TOWARD OBJECTIVE MEASURES OF TEAM DYNAMICS DURING HEALTHCARE SIMULATION TRAINING

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Three-person teams of fourth-year medical students or experienced operating room practitioners performed simulations around the construct of ventilation. Team member communications together with EEG-derived brainwaves were collected and classified each second and the changing neurodynamic as well as communication organizations of the team were modeled. The fluctuating neurodynamic organizations were obtained from symbolic representations of the EEG power levels of team members while changes in communication were determined by Latent Semantic analysis – derived measures of communication content.

The neurodynamic organizations of the teams at the 10 Hz (alpha) and 39 Hz (gamma) EEG frequencies fluctuated with task demands. The frequency, magnitudes, and durations of these fluctuations differed between novice and expert teams, and these changes in the team's neurodynamic organizations were paralleled by dynamic changes in communication and improvements in TeamSTEPPS® ratings. Neurodynamic and communication measures of team organization may therefore be valuable tools for understanding and assessing the short term dynamics of teams during simulation training, complementing and extending observational evaluations of teams.

INTRODUCTION

Simulation training is ubiquitous in medical and nursing education (McGaghie, Issenberg, Petrusa & Scalese, 2009; Aebersold & Tschannen, 2013), and the regular use of simulations is beginning to mitigate against adverse outcomes in community hospitals and medical specialty programs (Riley, Davis, Miller, Hansen, Sainfort & Sweet, 2011). One of the goals of simulation training is to improve team coordination and communications, as difficulties in these interactions have been associated with poorer healthcare outcomes (Sutcliffe, Lewton, & Rosenthal, 2004).

During simulation training the structural and process dynamics of teams continually shift in response to the changing task demands, and while these momentary dynamics are implicitly acknowledged by expert raters, they are not used explicitly as performance measures. Recently we have begun tracking the fluctuations in the neurodynamic organizations of teams (Stevens & Galloway, 2014, 2015). We have shown that the frequency, duration, and magnitude of these organizing and re-organizing neural phenomena are inversely correlated with the levels of team performance and the team's resilience (Stevens, Galloway, Lamb, Steed & Lamb, 2015). That is, the more organized (i.e. rigid) the team was neurodynamically, the lower their performance; while less neurodynamic organization seemed to represent more flexible teams. The similar team dynamics seen across diverse teamwork settings along with the links between performance measures and team neurodynamics, suggested that this approach might be useful for revealing the macro and micro neurodynamics of healthcare teams during simulation training and associating these dynamics with team performance.

METHODS

Simulations

The simulations followed a common training format beginning with a pre-simulation Briefing of approximately ten minutes. This orientation helped establish a psychologically safe learning environment and provided an introduction to the simulated clinical setting, equipment, supplies, and the mannequin. Teams were also briefed on key roles needed to manage a patient with an urgent/emergent clinical condition. These included Leadership, Compressions, Airway, Breathing, Medication/Fluid Administration, Electrical Therapy, Heart Rate Monitors, and Scribe. During the briefing a short introduction to the case set the stage for the simulation. The Briefing was followed by the simulation Scenario lasting 15-20 min. Subsequently a reflective Debriefing was led by the instructor (15-20 min). The teams included a fourth-year medical student team that was observed over three sequential performances and three teams of experienced practitioners who performed one simulation each; the total teamwork time observed and modeled was 3 hours, 40 minutes.

The simulation series focused on ventilation and included: anaphylactic shock with airway and circulatory compromise; suspected narcotic or Benzodiazepine overdose; mild desaturation and bronchospasm in a patient undergoing induction of anesthesia who was subsequently involved in an operating room fire requiring evacuation; and a patient with a known difficult airway who experienced local anesthetic systemic toxicity and subsequent respiratory arrest.

The performances were independently evaluated by two experienced raters without consensus-reaching discussions using the Team Performance Observation Tool (TPOT), an evaluation component for the TeamSTEPPS® (Team Strategies and Tools to Enhance Performance and Patient Safety) program (Baker, Amodeo, Krokos, et al 2010). The inter-rater kappa for the TeamSTEPPS® was .33, a fair level of agreement (Baker, Cuzzola, Knox, Liotta, Cornfield, Tarkowski, Masters, McCarthy, Sturdivant, & Carlson, 2015).

