 1993; Serfaty, Entin, & Deckert, 1993). This research evidence also shows that it is this *team coordination strategy* (anticipating changes in the situation and in the needs of other team members) that contributes significantly to the teams' high performance under stress. It is also the reason these teams perform consistently better under a wide range of tactical conditions.

ADAPTATION MODEL AND HYPOTHESES

Based on the adaptation model presented in Figure 1, we assume that high-performing teams adapt their (a) decision-making strategy, (b) coordination strategy, and (c) behavior and organizational structure to the demands of the situation in order to either maintain team performance or to minimize perceived stress. The experiment we shall discuss focuses on the middle loop of the model depicted in Figure 1.

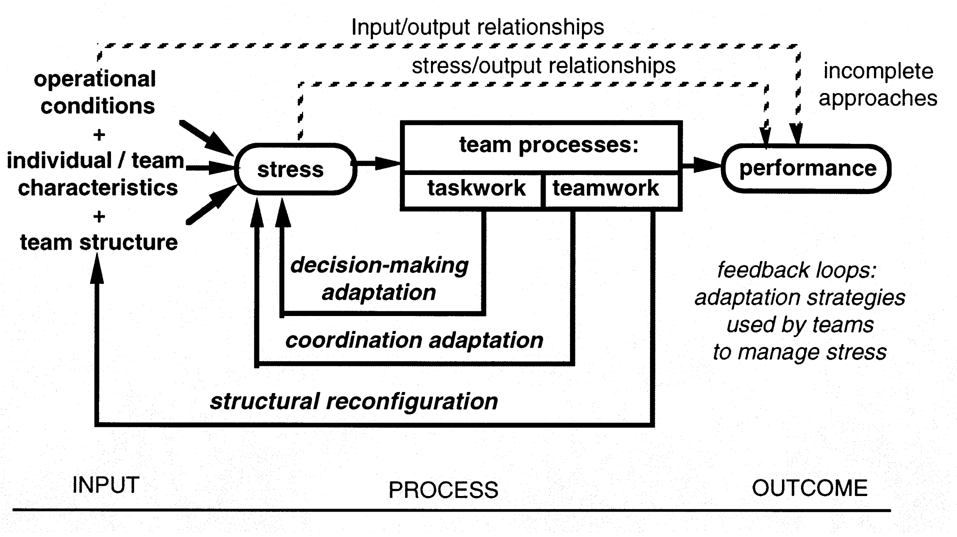

Figure 1. Theoretical framework for team adaptation.

To test the hypothesis that high-performing teams sense changes in the situational stress level and adjust their coordination strategies accordingly, we exposed ad hoc teams to the team adaptation and coordination training (TACT) procedure. (A glossary of abbreviations/acronyms is at the end of this article.) We taught ad hoc teams to recognize changes in situational stress levels, a set of adaptive coordination strategies, and the most appropriate conditions to use each adaptive strategy.

We reasoned that if teams could become aware of mounting stress and had a set of adaptive strategies to use in such conditions, then at the first signs of increased stress they would adapt accordingly. The adaptive strategies would help the team reduce their coordination overhead, freeing up more time for the increasing number of anti-air warfare (AAW) tasks they must perform. Several of these adaptive coordination strategies encourage switching to implicit modes of communication when the stress level is high. We hypothesized that teams exposed to the adaptive and coordination training (i.e., that were taught to recognize changes in the situational stress level and change to more effective coordination strategies) would perform better than teams without such training.

We also implemented an information structuring strategy that follows directly from the mental model perspective. We adapted the strategy used by Serfaty, Entin, and Deckert (1993), who instructed team leaders to periodically communicate their judgments (hostile, neutral) and related confidences about incoming targets to the other team members. The experimenters reported that providing this type of information to the team made the team more resilient to increasing ambiguity and time pressure. Serfaty et al. inferred that the information contained in the team leader's periodic briefings improved the mental models of individual team members. Improvement in the mental models occurred because the team leader's information focuses the team on the current tactical priorities and updates their understanding of the situation.

Adapting the Serfaty, Entin, and Deckert (1993) strategy, we instructed the team leader to give periodic situation-assessment briefs to the team. We held that these briefings would help team members update their mental models of the situation and leader, improving implicit communication within the team. The periodic situation-assessment briefs were combined with the TACT procedure to produce a second condition, TACT+. It is important to note that our design is not intended to provide a test of the isolated effect of the leader's updates without the adaptive coordination training. This is based on two arguments. First, we argue that the periodic information provided by the leader would be useful to the team members *only* if they had been trained to communicate and coordinate in an adaptive fashion beforehand. Second, practical considerations prevented us from conducting a full-factorial experiment with the four levels of a training manipulation necessary to test this hypothesis.

