Team Behaviors and Cognitive Cohesion in Complex Situations*

Cynthia Lamb[1], Jerry Lamb[2], Ronald Stevens[3], and Abaigeal Caras[2]

[1] URS Federal Services
[2] Naval Submarine Medical Research Laboratory
[3] The Learning Chameleon, Inc.
cynthia.lamb@urs.com,
jerry.lamb@med.navy.mil,
immex_ron@hotmail.com,
abaigeal.caras@med.navy.mil

Abstract. Our research has indicated that, in addition to technical skills, deliberate and effective team practices are necessary to manage the wide variety of simultaneous and increasingly complex problems that occur during tactical operations. This paper looks at team performance from two aspects, the first is observable team behaviors and the second is from two objective measures of team interactions. The combined results point toward a fuller understanding of team dynamics that can be applied to assessment, improvement, and prediction of team performance in operational situations.

Keywords: Team, Team Performance, Cognitive Cohesion, Team Behaviors, Submarines.

1 Introduction

The necessity for tactical teams to develop resilience is nowhere as evident as in the complex and constantly evolving world of submarine operations. Team success will not be achieved by doing one thing well: it requires flexibility, constant vigilance, redundancy, and variety in skills and thought process. Today's submarine operations are increasingly difficult due to expanded missions and tough operating environments in the littorals, some of the most heavily traveled and constricted waterways in the world. To meet these challenges, the submarine force turns to new technology

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and better sensors that generate overwhelming amounts of raw data; this data needs to be fused, analyzed, and available to decision makers. Because submarine technology is so intricate and pervasive, an engaged team is needed to extract the most significant information, which is then used to infer the state of the outside environment. It is impossible for each submariner to be an expert in all areas, therefore, backup and collaboration must be provided from all members of the team.

In an operating environment characterized by emerging complexity, in particular the Commanding Officers (COs) are responsible for developing resilient teams capable of adapting and responding to new and novel situations. COs need to be able to measure and develop tactical team behaviors that are aligned not only with skills, but with the unique performance needs of submarine environment as well. This research takes a high level/integrated look at team performance; building on such concepts as team cognition, shared understanding, and resilience in order to develop and test a model of tactical team performance.

2 The Unique Challenges of Submarine Tactical Teams

The submarine warfare domain is very different from the majority of domains studied for teamwork and decision-making. The need to discern the tactical situation of the highly uncertain, opaque underwater environment from limited data sources is a significant contributor to this difference. Understanding the external environment is a two-stage process: first analyzing and judging the validity and usefulness of sensor data; followed by the use of that data to generate the tactical picture. This is a unique process, since in most environments, sensor data, e.g., radar, is a direct representation of the real world. In the submarine environment, the inferential process, based on incomplete, discontinuous, and often ambiguous data, is a prerequisite for sound judgment and decision-making. This has several unique implications for submarine operations:

- It is team dependent, requiring specialists from several functions to look at the problem from different perspectives.
- It requires "generalists" to integrate the efforts of the team, to extract the meaning of source data, and to challenge that meaning.
- It is highly vulnerable to human error, including cognitive biases and faulty assumptions.

2.1 Team Practices

To address the need for a submarine team assessment and development tool, the Naval Submarine Medical Research Laboratory (NSMRL) in Groton, CT researched submarine team performance, determined most significant characteristics of a successful tactical team, and created a tool and reference manual to measure and develop team performance. NSMRL's efforts originated from a study of submarine mishaps to understand the impacts of emerging complexity on human performance. The initial methodology relied exclusively on the use of these submarine mishap reports, because mishaps are not only exceptionally well documented, but provided examples of operational performance, both good and bad.

This approach of studying mistakes is not uncommon. Nobel Prize-winning psychologist Daniel Kahneman spent over five decades examining "the marvels and flaws of intuitive thinking" by studying errors in cognition. Kahneman found that errors reveal much more about how something works than success performances. This was also true of the Tactical Decision Making Under Stress (TADMUS) Program: the 1988 USS Vincennes incident was the impetus for numerous research efforts in the areas of human factors and training for Air Warfare teams. *If you want to understand how teams really perform, then look at the errors they make*.

The original NSMRL study discerned team behaviors that are aligned with the unique performance needs of submarine warfighters. The researchers identified five sustainable tactical team practices for submarine crews: Dialogue (interaction among crewmembers), Decision Making (how teams distribute authority to make decisions), Critical Thinking (how they solve problems), Use of Bench Strength (how they build and utilize all members of the team), and Problem Solving Capacity (the degree of tactical complexity that the team can withstand) [1-3].