Participants and Data Collection

Twelve subjects participated in the studies; there were 3 fourth-year medical students and 9 experienced operating room staff. All subjects were recruited from the Order of Saint Francis Healthcare Center (OSHF) following protocols that had been approved by the OSHF institutional review board. Consent forms were signed by all participants and confidentiality was guaranteed. Video was recorded from three cameras that captured team interactions naturally without disturbances. Speech transcripts were prepared from the audio portions of these videos.

Electroencephalography

The X-10 wireless headsets from Advanced Brain Monitoring, Inc. were used for data collection. This wireless EEG headset system included sensor site locations: F3, F4, C3, C4, P3, P4, Fz, Cz, POz in a monopolar configuration referenced to linked mastoids. Embedded within the EEG data streams were eyeblink artifacts which were automatically detected and decontaminated using interpolation algorithms contained in the EEG acquisition software (Berka, Levendowski, Cvetinovic, Petrovic, Davis & Luminaco, 2004). These eye-blink interpolations represented ~5% of the simulation time and in previous studies have not significantly influenced the detection of team neurophysiologic activities which occurred throughout the performances (Stevens & Galloway, 2014; Stevens, Galloway, Wang, Berka, Tan, Wohlgemuth, Lamb, Buckles, 2012). The EEG power values were computed each second at each sensor for the 1 – 40 Hz frequency bins by the B-Alert® Lab software.

Neurodynamic Modeling

The goal of the neurodynamic modeling was to develop data streams that contained temporal information about the organization, function and performance of teams. To generate Neurodynamic Symbols (NS) for the three-person healthcare teams, each second the power levels of one (of the 40) EEG frequency bin of a team member was compared to his/her own task average levels. This identified whether at a particular time point an individual team member was experiencing above or below average levels of an EEG marker and whether the team as a whole was experiencing above or below average levels. The selection of the 10 Hz (involved in attention and prioritizing stimuli) and 39 Hz EEG (memory encoding & retrieval) frequencies for this study was based on prior studies (Stevens & Galloway, 2014, 2015).

As previously described (Stevens & Galloway, 2015; Stevens, et al, 2012), in this process the frequency-specific EEG power levels were partitioned into the upper 33%, the lower 33% and the middle 33%, which were assigned values of 3, -1, and 1 respectively, these values were chosen for data visualization purposes. Each second the values for each person were combined into a three-element vector. The values for the three histograms in Fig. 1A indicate that at this second the registered nurse (RN) had below average EEG levels, the scrub tech nurse (ST) had above average and the anesthesiologist (AN) had average levels. Figure 1B shows the complete neurodynamic symbolic state space when each second of the performance was symbolically processed.

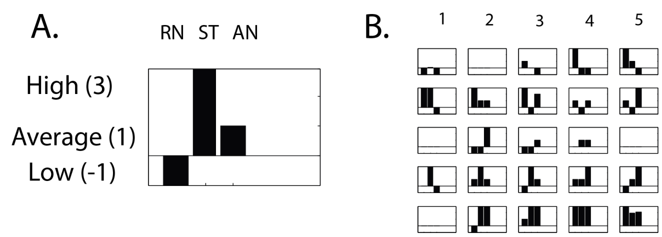

Figure 1. Neurodynamic symbols (NS) and symbol space. A) Sample neurodynamic symbol showing the power levels of three team members. B) The twenty-one symbol state space that was used for creating the neurodynamic symbol streams.

Each NS situated the EEG power levels of each team member in the context of the levels of the other team members and when the second-by-second symbols were aligned the data stream contained a history of the team's neurodynamics. A quantitative readout of this history could be generated by calculating the Shannon entropy (Shannon, & Weaver, 1949) of the symbol distribution over a 60s moving window (Stevens & Galloway, 2014). Performance segments with restricted symbol expression had lower entropy, thought to reflect rigidity, while segments with greater symbol diversity had higher entropy, thought to reflect neurodynamic flexibility.