Our primary hypothesis asserts that teams receiving TACT and TACT+ will exhibit higher mission performance than teams that do not receive this training. We further hypothesize that teams receiving TACT+ will be able to formulate better shared situational mental models and, therefore, will perform at a higher level than teams that receive only TACT. We expect that teams receiving the adaptive coordination training will perform at a higher level and exhibit higher scores on process variables supporting performance than control teams receiving neither adaptive coordination training nor periodic situation-assessment briefs. We also predict that the benefit of adaptive coordination training both with and without periodic situation-assessment briefs will be greatest in high stress/workload conditions.

METHOD

Participants

The participants were 30 naval officers attending Department Head School at the Surface Warfare Officers School (SWOS) in Newport, Rhode Island, and 29 officers plus 1 civilian enrolled in courses at the Naval Postgraduate School (NPS) in Monterey, California. The participants in each sample (SWOS and NPS) were organized into six teams of 5 individuals each. An officer with tactical action officer (TAO) experience was selected to play the role of TAO in each team. The remaining 4 team members apportioned themselves to the four watch stations of identification supervisor (IDS), tactical information coordinator (TIC), anti-air warfare coordinator (AAWC), and electronic warfare supervisor (EWS). All members of the sample participated in the experiment for about 8 h, which in some cases was distributed over more than 1 day.

Design

The experimental design used in this study was a pretest/posttest control group design (Design 4 in Campbell & Stanley, 1963). The three levels of experimental condition (control, TACT, and TACT+), the two levels of testing (pre- and postintervention), and the two levels of workload-induced stress (low and high) were completely crossed. This created a 3 (experimental condition) between-subjects × 2 (testing) within-subject × 2 (stress) within-subject factorial design. To control for site differences, the experimental design was replicated at both sites; two teams from each site were randomly assigned to the control condition, the TACT condition, or the TACT+ condition.

Independent Variables

Training manipulations. The training manipulations used to establish the three conditions of the primary independent variable (TACT, TACT+, and control) are outlined here; for a more detailed description, see Entin, Serfaty, and Deckert (1994). The aim of TACT is not to teach teams new task knowledge or skills. Instead, TACT teaches teams strategies that enable them to better manage the increases in coordination and communication overhead that result from increases in workload and stress.

TACT occurred in three phases. During Phase 1, teams were given expository instruction on how to identify signs and symptoms of stress in the external environment, in the team, and in individual team members (including workload-induced physical and psychological signs). In Phase 2, teams received instruction on five adaptive strategies they might use to cope with increases in workload and stress. These strategies, which were designed to reduce communication and coordination overhead within the team, are (a) preplanning, (b) use of idle periods, (c) favoring information transmission over action/task coordination, (d) anticipation of information needs (implicit communication), and (e) dynamic redistribution of workload among team members. (A more complete description of the strategies is in Entin et al., 1994).

Also as part of Phase 2, teams viewed three pairs of specially prepared videotape vignettes in which a team of five active-duty U.S. Navy and Air Force officers demonstrated effective and ineffective strategies, as well as indications of heightened stress on team behavior. Extensive discussions preceded each vignette, and vignettes were systematically interrupted to point out specific indications of stress and examples of effective and ineffective behavior and strategy utilization.

In Phase 3, teams were given the opportunity to practice what they had learned by completing two 12-min training scenarios. During and after each training scenario, the participants received feedback and comments on their coordination behavior and performance. Phase 3 concluded with the viewing of a summary videotape.

The TACT+ intervention was identical to TACT with one notable addition. During TACT+ the TAOs were given specific instructions and practice on how to give brief (approximately 30 s) periodic situation-assessment updates (SITREPs) to the rest of the team. These SITREPs included information on the TAOs' current priorities, targets of interest, and situation perception. TAOs were prompted by one of the role players at the control station to give the SITREPs approximately once every 3 min. Team members were taught that the SITREPs contained a digested summary of the situation as perceived by the TAO based on reports supplied by team members and other external sources. Team members were further instructed that these SITREPs represented the TAO's mental model of the tactical situation and, as such, could help unify the team's tactical picture. That is, team members could use the perspective and priorities contained in the TAO's SITREPs to select what to report to the TAO and what to filter out as nonessential information.

