Team Neurodynamics
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# Identification and Application of Neurophysiologic Synchronies for Studying the Dynamics of Teamwork

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**ABSTRACT** *We describe a process for collecting and combining neurophysiologic signals derived from individual members of a team to develop pattern categories showing the normalized expression of these signals at each second for the team as a whole. The expression of different neurophysiologic synchrony patterns is sensitive to changes in the behavior of teams over time and perhaps to the level of expertise. The utility and limitations of using this approach are demonstrated for three tasks including a team emotion recall research study, an educational study where teams of high school students solved substance abuse simulations and a complex training study where Submarine Officer Advanced Candidate trainees performed submarine piloting and navigation exercises.*

## 1. Introduction

Research on teamwork and cooperative behaviors often adopts an input-process-output framework (IPO). In this model the interdependent acts of individuals convert inputs such as the member and task characteristics to outcomes through behavioral activities directed toward organizing teamwork to achieve collective goals. These activities are termed team processes and include such activities as goal specification, strategy formulation, systems and team monitoring (Marks et al, 2001). Much of this teamwork research has made use of externalized events focusing on *who* is a member of the team, *how* they work together and *what* they do to perform their work. The studies often rely on post-hoc elicitation of the subjective relationships among pertinent concepts. There have been fewer studies looking at the *when* of teamwork interactions although the dynamics of team function are known to be complex (Mathieu et al, 2008) with temporal models of teamwork suggesting that some processes transpire more frequently in action phases and others in transition periods (Canon-Bowers et al, 1993; Cohen & Bailey, 1997; Cooke et al, 2003; Mohammed et al, 2000).

Our hypothesis is that as members of a team perform their duties each will exhibit varying degrees of cognitive components such as attention, workload, engagement, etc. and the levels of these components at any one time will depend (at least) on 1) what that person was doing at a particular time, 2) the progress the team has made toward the task goal, and 3) the composition and experience of the team. Given the temporal model of team processes, we believe that the balances of these metrics across the members of the team will not be random, but will be in rhythm with the team's changing activities and awareness of the situation. In this study we provide a direct confirmation of this hypothesis.

## 2. What Are Neurophysiologic Synchronies?

We define neurophysiologic synchronies (NS) as the second-by-second quantitative co-expression of the same neurophysiologic / cognitive measures by different members of the team. Figure 1 shows an illustration of a neurophysiologic measure being simultaneously detected at a particular point in time from the members of a hypothetical six person team where team members 3 and 5 expressed above average levels of this particular measure while team members 1, 2, 4 and 6 expressed below average levels.

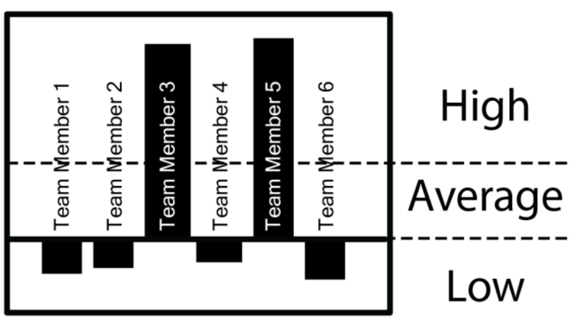


**Figure 1.** Example Expression of a Generic Neurophysiologic Measure by Individual Members of a Six-Person Team

## 3. How are Neurophysiologic Synchronies Detected and Analyzed?

The data processing begins with the eye-blink decontaminated EEG files containing second-by-second calculations of the probabilities of High EEG-Engagement (EEG-E), Low EEG-E, Distraction and High EEG-Workload (EEG-WL) (Levendowski et al, 2001, Berka et al, 2004). Most of the studies to date have used the High EEG-E and EEG-WL metrics.

In prior studies with individuals performing complex tasks the raw EEG-E levels were used for studying the problem solving dynamics (Stevens et al, 2007, 2008). Studying team processes using EEG measures; however, requires a normalization step, which equates the absolute levels of EEG-E of each team member with his own average levels. This allows the identification not only of whether an individual team member is experiencing above or below average levels of EEG-E or EEG-WL, but also whether the team as a whole is experiencing above or below average levels. In this normalization process (outlined for one individual in Figure 2.1) the EEG-E levels are partitioned into the upper 25%, the lower 25% and the middle 50%; these are assigned values of 3, -1, and 1 respectively, values chosen to enhance subsequent visualizations.

