How Tasks Help Shape the Neurodynamic Rhythms and Organizations of Teams

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Abstract. We have modeled neurophysiologic indicators of Engagement and Workload to determine the influence the task has on the resulting neurodynamic rhythms and organizations of teams. The tasks included submarine piloting and navigation and anti-submarine warfare military simulations, map navigation tasks for high school students and business case discussions for entrepreneurial / corporate teams. The team composition varied from two to six persons and all teams had teamwork experience with the tasks. For each task condition teams developed task-specific neurodynamic rhythms. These task-specific rhythms were present during much of the task but could be interrupted by exogenous or endogenous disturbances to the team or environment. The effects of these disturbances could be rapidly detected by changes in the entropy levels of the team neurodynamics symbol streams. These results suggest the possibility of performing task-specific comparisons of the rhythms and organizations across teams expanding the opportunities for rapid detection of less than successful performances and targeted interventions.

Keywords: team neurodynamics, entropy, coordination dynamics, rhythms.

1 Introduction

Teamwork is an important, and most would argue, integral part of all human activities. Like most forms of social coordination, teamwork is not simple. Early studies showed that communication is dynamic during social interactions like teamwork with cyclic exchanges having both synchronous and lead-lag relationships; when repeated these can evolve into shared rhythms and refined speech patterns [1]. It is now widely appreciated that within the context of coordinated team activity such linkages and synchronizations extend beyond speech to include gestural, postural,

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functional, and physiologic systems [2-4]. It is not surprising that neurophysiologic events are the underpinnings of these dynamics yet it is only recently that their evolving dynamics in real-world teamwork settings have begun to be modeled [5-9].

Our work has focused on developing an information and organization-centric framework for team neurodynamics that is information centric in the sense that raw EEG measures from each team member are combined into symbols showing the levels of different cognitive measures of each team member and the team as a whole [10, 11]. These neurodynamics symbol streams (NS) are probed for regions containing information related to team performance much in the way that words in a sentence or the codons in nucleic acids convey information. Importantly, fluctuations in the mix of symbols identify 'interesting periods' of team organization and the frequency, duration, and magnitude of these fluctuations can be quantified by measuring the Shannon entropy of the data stream [12].

The purpose of this study was to expand a research framework describing successful teamwork by focusing on how elements of the task help shape team neurodynamics. This perspective could be useful for better understanding team-related concepts like organization, rhythm, resilience and the effects of exogeneous and endogeneous disturbances to the team, and lead to the development of more quantitative approaches for comparing across teams. To test the generality of this approach we describe the team neurodynamics of four tasks where the teams were experienced with the task and had worked with the other members of the team, i.e. in the Phase 4 of Team Development as described by Kozlowski et al [13].

2 Hypotheses

The hypotheses for this study were:

1. Teams develop identifiable task-related neurodynamic rhythms and organizations
2. These rhythms and organizations are dynamically modified in response to endogenous and exogenous disturbances to the task

3 Methods

3.1 Tasks and Participants

Map Navigation Task (N = 15 High School Teams)

The task was a two-person problem solving / navigation exercise based on the Edinburgh Map Task corpus [14]. Two team members sat facing and each had a sketch-map with several landmarks on it. The two maps were similar, but not identical and they could not see each other's map. One person, the instruction giver (Giver or G), had a path printed on the map and attempted to verbally guide the other person, the instruction follower (Follower or F) in drawing that path on the Follower's map. The subjects for this task were fifteen 11th and 12th grade science student teams.

Anti-Submarine Warfare Helicopter Teams (N = 3)
The second task was a training exercise for experienced Anti-Submarine Warfare Helicopter Teams (ASWT). Three crewmembers, the pilot, the sonar operator and the tactical officer performed simulated search, track and attack missions in support of surface combat groups. The role of the pilot was to steer the helicopter to the location of a submarine sighting and to fly appropriate paths for buoy configuration. When the approximate location was reached the sonar operator directed the three-dimensional positioning of the passive and active sonar buoys. The tactical officer directed the overall mission and munitions drop. There were three teams based out of Orlando, FLA and San Diego, CA that each conducted two mission simulations; these teams had in-flight crew experience.