All five practices are necessary for submarine teams to achieve operational resilience. Operational resilience is defined as the ability to react to and recover from disturbances at an early stage, with minimal effect on the dynamic stability of the organization. Operational Resilience is necessary to manage the wide variety of increasingly complex problems that occur during tactical operations; the practices provide a means to measure the critical behaviors that contribute towards effective teamwork and tactical performance. NSMRL developed the Submarine Team Behaviors Tool (STBT) to formalize a traditionally subjective assessment of a team's ability. The tool provides a structure and a language, previously missing, that will help evaluators address team performance from a behavioral perspective in a real-time operational setting. It is a rubric to consistently and objectively assess teamwork.

The STBT articulates the practices as observable behaviors that characterize the degree of resilience of a tactical team. By watching a team work together in a challenging scenario, and noting the presence (or absence) of these behaviors, an experienced observer can gauge the Team Resilience Level (TRL). There are four levels of team resilience in the STBT: Unstressed Battle Rhythm, Leader-Dependent Battle Rhythm, Team-Based Resilience and Advanced Team Resilience. These correspond to the ability of a team to handle the complexity of the situations with which they are faced.

The first level, Unstressed Battle Rhythm, is considered the most basic and is usually observed in inexperienced teams. The team is able to maintain basic Battle Rhythm, or the ability to perform operational routines smoothly, as long as nothing unusual or straining occurs. A team with Leader-Dependent Battle Rhythm is able to sustain their battle rhythm under stress because of single person, who is usually highly experienced and takes charge to direct the team. The team does not possess any reserve capacity to mitigate errors made by this individual. Team-based resilience is the first level where team resilience is observed. There is reserve capacity within the team to respond to routine problems while continuing to move forward. Senior leadership is able to remain detached from the detailed work of the team in order to maintain big picture oversight. At the final level, Advanced Team Resilience, a team had sufficient reserve capacity to manage multiple dynamic problems and unexpected situations at once.

Table 1. Practices and Associated Threads

Practice	Threads
Dialogue	Orders, Reports, Briefs & Litanies
	Discussions
Decision-Making	Leader Detachment
	Decisiveness
Critical Thinking	Forceful Backup
	Search for Disconfirming Indicators
	Checklists & Tripwires
	Planning & Time Horizon
	Setting Context
	Managing Complexity
Bench Strength	Future Bench Strength Development
	Watch Team Structure
	Watch Transitions
	Performance Feedback
	Use of Current Bench Strength
Problem-Solving Capacity	Missions Transitions
	Problem-Solving Outcomes

The STBT assumes the presence of novices and journeymen in every team, even very capable teams. The level of resilience characterizes and measures the team as a whole, not its individual members. In fact, credit is given in the Bench Strength practice to the team for using and developing novices during problems. In some cases, a team has been characterized as having achieved a high TRL, even when the leader was clearly a struggling novice. In these cases, the team was able to compensate for the leader's vulnerability, and improve his ability for the future. The STBT evaluates the team, not individuals.

To make the STBT easy to use, by COs and other senior evaluators, the many behaviors that can be observed within each Team Practice were grouped into similar themes or Behavior Threads. The threads provide additional structure to the submarine team behavior model – using terms that convey a sense of their basic intent. These terms should also be somewhat familiar to submariners. There are a total of seventeen (17) threads. A list is provided in Table 1.

2.2 Linking Behaviors with Cognition

Submarine operations are fundamentally a mental process that manifests in the observable world of team dynamics and team behavior. We "see" the building of shared understanding, for example, through orders, reports, discussions, attention, body language, and posture. It should be possible, therefore, to improve the cognitive performance of tactical teams by focusing on the purposeful and deliberate use of those tactical team practices and behaviors that are most closely associated with improved problem solving.

The objective of our research has been to identify just such a set of practices and behaviors; a set that when properly applied can enable submarine tactical teams to develop higher levels of critical thinking. This is necessary in order to improve their problem-solving and decision-making efforts, especially in complex situations where information is incomplete or ambiguous.

3 Finding Evidence for the Use of the Practices

3.1 Initial Validation

The STBT was derived from studying historical mishap data by a multi-disciplinary team, and while approved by experienced submarine officers, it needed to be validated against other measures of team resilience and processing. That was done in three ways: (1) input from the experts used by the Submarine Force to evaluate team proficiency; (2) neurological measures of team cohesiveness; and (3) sociological patterns of team interaction. All evaluations were conducted in either the Submarine Piloting and Navigation (SPAN) or the Submarine Bridge Trainer simulations.