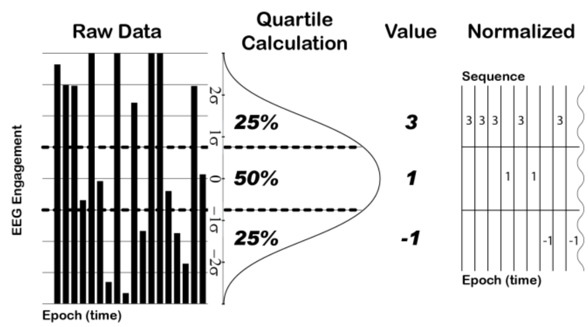


**Figure 2.1.** Normalization of Neurophysiologic Measures into Quartile Ranges.

The next step combines these values at each epoch for each team member into a vector representing the state of EEG-E for the team as a whole, (this is shown for a team of 3 persons in Figure 2.2).

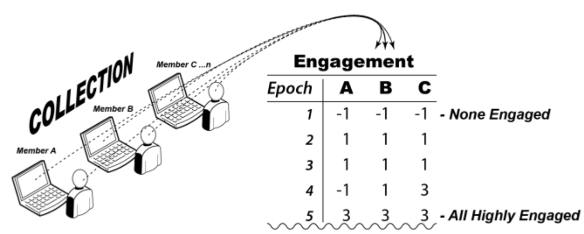


**Figure 2.2.** Creation of Team Performance Vectors. While the process is illustrated for three-member teams it can be expanded to include larger or smaller teams.

The second-by-second normalized values of team EEG-E for the entire episode are then repeatedly (50-2000 times) presented to a 1 x 25 node unsupervised artificial neural network. During this training a topology develops such that the EEG-E vectors most similar to each other become located closer together and more disparate vectors are pushed away. The result of this training is a linear series of 25 team EEG-E patterns that we call neurophysiologic synchronies (NS).

## 4. A Simple Example: Emotion Recall by a Team

A simple exercise in emotion recall by three team members illustrates the application and applicability of neurophysiologic synchronies for studying the dynamics of teamwork. In this exercise three team members were asked to recall different emotions while wearing an ABM wireless EEG sensor headset. The emotions included anger, grief, hate, joy, romantic love, platonic love, reverence and good learning and bad learning. Each three minute period of emotion recall was separated by 1-2 minutes of rest time before the next emotion was elicited. During both the emotion recall and the rest periods there was minimal talking and the subjects tended to focus on a region of space and / or object. EEG-E and EEG-WL were collected at 1 second epochs, normalized as described in Figures 1 & 2.1 and used to train unsupervised ANN. The resulting EEG-E NS patterns are shown in Figure 3.1. The most common NS was pattern 22 representing the epochs where all individuals expressed low levels of EEG-E and this was followed by node 20 where only individual #1 showed elevated EEG-E levels.

EES Engagement Nodal Map

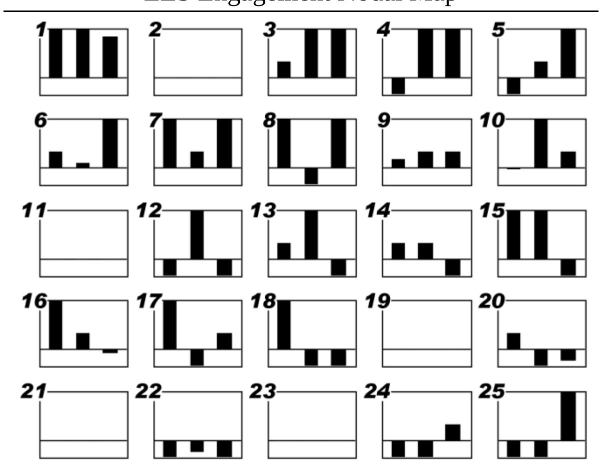


**Figure 3.1** Neurophysiologic Synchronies for EEG-E and EEG-WL During Emotion Recall

The time course of EEG-E expression for the session is shown in Figure 3.2. at each second of the exercise. The epochs in black indicate resting periods and those in gray indicate recall of emotions.