Submarine Piloting and Navigation Teams (N = 21)
Submarine Piloting and Navigation (SPAN) is a high fidelity simulation where events include encounters with approaching ship traffic, the need to avoid shoals, changing weather conditions, and instrument failure [15]. Each SPAN session contains three segments beginning with a Briefing where the overall goals of the mission are presented. Next, the Scenario is a dynamically evolving task containing both easily identified and less well-defined processes of teamwork. The final segment, the Debrief is the most structured part with team members reporting on their performance.

Entrepreneurial Teams (N = 6)
A fourth set of data was collected from teams of experienced / advanced student entrepreneurial teams at two international business schools. The simulations lasted ~40 minutes and were structured around business case discussions of corporate social responsibility concerns [16]. The task segments included: 1) defining the task and surfacing pertinent information; 2) prioritizing and discussing issues; 3) developing a team consensus about how to proceed; and 4) formalizing the team recommendation.

3.2 Electroencephalography (EEG)

The B-Alert® system by Advanced Brain Monitoring, Inc. contains an easily-applied wireless EEG system that includes software that identifies and eliminates multiple sources of biological and environmental contamination and allows second – by - second classification of cognitive state changes [17]. The 9-channel wireless headset includes sensor site locations: F3, F4, C3, C4, P3, P4, Fz, Cz, POz in a monopolar configuration referenced to linked mastoids. B-Alert® software acquires the data and quantifies engagement (EEG-E) and mental workload (EEG-WL) in real-time using linear and quadratic discriminant function analyses with model-selected PSD variables in each of the 1-hz bins from 1 – 40 Hz, ratios of power bins.

3.3 Team Neurodynamics

When combined data from multiple time series (i.e. team members) are treated as symbols instead of numeric points it becomes easier to mine them and detect interesting patterns. Normalized second-by-second values of EEG-E or EEG-WL were concatenated into vectors representing the levels being expressed by each team member. For instance, in Fig.1A team members 1, 3 and 5 were expressing below average levels of EEG-E and were assigned values of -1. Team members 2 and 4 were expressing average levels of EEG-E and were assigned the value 1, and team member six was expressing above level values and was assigned the value 3; the vector representation was therefore (-1, 1,-1,1,-1,3). Using artificial neural networks (ANN), the vectors from multiple performances were modeled into collective team variables termed neurodynamic symbols of engagement (NS_E) or workload (NS_WL). ANN classification of these second-by-second vectors created a symbolic state space showing the possible combinations of either EEG-E or EEG-WL across team members (Fig. 1B). Experimentally, the EEG data has been modeled into state spaces between 9 and 900 symbols depending on the task and team [17].

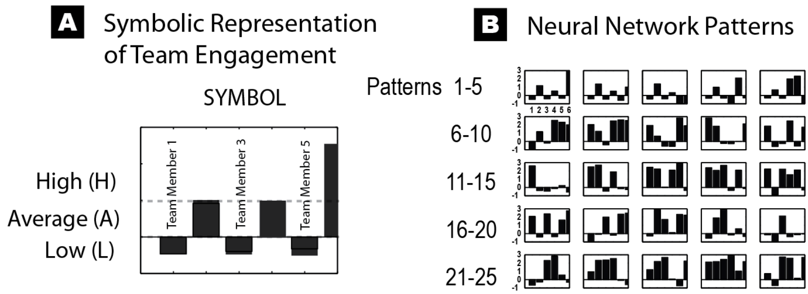

Fig. 1. Data Flow for Creating Team Neurodynamics Models. ANN classification of second-by-second vectors (A) creates a symbolic state space showing the possible combinations of EEG-E or EEG-WL across members of the team (B).