The STBT does not measure results - it measures process, we hypothesized that the STBT evaluations would correlate to performance outcomes and to the neurological measures. Teams with high operational resilience should have higher probabilities of success (e.g., maintain the safety of the ship, avoid counter-detection, and complete the mission) than teams that have poor operational resilience.

3.2 Rater Evaluations

Tactical teams currently receive one primary measure of performance during a training exercise from the Greybeard or onsite subject matter experts (SMEs) observing them. "Greybeards" are subject matter experts in the area of submarine preparation and evaluation for operational deployment. They are usually retired post-deployment submarine commanders, and have been trained to systematically evaluate training evolutions and give performance feedback.

If the model and the tool have validity, the researchers (through the use of the STBT) and SMEs (Greybeard and senior instructors) should reach similar conclusions regarding a TRL. In various training exercises there was an observable agreement between both parties. The research team's assessments of the observed watch teams' behaviors correlated very highly (Pearson r = 0.66 ($p < 0.1$)) with the SMEs' overall TRL ratings.

Data was also collected regarding the usability of the tool. Immediately after each training exercise the SMEs had an opportunity to use the STBT, they were then interviewed to elicit feedback. Data was collected regarding: the face-validity of the content, the manner in which the tool was used, the frequency it was used, the ease or difficulty in use, suggestions for improvement, and what value, if any, it provided or feel it could provide with changes. In general, the feedback indicated that the tool related well in concept and language to the Submarine Force and recommendations were made for improving its usability.

While this provides objective evidence that the STBT will prove useful in an operational setting, we have also used more quantitative methods of validation. In addition to validation using observer ratings, we have also performed comparisons under controlled, experimental conditions against a quantitative model of team performance called Team Neurodynamics.

3.3 Team Neurodynamics

Within the context of a coordinated team activity, the communication linkages and synchronizations among team members extend beyond speech to include, gestures, postures and physiologic systems that span biological processes and broader social activities [4, 5, 6, 7, 8]. While it is not surprising that neurophysiologic events are the underpinnings of these dynamics, it is only recently that their changing dynamics in real-world teamwork settings have begun to be measured and modeled [9, 10].

Team neurodynamics applies the measurement of neurophysiologic indicators to the modeling of teamwork with electroencephalography (EEG) being the tool of choice. Electroencephalography is the recording of electrical activity of the brain at different regions along the scalp. The rhythmic patterns in the electrical oscillations from different brain regions contain signals representing complex facets of brain activity. While EEG has traditionally been viewed as a tool for studying individual cognition in the milliseconds to seconds range, its range is being extended to include teams operating over much longer periods leading to the emergence of team neurodynamics as a discipline [11]. At the center of these studies are symbolic representations of the cognitive state of the team called Neurophysiologic Synchronies (NS), which show the second-by-second changing cognitive dynamics of the team and each of its members.

Neurophysiologic measures of engagement, workload and other cognitive markers have been modeled into NS and have been shown to vary with the context of changing task demands, across different timescales, and varying levels of teamwork. As teams experience changes in the dynamics of the task or encounter perturbations to the normal flow of teamwork, the organization of NS data streams fluctuate in a corresponding way. Organization in this context is statistically quantified by the entropy levels in the data stream. Entropy, which comes from information theory [12], is a measure of the uncertainty or randomness of a variable sequence. In team neurodynamics, low entropy indicates a greater degree of organization of team neurophysiologic state (less randomness) and high entropy indicates less organization (more randomness).

Complexity theory concepts are driving expanded neurodynamic models of teams; including determining how teams cognitively organize around changes in the task and the environment, and how this organization differs from novice to more experienced teams. During Submarine Piloting and Navigation (SPAN) and Submarine Bridge Trainer simulations, interesting team re-organizations have been seen as the effects of prior navigation decisions begin to accumulate and change (and sometimes limit) future options. In Figure 1, the bar indicates a period when the submarine was navigating in the fog while transiting a difficult stretch of water. Oncoming shipping was also forcing the submarine to deviate from their operations plan; combined, this created a great deal of uncertainty for this team. One result was the increased organization as indicated by the decreased NS entropy. Following a successful resolution to the situation, the organization of the team relaxed as they regained their rhythm. Such NS entropy fluctuations tend to occur around periods of increased stress or intense discussion.