The control condition provided control teams with an experience comparable to that experienced by the teams in the TACT and TACT+ groups. Teams in the control condition were told they were being trained to appreciate the "big picture" and how their team's performance affected other teams on their platform and in the battle group. Care was taken to ensure that the control condition training was of the same duration, was approximately the same intensity, and appeared logical. Moreover, control teams were afforded the same practice opportunities as the teams in the two training conditions. Postexperiment interviews showed that participants in the control condition viewed the experience as a legitimate training situation and that no one suspected that he or she was in a control condition.

Testing. All teams performed two data-collection scenarios prior to the training manipulation and two data-collection scenarios after the training manipulation.

Workload-induced stress. The four-data collection scenarios used during the experiment were developed by the Naval Air Warfare Center Training Systems Division (NAWCTSD). Two scenarios were developed with high workload (stress) and two with low workload (stress). In the high-workload scenarios there were 50% more targets to process than in the low-workload scenarios. Each scenario lasted between 25 and 30 min. The primary task performed in each scenario by the five-person combat information center (CIC) team was situation assessment and deconfliction (the process of discriminating friend or foe). The team's objective was to correctly infer the identity, and thus the intentions (i.e., potentially hostile or neutral), of detected air and surface contacts. The function of each watch station was to supply the TAO with information necessary (but not always sufficient) to draw conclusions regarding a contact's identity, capability, and intention. The TAO then prescribed how the contacts were to be processed.

Prior to and again after the training intervention, each team participated in one high- and one low-stress scenario. The presentation of high- and low-stress scenarios was counterbalanced over the four trials using an a-b-b-a (or b-a-a-b) ordering. A manipulation check showed that subjective workload means derived from the Task Load Index (TLX; Hart & Staveland, 1988) were significantly higher under high than under low stress, indicating that the stress manipulation was effective.

Dependent Measures

Anti-air warfare performance outcome and teamwork assessment. Performance outcome and teamwork were assessed during each trial by two active-duty naval officers at the NPS site and two retired naval officers at the SWOS site who were trained to use the Team AAW Performance Scale. The scale consists of 12 behaviorally anchored items that assess overall AAW team performance and 15 behaviorally anchored items that assess the six dimensions of teamwork (i.e., team orientation, communication behavior, monitoring behavior, feedback behavior, back-up behavior, and coordination behavior). The performance items are based on the AAW Team Performance Index and the Behavior Observation Booklet (Hall, Dwyer, Cannon-Bowers, Salas, & Volpe, 1993; Johnston, Cannon-Bowers, & Jentsch, 1995). The teamwork items were adapted from teamwork assessment instruments used by Serfaty, Entin, and Deckert (1993) and Entin et al. (1993), which in turn are based on the AAW Team Observation Measure (ATOM) developed by NAWCTSD and a model of team evolution and maturation by Glickman and Zimmer (1989) and Glickman et al. (1987).

The agreement between the two observers scoring teamwork and performance outcome, for the NPS and SWOS sites combined, was found to be high. Coefficient alphas (Cronbach, 1970) were .79 or higher. Therefore, the scores from the two observers were averaged to form a performance outcome score and a teamwork score for each team.

Communication/coordination assessment. Two psychologists, who had previous experience coding verbal behavior and who demonstrated at least 85% agreement on practice materials, coded the behavior of the teams throughout the scenario. Observers used specifically designed observation matrices to code the verbal behavior of the teams; one matrix was designed to code the TAO's verbal behavior, and the other matrix was designed to code the subordinates' verbal behavior. Both matrices are laid out in a similar manner. Down the side of the matrix are the types and contents of communication messages to be noted (e.g., request information, request action and task, transfer information, transfer action and task, acknowledgments), and across the top are the message destinations (e.g., on the TAO's form: TAO to TIC, TAO to IDS, TAO to All; and on the subordinate's form: TIC to TAO or Team, IDS to TAO or Team, Team to Out). Each tally mark a coder makes in a matrix denotes a particular message type and content and to whom that message was directed. Both coders wore earphones connected to the communication net to monitor team communication.

To derive the various communication/coordination measures from the raw communication matrices, appropriate rows and/or columns were summed. In addition, the duration (in minutes) of each data-collection trial (scenario) was recorded and used to compute communication-rate variables.