While a symbolic representation of the team state is useful for characterizing team neurodynamics, it is not the best representation for quantifying team neurodynamics. Although there are methods for the quantitative representation of symbols, we chose a moving average window approach to derive numeric estimates of the Shannon entropy of the NS symbol stream. Entropy is expressed in terms of bits; the maximum entropy for 25 randomly-distributed NS symbols would be log2 (25) or 4.64. For comparison, an entropy value of 3.60 would result if roughly half (12) of the NS symbols were randomly expressed. To develop an entropy profile over a session, the NS Shannon entropy was calculated at each epoch using a sliding window of the values from the prior 60 -100 seconds. As teams entered and exited periods of organization, the entropy should fluctuate as a function of the number of NS symbols being expressed by the team during a block of time [15]. Entropy is a quantity, the value of which is determined by the state of the system, in our case with regard to the EEG-E or EEG-WL of the team members. By itself, it says nothing about the state of the system; this information comes from the NS symbols.

4 Results

4.1 Map Task

The detailed NS_WL dynamics for one Map Task team are shown in Fig. 2. NS symbol 2 was expressed twice as often as other symbols (Fig. 2A), represented periods where the Giver expressed high levels of EEG-WL and the Follower was expressing average or, below average levels. The dominance of NS 2 was also seen in the second-by-second NS symbol expressions (Fig. 2B). Around epoch 200 the Follower began having difficulties drawing the map with the mouse. As the difficulties persisted (indicated by the frequency of mouse clicks in Fig. 2D) this resulted in a team reorganization where NS 2 expression was sequentially replaced by NS 4 (G↕F↑), NS 5 (G↓F↑), NS 7 (G↓F↕) and NS 9 (G↓F↓); i.e. the team slowly reduced its EEG-WL. This increased organization was reflected in the slowly decreasing entropy levels. Once the Follower regained control of the mouse the entropy levels rapidly increased as the team re-established its normal operating rhythm NS 2.

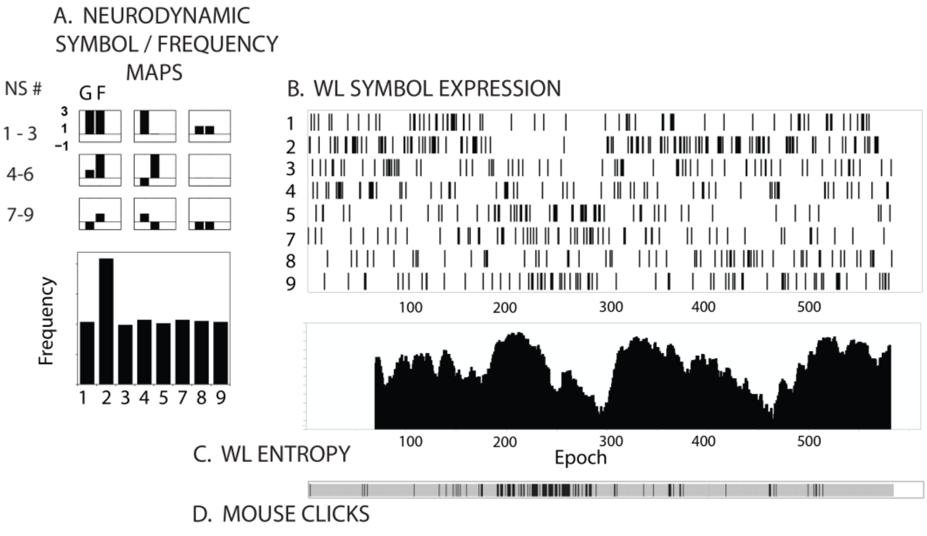

Fig. 2. Linking NS symbols (A) with temporal NS expressions (B), entropy fluctuations (C) and drawing mouse clicks (D)