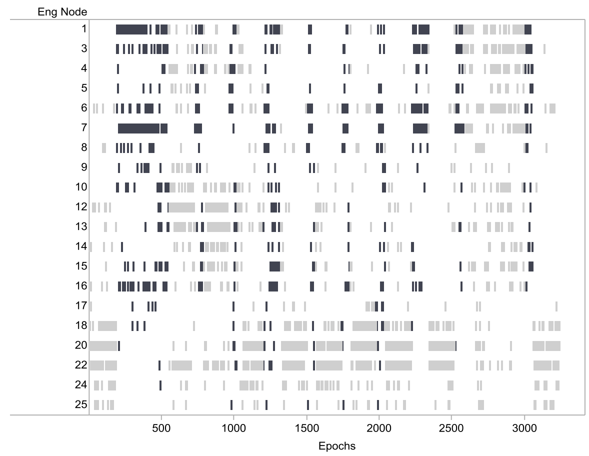


**Figure 3.2.** Neurophysiologic Synchronies for EEG-E During Emotion Recall

Neurophysiologic Synchronies # 20 and 22 were associated with most of the emotion expression shown during epochs 600-2500 and these were characterized by below normal expression of EEG-E by all members of the team. The exceptions to this pattern were for the emotions anger and hate. During these epochs individual #2 showed above average expression of EEG-E while individuals 1 & 3 were still average / below average in EEG-E expression. These NS were also not associated with the Resting period or the Unknown periods; the Unknown period was a resting period that was extended for 7 minutes. The epochs where 2 or more members of the team showed elevated EEG-E levels were primarily found during the resting periods.

Thus, in a simple teamwork task with little interaction among the team members a consistent pattern of NS expression could be observed which varied with the properties of the task. Interestingly, periods of low EEG-E expression were associated with the active portion of the task suggesting that these low levels do not indicate lack of engagement, but rather the lack of external involvement of each individual.

## 5. A More Complex Teamwork Simulation: Substance Abuse Decision Making.

The second task represents an educational activity where teams of three high school students explored an online IMMEX™ problem space where the goal was to make a decision whether the simulated person should seek help for substance abuse. One member of the team accesses physiologic and neurophysiologic data, one member examined social issues such as school / job performance, difficuties with the law, interactions with peers, etc, and the third person leads the group interactions and guided the decision.

During the task audio and video recordings were made of each student enabling a reconstruction of team member actions and the interactions of the group, allowing a mapping of NS expression to team events. An example of this mapping for one of six groups is shown in Figure 4.1. Here two segments of the team discussions are highlighted, one where EEG-E levels were low and another where they were high. During the period where EEG-E NS was low the team conversation focused on determining how to spell 'psychiatrist' whereas when high, the team was involved in a formulation of a final decision.