Workload measure. At the conclusion of each trial, team members completed the TLX (Hart & Staveland, 1988) developed for the National Aeronautics and Space Administration. The TLX is a self-report subjective measure of workload that requires participants to rate the workload they just experienced on six dimensions (mental demand, physical demand, temporal demand, performance, effort, and frustration). Participants respond to each dimension using a 20-point graphical scale anchored at one end by the words *very low* and at the other end by the words *very high.* The TLX has exhibited good validity and reliability in the past (Lysaght et al., 1989). Its reliability in this study, as assessed by coefficient alpha, was .85.

Procedure

The Decision-Making Evaluation Facility for Tactical Teams (DEFTT) simulation provides a relatively realistic abstraction of five AAW CIC watch stations in "air-alley" found aboard an Aegis-capable platform. The teams received training on how to play the DEFTT simulator and engaged in three practice scenarios developed by NAWCTSD. NAWCTSD personnel were available to help any team member in need during the practice scenarios and to give detailed feedback at the end of each one. The DEFTT instruction and practice phase of the experiment lasted approximately 2 h.

A two-channel communication system provided a representation of the open-net communication network aboard ship. Team members at each of the watch stations could use one channel to communicate with team members at other watch stations and the other channel to communicate with the "outside world" (i.e., role players at the control station). Duplicating the arrangement found aboard ship, team members wore headsets equipped with a microphone and earphones (one in each ear) configured to allow simultaneous monitoring of each channel.

Before each data collection scenario, the teams received a mission brief delineating their mission, goals, potential threats, and rules of engagement. The briefing was always delivered by an active or retired naval officer. Prior to each data-collection scenario, the acting TAOs were always afforded time to brief their teams if they so desired. The first scenario was then presented. At the conclusion of the scenario, participants completed the TLX. Teams were then given a break, during which they received little or no feedback with regard to their performance. This was followed by a second scenario, which followed the same format as the first. The training intervention, which was administered after completion of the second scenario, lasted approximately 2 h and was always conducted by the same individual (EEE) regardless of site. After the adaptive or sham training, data collection Scenarios 3 and 4 were administered in the same manner as Scenarios 1 and 2.

RESULTS

Team AAW Performance

The average team AAW performance (hereafter referred to as *team performance*) was derived by taking the mean of the 12 items constituting the Team AAW Performance Scale. Analysis of the average team performance scores clearly demonstrates that the adaptation training intervention was effective. As shown in Figure 2, the team performance means of the three groups – control, TACT, and TACT+ – were not different from one another prior to the adaptation training intervention, $F(2, 9) = 1.50$, *ns,* whereas after training the performance of the three groups differed significantly, $F(2, 9) = 4.91$, $p < .04$. Figure 2 also shows that teams that received the adaptation training performed at a higher level after the intervention than before – the preintervention mean was 4.13, and the postintervention mean was 4.90; $t(9) = 2.44$, $p < .05$ – whereas the teams in the control condition showed about the same level of team performance pre- and postintervention. Although the main effect for stress was significant, $F(1, 9) = 5.88$, $p < .04$, showing higher team performance under the low- than the high-stress condition, there was no difference between the low- and high-stress scenarios prior to or after the adaptation training intervention; nor were any significant interactions found involving stress before or after the adaptation training intervention. These findings indicate that the stress induced by the high-stress scenarios was relatively subtle, appearing only when both high-stress scenarios are compared with both low-stress scenarios over the entire sample.

Campbell and Stanley (1963) recommended that when using Design 4, one should combine the computation of pretest/posttest gain scores for each group with pretest scores as the covariate in an analysis of covariance in order to obtain the most responsive analysis procedure. To implement this analysis, we subtracted the pretest average performance score from the posttest average performance score to yield a gain score for each team in the sample. Using pretest average performance scores as a covariate on the computed gain scores, a Training Treatment × Stress analysis of covariance was computed. Inspection of the adjusted performance gain score means in Figure 3 confirms that the adaptive training intervention was effective and that teams receiving TACT and TACT+ performed significantly better than teams in the control condition, $F(2, 19) = 5.73$, $p < .02$.