4.2 ASWT Teams

The neurodynamics are shown for one ASWT team where the major task segments Search, Track and Attack have been identified. For these teams, across team NS-WL models were developed by pooling the NS vectors from four performances and then testing teams individually against this model [15]. The NS maps for EEG-WL showed that that NS 1 and 25 had twice the expression of the remaining symbols. These symbols represent periods where the ATO & SO had high EEG-WL levels and the Pilot had low (i.e. [ATO,SO]↑P↓) (e.g. NS 1) or the combination [ATO,SO] ↓P↑ (e.g. NS 25). From the perspective of teamwork these NS_WL patterns are consistent with what would be expected from the task as the ATO & SO work closely together once contact is made while the pilot needs less second-by-second coordination with the other members while flying to the initial location, or when changing the search area. Entropy fluctuations were present in the three major task segments that corresponded to identifiable simulation events like in Fig. 3C.1.a where the sonar instrument was malfunctioning and needed repair. During that period the predominant NS_WL symbols were NS 3-10 indicating periods where all team members had average or below average EEG-WL.

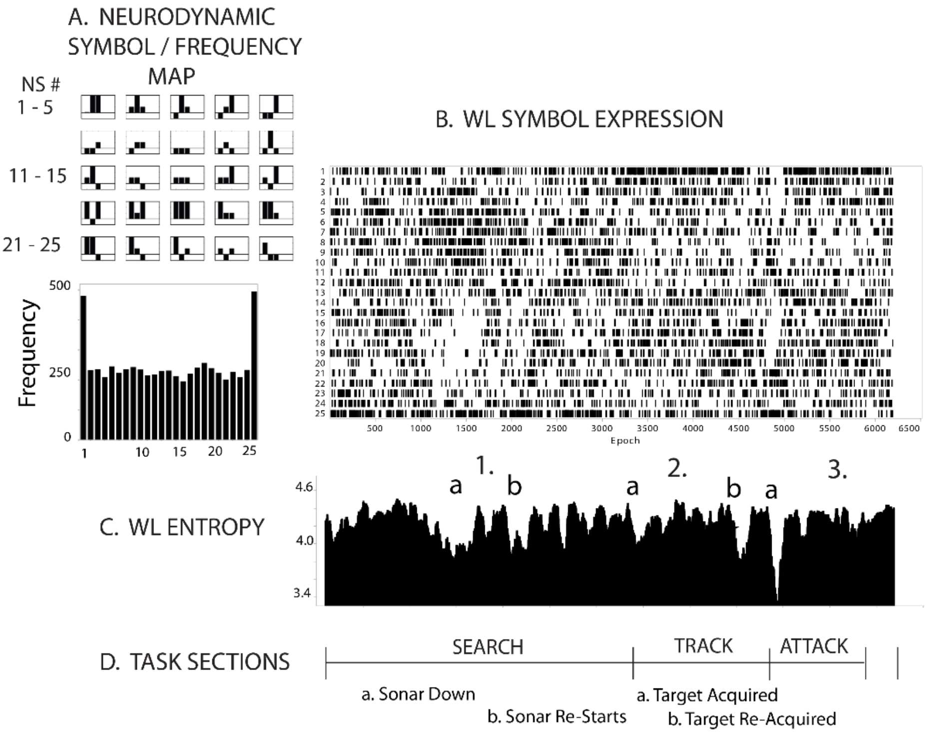

Fig. 3. Linking NS symbols (A) with temporal NS expressions (B), entropy fluctuations (C) and segments of the task (D)

4.3 Submarine Piloting and Navigation Teams

The members of SPAN teams also have defined roles but with up to ten team members the teamwork is more complex. As with other teams, the NS expressions were not uniform, but showed qualitative changes over time, particularly at the Scenario / Debriefing junction. For instance NS_WL symbols 10, 11 and 18 which were poorly expressed during the Scenario, dominated during the first half of the Debriefing. Qualitative dynamic changes also occurred during the Scenario, but these were generally less obvious than those at task junctions. They were sufficient however to be detected by entropy fluctuations such as those between epochs 2300 - 2500 when the submarine deviated from its safe operating envelope (Fig. 4C.2.c). More pronounced neurodynamic reorganizations were seen during the Debriefing Segment (Fig. 4C.3.a) as the causes for this deviation were discussed.