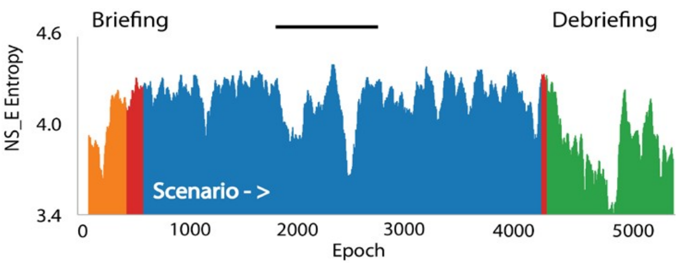

Fig. 1. NS Engagement Entropy Profile of a SPAN Performance with the Task Segments Highlighted

Not only does neurodynamic analysis provide a way to objectively analyze teams in action, but it offered a unique opportunity to evaluate elements of the STBT. This was done by directly comparing the NS Entropy levels (a measure of team flexibility) and detailed evaluator rankings (collected by observers using the STBT) for six Submarine Officer Advanced Course (SOAC) teams and one experienced navigation team. As shown in Figure 2, there was a positive correlation between these two measures when teams were ranked from the lowest to highest levels; the correlation was significant at the $p < 0.05$ level. (This graph also shows that flexibility becomes more important as problems become more numerous and difficult. The ability to successfully handle these problems is really what matters in submarine teamwork.)

Team neurodynamics holds much promise as a way to quantitatively determine the functional status of a team in order to assess the quality of its performance. As entropy fluctuations are a key feature of team neurodynamics, they may serve as a starting point around which to develop quantitative models of team performance and resiliency.

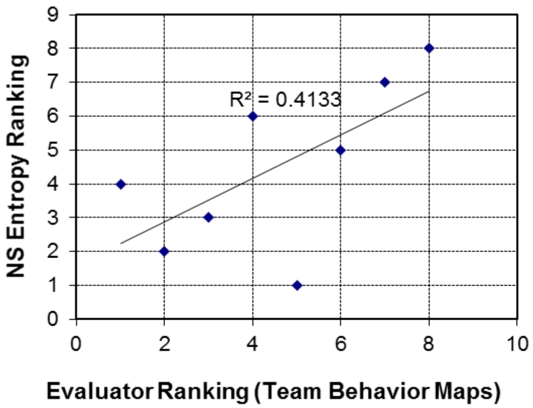

Fig. 2. NS Entropy Rankings vs. Evaluator Rankings (using the STBT)

3.4 Sociometric Data

As discussed earlier, the undersea environment is dynamic, complex, and requires multi-component, multi-operator decisions to navigate successfully. A submarine team's ability to actively recognize and respond to problems in these situations depends heavily on the technical proficiency of crewmembers as well as their abilities to work as a team. Research by Pentland et al. at the MIT Media Lab suggests that the pattern, frequency, and variety of communications within a team are useful indicators of team performance; and that there are patterns of communication that are associated with the most productive and effective teams [13, 14].

Their research used novel pieces of technology, called "sociometric badges;" devices that automatically capture aspects of non-verbal and verbal communication between groups, behaviors that correlate with team performance. Sociometric badges are small, unobtrusive piece of hardware that are worn around a person's neck, or fixed to a workstation, and employ multiple sensors to collect various types of data as teams of people interact in complex mission environments (see Figure 3).

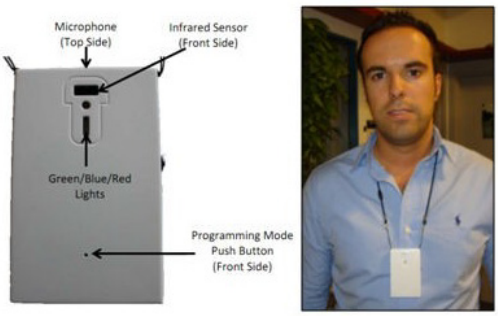

Fig. 3. A diagram of a Sociometric Badge (left), and a person wearing a badge (right)

Each badge is equipped with microphones, accelerometers, infrared (IR) sensors, and BlueTooth transceivers that collect, for example, artifacts of speech, face-to-face interactions, and the proximity of people with respect to one another or work stations. They can be configured in different ways to match the information assurance needs of a testing environment; for example, experimenters have the option of deactivating any of the sensors (such as the BlueTooth transceivers). These devices are being used in various applications and domains to automatically collect data that measure conversational time, physical activity levels, physical proximity to other people, and interaction patterns (such as who talks to who) [14].