The covariance analysis also shows the benefit of the intervention to help teams cope with the debilitating effects of stress. Examining the adjusted means, we see that high stress caused a drop in team performance when compared with low stress for teams in the control condition. Although the performance of teams receiving TACT was worse under high stress than under low stress, TACT provided some improvement in the performance of teams under high stress when compared with teams under high stress in the control condition. Clearly, however, the TACT+ intervention yielded the greatest benefit to teams under high stress. The TACT+ intervention allowed teams to perform as well under high stress as

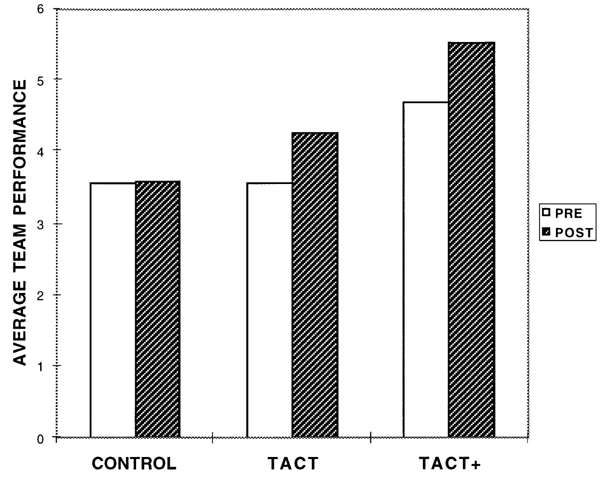

Figure 2. Average team performance by training treatments, pre- and postintervention.

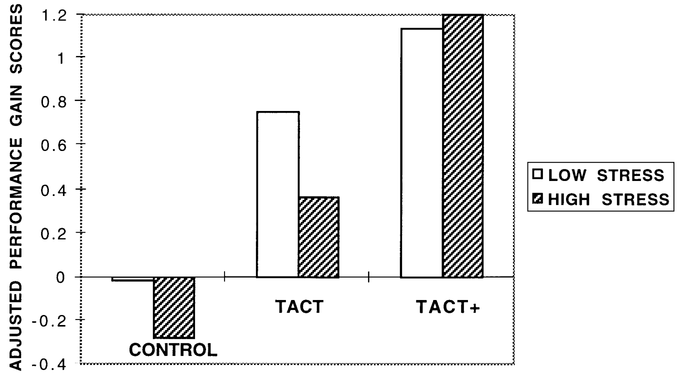

Figure 3. Adjusted performance gain scores by training treatments and stress.

they did under low stress such that their performance under high stress was significantly better than that of the control condition teams, $t(8) = 1.98$, $p < .05$, one tail.

Teamwork

To analyze the process measures of teamwork, we averaged and analyzed the six items representing the original ATOM measures (see Entin et al., 1993; Serfaty, Entin, & Deckert, 1993). Results of the ATOM teamwork-measure analysis closely parallel the performance findings. Figure 4 shows that teamwork for the three groups differed significantly after training, $F(2, 9) = 5.48$, $p < .03$, but not prior to training, $F(2, 9) = 1.78$, *ns*. The analysis also shows that the teamwork of the two groups receiving training improved significantly after the adaptation training intervention – the preintervention mean was 4.08, and the postintervention mean was 4.85, $t(9) = 2.26$, $p < .05$ – whereas the teamwork for the control teams was about the same pre- and postintervention. We contend that adaptation training positively affected teamwork skills, which in turn gave rise to the superior performance outcomes observed for the TACT and TACT+ teams.

Similar to the performance results, ATOM teamwork was better under low stress than under high stress, $F(1, 9) = 6.76$, $p <.03$; however, none of the interactions involving stress were significant. The covariance gain score analysis performed on the ATOM teamwork

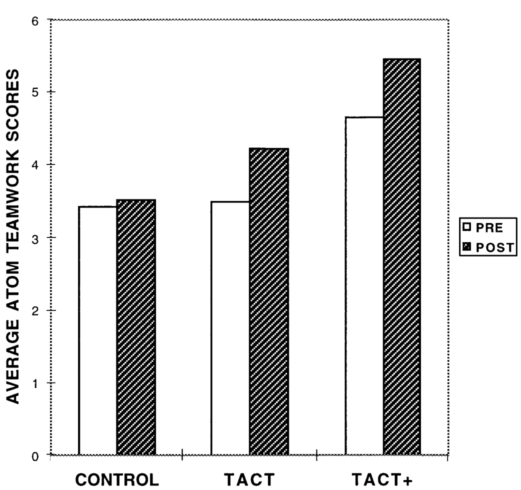

Figure 4. Average ATOM scores by training treatments, pre- and postintervention.