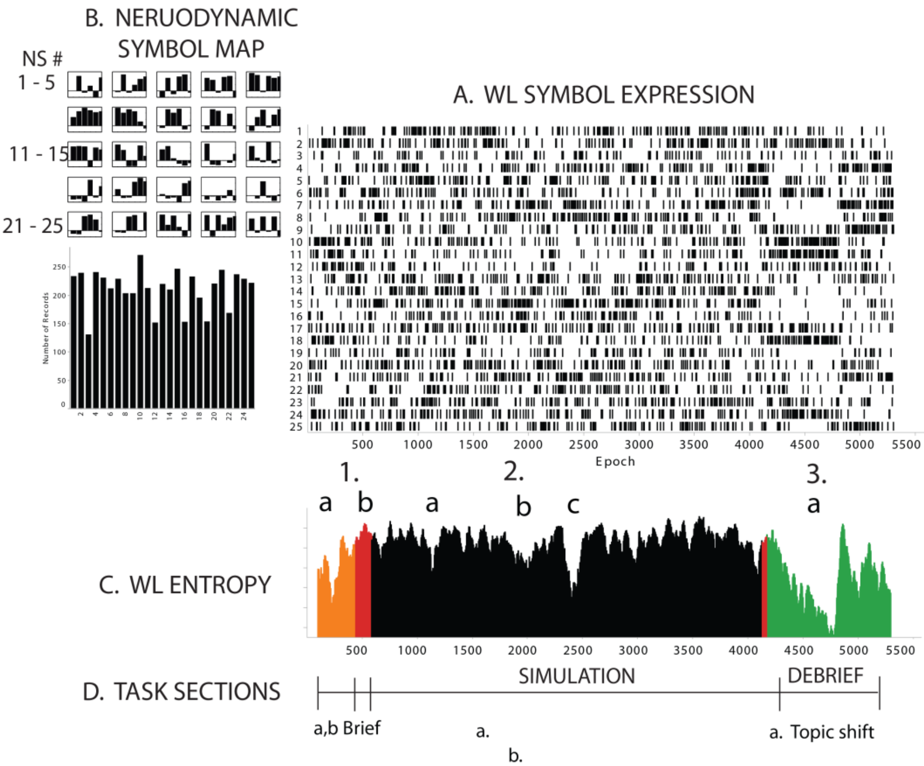

Fig. 4. Linking NS symbols (A) with temporal NS expressions (B), entropy fluctuations (C) and segments of the task (D)

4.4 Entrepreneurial Teams

Teams participating in the business simulations do not have defined member roles like other tasks and the discussions and teamwork are less structured. The data of one team is shown in Fig. 5 where the second-by-second expression of the 25 NS (Fig. 5A) are plotted (Fig. 5B) along with the profile of the Entropy (Fig. 5C). Sections of the entropy profile have been highlighted to indicate task segments. To show the modeling generality this study highlights EEG-E rather than EEG-WL.

Prior to the start (Fig 5C.1) many of the team members had low EEG-E (NS 6, 13, & 14) as general instructions were given. The team then began to surface issues and during this segment NS 1 emerged as the dominant symbol. This symbol represented periods where team member 1 had high EEG-E while the rest were average / low.

This team rhythm intensified as the end of this session was approached and the resulting organization was reflected in a drop in the entropy. The team was then instructed to begin developing a consensus and NS 1 was replaced by a variety of other NS. After ~10 minutes NS 1 re-emerged as the dominant NS as consensus was reached. The team then entered the last segment of the task where their recommendations were finalized (Fig. 5C.4).