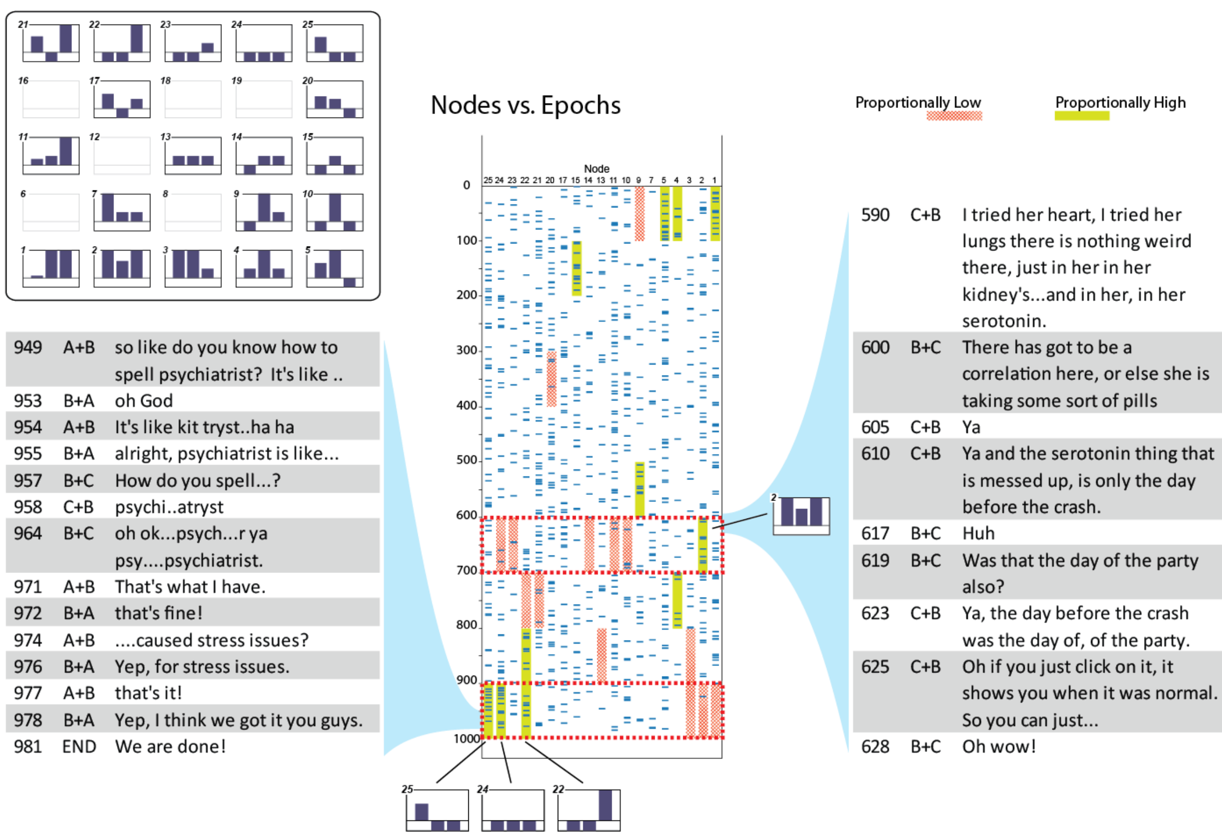


**Figure 4.1**. Mapping Different NS Expressions to Collaboration Events and Discussions. The NS patterns for the group are shown in the upper left corner and their expression is shown for each epoch. The highlighted segments represent areas where particular NS patterns are expressed at higher or lower levels by crosstabulation. Two segments of the discussions are highlighted where particular NS were either high or low.

## 6. A Very Complex Teamwork Simulation: Submarine Piloting and Navigation

The final example shows the application of the approach to a very complex training task which is the safe piloting of a submarine. These studies were conducted with navigation training tasks that are integral components of the Submarine Officer Advanced Course (SOAC) where Junior Officers train to become department heads and ship drivers.

The task the trainees performed is a high fidelity Submarine Piloting and Navigation (SPAN) simulation that contains dynamically programmed situation events which are crafted to serve as the foundation of the adaptive team training. Such events in the SPAN include encounters with approaching ship traffic, the need to avoid nearby shoals, changing weather conditions, and instrument failure. There are also task-oriented cues to provide information to guide the mission, and team-member cues that provide information on how other members of the team are performing / communicating. Finally there are adaptive behaviors that help the team adjust in cases where one or more members are under stress or are not familiar with aspects of the unfolding situation.

Each SPAN session begins with a briefing detailing the navigation mission including a determination of the static position of the ship; weather conditions; potential hazards; and overall plan of the mission. This section is followed by the simulation which can last from 20 – 60 minutes or more. The simulation is then paused and a debriefing session begins that helps teams monitor and regulate their own performance based on the dimensions of teamwork deemed critical for effective team performance: From a cognitive perspective this teamwork task is complex, requiring not only the monitoring of the unfolding situation and the monitoring of one's work with regard to that situation, but also the monitoring of the work of others.

Each neurophysiologic synchrony shows a pattern of EEG-E for each member of the team and provides a snapshot of the overall team engagement. As an example, NS 21 indicates a pattern where the Contact Coordinator (Position 3) and Primary Recorder (Position 5) are highly engaged and the other 4 team members are at below average levels of engagement (Figure 4.1). Node 4 indicates a pattern where the Contact Coordinator (Position 3) is below average in EEG-E expression and the team members at the other positions have high levels.

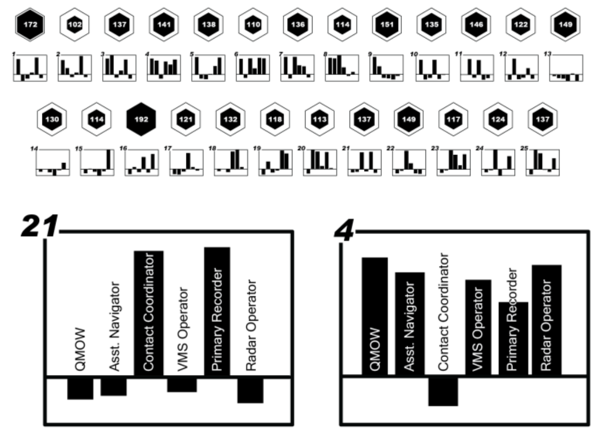


**Figure 4.1** The Neurophysiologic Synchrony and Frequency Map for a Submarine Piloting and Navigation Team. The neurophysiologic synchrony patterns are shown by the histograms in the boxes representing each neural network node, and the frequency of occurrence of each neurophysiologic synchrony is shown by the degree of fill in the hexagons. An expanded view of patterns 21 and 4 are shown in the lower portion of the figure.