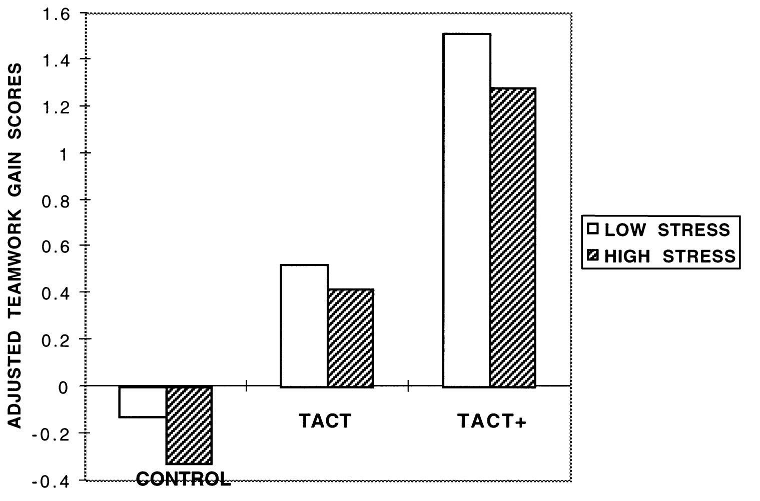

Figure 5. Adjusted teamwork gain scores by training treatments and stress.

measure is depicted in Figure 5. There is no longer a main effect attributable to stress. Teamwork increases monotonically from the control to the TACT+ condition under low stress, $F(2, 8) = 4.58$, $p < .05$, and the increase in teamwork under high stress is almost as strong. Teamwork means for the TACT+ condition are significantly higher than the control means, $t(8) = 1.87$, $p < .05$. We contend that it is more difficult to perform and exhibit good teamwork skills in a high-stress environment than in a low-stress one. That teamwork skills were significantly higher in the TACT+ condition than in the control condition, and that teamwork skills showed higher gain scores under the high-stress condition than under the low-stress one, indicates that TACT training offered a greater benefit to teams under high stress than to those under low stress. Otherwise, teamwork skills under high stress would be expected to be significantly below teamwork skills under low stress.

Communication/Coordination

Our theory predicts that TACT intervention will induce teams to shift away from explicit communication to more implicit communication. This might lead one to predict that the overall communication rate would decline as a result of this intervention; however, this is not necessarily the case because several factors come into play. The total communication rate means as a function of experimental condition, training, and stress are depicted in Table 1. A significant three-way interaction, $F(2, 9) = 11.41$, $p < .009$, shows that the communication rate did decline after the training intervention, but only for the low-stress scenarios. In the high-stress scenarios communication rates stayed about the same pre- and post-intervention. Although the TACT intervention made teams more efficient when they communicated – hence the drop in communication after training in the low-stress scenario – the

TABLE 1: Total Communication Rate Means as a Function of Experimental Condition, Training, and Stress

	Pretraining		Posttraining	
	Low Stress	High Stress	Low Stress	High Stress
TACT+	8.25	8.33	6.66	8.59
TACT	8.36	8.24	6.43	8.25
Control	7.24	6.96	6.09	7.59

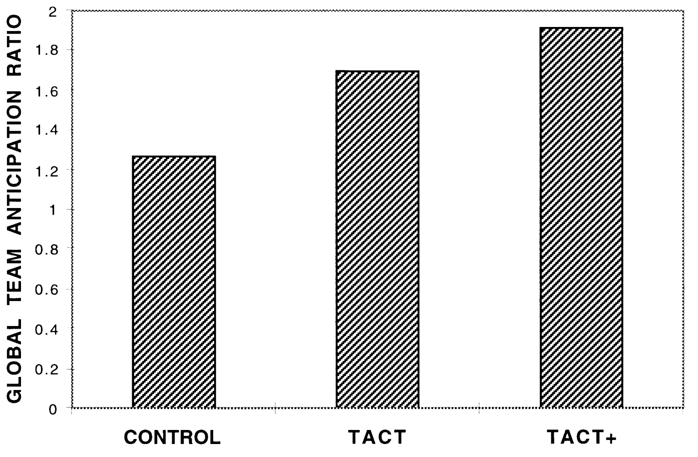

Figure 6. Global anticipation ratio by training treatments

increased demands in the high-stress scenarios required higher rates of communication among the team members. However, as we explain in the next set of results, the TACT and TACT+ interventions induced *different* communication patterns in a high-stress condition.