Data collection in Submarine Piloting and Navigation (SPAN) trainers suggest a number of findings that speak to the efficacy of this technology when applied to the undersea warfare domain [15]. For example, the total volume of discussion in the control room (as measured by the amplitude of sound recorded by the microphones) appears to change with respect to team performance, where performance is defined by the distance between the ship's present location and where it should be located given the crew's planned route (cross-track error). During these operations, teams conduct prescribed checks of sensors to establish situational awareness, known as "cyclic routines." Two teams were observed practicing cyclic routines, one experienced and one less-experienced; there were patterns seen in the recorded audio data that could be used to identify this difference in expertise. The IR sensor data, which indicates the times at which two badges faced each other in close proximity, can be easily captured and graphed for analysis. Preliminary results suggest that the IR data can be used to produce a map of control room activity that visualizes where crewmembers were located at any given time throughout an exercise.

By examining the aggregated data collected from the sociometric badges, it was determined that there were opportunities for improvement in the team's communication patterns. From this data it was also possible to measure team member participation, bottleneck, or too many instances of people going it alone or just relying on one or two people. While further data collection is needed to validate these initial findings, the technology has shown its potential in helping us understand, assess, and model team behavior.

4 Integration of Approaches to Assess Team Performance

This paper has looked at team performance from two aspects, the first is observable team behaviors and the second is from two objective measures of team interactions. The two are converging to provide a descriptive model of team performance that can inform future efforts in team development, submarine technology, work design, as well as aspects of team performance degradation.

The team practices, as noted, define the team's current position on a resilience scale. In order to be fully resilient, teams need to have flexibility, maintained vigilance, and diversity in skills and thought process.. One interesting finding from team neurodynamics is that highly organized teams are not the most effective, nor are teams whose engagement is too disorganized. Instead, there is an intermediate 'sweet spot' of neurophysiologic organization that allows teams to flexibly adapt to the current and unfolding demands and distractions of the situation. The data from sociometric badges shows patterns of team physical interactions and verbal interactions can provide insight into the team's performance.

When viewed as a whole, the different approaches offer guidance for use in team development. While collecting EEG data during at-sea Pre-Deployment Training (PDT) events is currently not feasible, both observation using the behavior maps and proximity and verbal data using the sociometric badges are. These can provide senior observers with structured information for feedback and team development without creating the need for a "checklist" of team behaviors. The growth of a team's problem solving capacity (performance) can be assessed over the training period prior to deployment. This is the most immediate and greatest benefit from the current research.

Team behaviors are driven by the information available to the team and the ability to interact effectively. The behavior maps and badges can be used in developing and evaluating information displays and, more broadly, the layout of team spaces.

5 Conclusion

Early feedback on the submarine team behaviors model is that it provides a structure and a language, previously missing, that will help Commanding Officers and other senior personnel address team performance from a behavioral perspective in real-time and in real (operational) settings. Even though some cutting-edge technologies are being used to support validation of our model of tactical teams (e.g., sociometric badges and EEG headsets), the model's real operational value comes from its technology-independence and simplicity. The model, therefore, can be used in the field as well as the schoolhouse.

Given the suitability and usability of the STBT and its underlying model, how can it be used beyond simply assessing the resilience level (TRL) of the team? First is using the STBT to provide feedback to the teams on their current level of resilience and what factors (threads) need improvement. Feedback is the first step toward improvement and the STBT provides a common and familiar language to discuss the team's performance.

The next step is the development of interventions or training techniques to help improve performance beyond simple feedback. In order to assess this approach, NSMRL will conduct additional validation testing during tactical training. NSMRL will correlate expert observer scores, objective outcome measures, and other measures with STBT scores. The study will also explore the individual threads of the STBT to better understand the relationship between specific aspects of team performance and the general outcome of operational readiness and competency. Specific interventions will also be introduced to help improve the quality and effectiveness of the team development process. Teams that receive interventions during initial training will be evaluated during advanced training to measure the effect of the interventions and compared to teams with no intervention.

Finally, maintaining effective operational team performance during prolonged stressful missions is a common challenge faced by the submarine fleet. Teams will eventually fail to accomplish their tasking, but such breakdown may be preceded by observable behavior changes. While team breakdown is often perceived as a sudden event with a dramatic loss of effectiveness, this decrease in performance may in fact be a gradual or incremental process that is presently undetectable and behavior observations may identify specific precursors prior to breakdown. STBT behavior observations could be the method to provide that early warning system to prevent catastrophic team degradation and future mishaps.

This paper has described the evolving of a tool to measure team behaviors into a submarine team behaviors model, which was initially validated against both behavioral and experimental variables. Potential extensions of the tool extend beyond simply measuring a team's resilience level to improving team performance or perhaps even avoiding team failures.

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