The neurophysiologic synchronies so defined, can then be applied to explore multiple dynamics of teamwork such as: 1) Does the quantitative and qualitative expression of NS patterns change with varying task demands? 2) Is the team's convergence toward shared situation awareness reflected in NS patterns? 3) Do preferred NS patterns change with team experience?

The following example shows how the expression of different neurophysiologic synchrony patterns changes over the course of a SPAN task by one team (Figure 4.2) with the pre-briefing epochs (0-4 minutes), simulation epochs (4-35 minutes), and the debriefing epochs (35-55 minutes) highlighted.

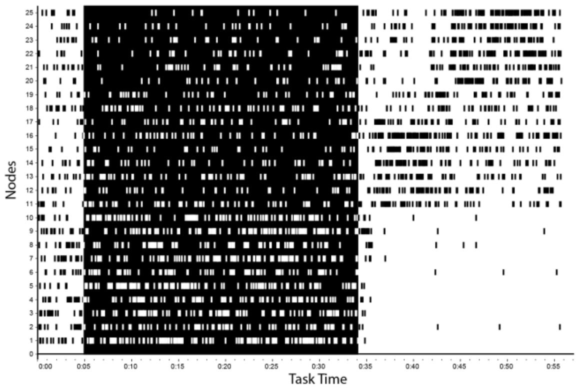


**Figure 4.2.** Distribution of Neurophysiologic Synchrony Patterns during a SPAN Performance. The NS expressed at each second of the session are plotted vs. the task time. The initial segment on the left is the briefing period, the darkened section in the middle is the simulation itself, and the final segment to the right is the de-briefing segment.

The most noticeable difference was the near absence of NS 1-10 expression during the debriefing section; instead these were replaced by NS 11-25 which are those NS where the majority of team members expressed low EEG-E levels. These appeared as soon as the debriefing began, and it is interesting that they are expressed infrequently during the simulation suggesting a difference in team coordination across these two task segments. After several minutes of the debriefing there was elevated expression of NS 21-25 which represents moments where the team members, especially the contact coordinator, are expressing above average levels of EEG-E.

The differences between the pre-briefing and the simulation are less striking, perhaps due to the relatively short briefing period, but statistical comparisons (cross tabulation) showed that NS 1, 9 and 10 were underrepresented during this segment (this is where the common feature is the Navigator and Primary Recorder have high EEG-E levels) and synchrony 16 was over represented (this is where the VMS and Radar Operators had elevated EEG-E). These results suggest that neurophysiologic synchronies can change rapidly in response to changing task situations and that the changed synchrony patterns can persist over periods of 10 minutes or more.

## 7. Discussion

One of the challenges for extending the measurement of team behavior is the development of unobtrusive and real-time measures of team performance that can be practically implemented (Salas et al, 2008). We believe that the approach we have described begins to address some of these challenges and can be applied to a wide variety of team tasks. Three examples were presented, one from a research perspective, one from an educational perspective, and one from a training perspective. In all three examples extended periods of time (minutes or more) were observed where NS patterns were preferentially expressed.

From the perspective of neurophysiologic synchronies and teamwork, the emotion recall results are important as they show that the different members of the team *consistently* entered a particular neurophysiologic state during the elicitation of emotions and they consistently exited that state during the rest periods. This was observed both for EEG-E and EEG-WL although it was more pronounced with the EEG-E. As the team was not engaged in verbal communication, it also indicates that the state that was entered into during emotion recall was not dependent on active communication among the team members but was more related to the internal representation of the task being generated by each of the team members. Thus NS expression may be a reflection of the internal state of team members and of the team as a whole.

The second and third studies with the high school students in classrooms and the SOAC trainees in the SPAN similarly demonstrated that the techniques can be practically implemented. Combined, these findings suggest that neurophysiologic indicators measured by EEG may be useful for studying team behavior not only at the milliseconds level, but at more extended time frames.

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