Anticipation ratios. Anticipation ratios are computed by dividing the number of transfers to individual X by the number of requests made by X. An anticipation ratio greater than 1.0 indicates that X's needs are being anticipated, and X receives what is needed without having to request it every time. Anticipation ratios greater than 1.0 can also be interpreted as a shifting away from explicit communication and toward implicit communication. To shift from explicit to implicit communication, team members must rely on mental models of the other team members, developed earlier, to anticipate their needs. Thus a large anticipation ratio can be taken as partial confirmation for mutual mental models.

An important anticipation ratio, because it reflects the tenor of the team as a whole, is the one based on all transfers and all requests issued in a team and is referred to as the *overall (or global) anticipation ratio.* As hypothesized, both the TACT and TACT+ interventions produced significantly higher global anticipation behavior than did the control condition (see Figure 6). Analysis revealed that the TACT intervention produced a 23% increase in the overall anticipation ratio – a shift from 1.46 in the preintervention condition to 1.79 in the postintervention condition, $F(1, 9) = 34.59$, $p < .001$. In the main, TACT appears to increase team members' awareness of the needs of others, thus allowing them to push needed information before it is requested.

Also as predicted, the anticipation ratio based on subordinate-to-TAO transfers contrasted with the TAO-to-subordinate requests showed a significant increase with training: a shift from 1.80 in the preintervention condition to 2.26 in the postintervention one, $F(1, 9) = 17.49$, $p < .003$. Moreover, the anticipation ratio based on team members' information transfers to the TAO compared with TAO information requests from team members (1.58 pre- vs. 2.31 postintervention), and TAO information transfers to team members compared with team members' information requests from the TAO (4.14 pre- vs. 6.36 postintervention), show the same pattern of results: The anticipation ratio is greater after intervention than before, $F(1, 9) = 15.70$, $p < .004$, and $F(1, 9) = 8.95$, $p < .02$, respectively. Across experimental conditions the pattern is also complementary to the effect of the training intervention. The ratio of the TAO information transfer to team members compared with team members' information requests from TAO was greater for teams receiving the training (TACT+ and TACT conditions) than in the control condition (6.69 and 3.26, respectively), $t(9) = 1.99$, $p < .05$, one-tail. These significant anticipation ratio results between subordinates and the TAO confirm the overall anticipation results, further indicating that TACT facilitates the development of better mutual mental models for all members of the team.

DISCUSSION

This study tested the hypothesis that highly effective teams adapt to stressful (high-workload) situations by using effective coordination strategies and that ad-hoc teams can be trained to employ many of these adaptive strategies to maintain performance under conditions of high stress and workload. We developed, implemented, and evaluated team-training procedures, TACT and TACT+, designed to teach ad-hoc CIC teams to adapt to high-stress situations by improving their coordination strategies. In the face of increasing stress, trained teams were expected to minimize their communication/coordination overhead in order to maintain performance level. The training program was predicated on the importance of a shared mental model of the situation and the task environment, as well as mutual mental models of interacting team members' tasks and abilities.

Results plainly demonstrate that the TACT and TACT+ adaptation training procedure was successful. Teams in the TACT and TACT+ conditions performed significantly better than teams assigned to a control condition. Comparisons of pre- and posttraining conditions showed that the teams' AAW performance was significantly improved, by an average of 21%, as a result of the TACT and TACT+ interventions. The four teams constituting the control group showed about the same level of performance before and after the sham training, which included the same amount of practice time as the adaptation training procedures. Teamwork for the three experimental conditions differed significantly, and the results paralleled the performance findings. We contend that the adaptation training program improves teamwork behaviors and coordination strategies, which in turn lead to better performance. Specifically, teams that received the training program reduced their coordination and communication overheads and thereby had more time and cognitive resources to devote to the task, resulting in better performance.

Another performance-related hypothesis supported by the results concerns performance levels in conditions of high stress and workload. We felt that because of its inherent design to be adaptive to stress and workload, the TACT (and TACT+) interventions would mitigate the effects of stress so that performance would reach similar levels under high stress and low stress. Findings for the adjusted gains (see Figure 3) revealed that teams receiving the TACT+ intervention demonstrated substantially improved performance for both the high- and low-stress conditions over the control and the TACT manipulations. Moreover, the TACT+ teams did as well under high stress as they did under low stress. Evidently, the adaptation training, and TACT+ in particular, made teams more resilient to stress. This resilience to stress may be attributable in part to better teamwork skills fostered by the adaptation training.