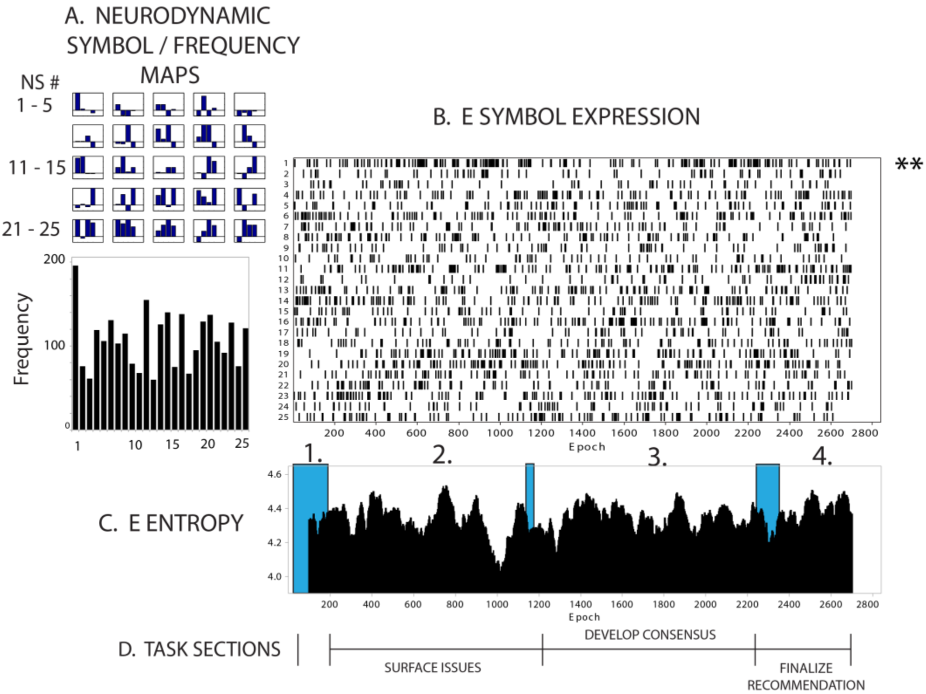

Fig. 5. Linking NS symbols (A) with temporal NS expressions (B), entropy fluctuations (C) and segments of the task (D). The blue regions indicate times where instructions were being given. The ** represents the dominant symbol.

5 Discussion

The first hypothesis was that teams develop task-related neurodynamic rhythms and organizations when performing a task. As cycles and rhythms are widespread across different systems and subsystems during social interaction it would not be unusual to find a form of neurodynamics rhythm. What was less certain was if and how these rhythms would be manifested in EEG-defined measures of Engagement or Workload, and what the prevalence, magnitude, and duration of such rhythms would be. The data in this study suggest that many, if not most successful teams develop what we would term a Normal Operating Rhythm (NOR). The NOR is operationally described as a symbolic representation of a quantitative combination of an EEG-defined measure that is expressed most often. In terms of complexity theory these preferred patterns of neurodynamics expression can be thought of as a rhythm that the team frequently returns to or an attractor system. As described by Goldstein et al [18] attractors are likely more than repetitive patterns, but are more representative of the underlying system of beliefs '…the core drivers of organizational culture that lead to consistent individual choices and actions.'

These rhythms often did not appear immediately, particularly with teams that had not worked together, but emerged with the progress of the performance. For both the MT and the ASWT teams these rhythms and organizations were not team or session specific but were seen across teams and sessions indicating a more generalized organizational phenomena. Such rhythms may be useful for evaluating different combinations of team members to determine which teams develop the most efficient and effective synchronies.

Neurodynamic re-organizations were often a result of these rhythms or of disturbances to the rhythms, but the question remains open as to why such organizations develop. A simple answer would be that it is an energy savings / efficiency device, i.e. self-organization of complex systems often results in reduced system entropy. When one complex system (task) interacts with a second complex system (team) it is difficult to reduce the constraints of the task, but the degrees of freedom of interaction of the team members can be reduced by mutually agreeing on a defined protocol of exchanging information. A final possibility is that they are a manifestation of shared situation awareness or of team macrocognition. If so, they may provide a pathway for linking the neurodynamic and behavioral models of teamwork.

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