Results also support the hypothesis that TACT+ improves on TACT. We hypothesized that the SITREPs, which differentiated TACT+ from TACT, would provide all team members with more continuous and coherent situational mental models based on the TAO's current tactical priorities. As shown in Figure 2, the TACT+ procedure produced performance improvements beyond TACT alone. From these results we conclude that the addition of a SITREP component to adaptation training significantly improves the performance of teams beyond adaptive coordination training alone (TACT).

Changes in communication patterns were dominated by a stronger upward (from subordinates to leader) information push and more anticipatory behavior for the TACT and the TACT+ teams, supporting the hypothesis that the training program induces implicit team-coordination mechanisms that are essential to effective adaptation to stress. Moreover, results show that changes in team communication patterns from pre- to postintervention performance were in accord with the adaptation training objectives. Specifically, the hierarchical organizational structure of the CIC team (i.e., TAO-subordinates) and the nature of the AAW tasks are such that the lion's share of the team communications (about 50%) is concentrated around the TAO. Therefore, training manipulations focused on the "upward anticipatory behavior" (i.e., subordinates' anticipation of the TAO's needs).

We found that both the TACT and TACT+ training produced anticipatory behavior that primarily lowered the downward communication rate but also reduced the TAO's information requests. Furthermore, the TACT+ procedure had the additional effect of increasing significantly the lateral (subordinate-to-subordinate) information-exchange and action-coordination messages. Our contention is that coordination behavior is a by-product of the periodic SITREPs sent to the team by the TAO. A coherent picture of the situation, acquired through frequent SITREPS, prompts the subordinates to exchange information and resolve problems at their level first, before providing information to the TAO.

Plainly the TACT and TACT+ training procedure enhanced various types of anticipatory behaviors, which intimates that team members must have used mutual mental models of other members and situational mental models to preempt the needs of the TAO and other team members. We did not find differences in anticipatory behavior between low- and high-stress conditions. Contrary to our hypothesis, the same level of implicit coordination was present in both conditions. This lack of evidence of differential adaptation to stress might be attributable to the subtle stress differences present in the scenarios.

This study demonstrates that teams can be trained to recognize the signs of increasing workload and stress and then use adaptive coordination strategies to mitigate some of the debilitating effects of high workload and stress. The finding that appropriate training can significantly improve both teamwork skills and task performance supports the assertion that the dual concepts of shared mental models and adaptive coordination are a productive approach for understanding and developing effective teamwork. It is also noteworthy that although all of the participants in this study were military officers, the majority being Navy officers, the sample was still diverse. Of the NPS sample, 25% were drawn from services other than the Navy, and the Navy officers themselves were drawn from different programs. Despite this diversity, the performance and process hypotheses were supported. This argues for the robustness of the experimental findings.

We hypothesize that further strengthening of the shared mental model will have a very positive effect on team processes and improve team performance. Strengthening of the shared mental model, however, employing only cross-training and interpositional training (which familiarize team members with their teammates' tasks, functions, and information needs in a dynamic fashion) will not be most effective. Such techniques are not sufficient to maintain performance under stress. Team members must also be trained to exercise their shared mental models through specific training of coordination strategies. Future team-training procedures must adopt an integrated approach to team training. Skill-based training (coordination/adaptation) supported by sound communication procedures (through information structure) – in addition to knowledge-based training (mental models) – are necessary ingredients for superior team performance.

GLOSSARY OF ABBREVIATIONS

AAW:	anti-air warfare
AAWC:	anti-air warfare coordinator
ATOM:	AAW Team Observation Measure
CIC:	combat information center
DEFTT:	Decision-Making Evaluation Facility for Tactical Teams
EWS:	electronic warfare supervisor
IDS:	identification supervisor
NAWCTSD:	Naval Air Warfare Center Training System Division
NPS:	Naval Postgraduate School
SITREP:	situation-assessment update
SWOS:	Surface Warfare Officers School
TACT:	team adaptation and coordination training
TACT+:	team adaptation and coordination training + periodic situation assessment briefs
TAO:	tactical action officer
TIC:	tactical information coordinator
TLX:	Task Load Index

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