Analyzing Team Communication Using Latent Semantic Analysis

Latent Semantic Analysis (LSA) (Landauer, Foltz & Laham, 1998; Foltz, Laham & Landauer, 1999) is a statistical-mathematical approach to discourse analysis that models the domain of discourse as a high-dimensional vector space. Plotting transcribed communications in this space provides domain-relevant metrics of the content of speech acts. We used LSA to measure the semantic content of speech acts (utterances; "…connector once I have the endotracheal tube in place?"). This content metric is called "vector length", and it measures the amount of speech (number of words) weighted by the domain-specificity of the words; the larger the vector length, the more densely packed it is with domain specific communication (i.e., more medical "jargon"). The other content metric is called "cosine", and it measures how semantically related (or correlated) speech acts are; the larger the cosine, the more semantically similar the domain specific communication across team members. We have successfully used these communication content metrics to quantify team effectiveness in terms of their communication characteristics in uninhabited air vehicle and submarine teams (Gorman, Foltz, Kiekel, Martin & Cooke, 2003; Gorman, Martin, Dunbar, Stevens, Galloway, Amazeen, P. & Likens, 2015).

RESULTS

Objectively Capturing Team Neurodynamics

As tasks evolved the distributions of NS changed, and by plotting the time ordered neurodynamic symbols the changing neurodynamics could be reconstructed and visualized (Fig. 2). The second-by second NS expressions for both the 10 Hz (Fig. 2B) and the 39 Hz EEG (Fig. 2C) frequency bins from the CzP0 channel are shown for a three-person medical school team. One obvious feature was that the 10 Hz and 39 Hz NS expressions were temporally different indicating that these frequencies carried alternative neurodynamic information about the team.

A second feature was the changing NS distributions at the task segment junctions. During the Scenario NS # 1 & 3 predominated at 10 Hz (Fig. 1B), indicating times when all members had low 10 Hz power. At the Debriefing junction, these symbols were replaced by NS # 24 & 25 indicating the three team members had switched to high 10 Hz power.

Changes were also seen in the 39 Hz EEG frequency bin at the Scenario-Debriefing junction, but at 39 Hz the major shift was from the team expressing high gamma band power in the Scenario to lower levels in the Debriefing. These changing Scenario – Debrief dynamics are typical of what we have seen with military tasks (Stevens, Gorman, Amazeen, Likens & Galloway, 2013). The rapidity of these changes (seconds) indicates that NS expression is highly sensitive to the team experiences and changes in the task environment. A final NS expression feature was that symbol distributions were not uniform, but were characterized by segments where a limited symbol subset persisted.

Estimates of the degree of NS persistence were quantitated by calculating the Shannon entropy of the NS stream (Stevens, Galloway, Wang, Berka, Tan, Wohlgemuth, Lamb & Buckles, 2012; Stevens, Gorman, Amazeen, Likens & Galloway, 2013; Shannon & Weaver, 1949). The maximum entropy that could be expected from the 21 symbols in Fig. 1B is 4.39. Compared with other team / task combinations we have studied (Stevens & Galloway, 2014, 2015), this team had low entropy levels at both 10 Hz (3.61 bits) and 39 Hz frequencies (3.5 bits). This indicated a high degree of neurodynamic organization, equivalent to an average usage of only 12 of the 21 NS available. The highest NS entropy was found in the 10 Hz EEG bin of the Briefing (3.78 bits or ~ 14 NS) while the lowest averages were in the Scenarios for both 10 Hz and 39 Hz (2.4 bits or ~ 5.5 NS). The neurodynamic picture that emerged from these initial studies was one of a team with a high degree of neurodynamic organization, i.e. although there were 21 different combinations of neurodynamic states available to the team, for much of the time the team was rigidly using a limited subset of these states. The Scenario was characterized by large fluctuations in this organization, particularly in the 39 Hz (gamma) bin. This decreased entropy resulted from most team members having high gamma levels (i.e. NS # 24 & 25), suggesting significant working memory / cognitive activity.

The differential in 10 Hz and 39 Hz neurodynamics across the Scenario and Debriefing raised questions regarding the team neurodynamic profiles in the remaining thirty eight 1- Hz bins. A three-dimensional time-frequency-entropy map was next created displaying the NS entropy for the same performance across the 1-40 Hz EEG spectrum (Fig. 3A).

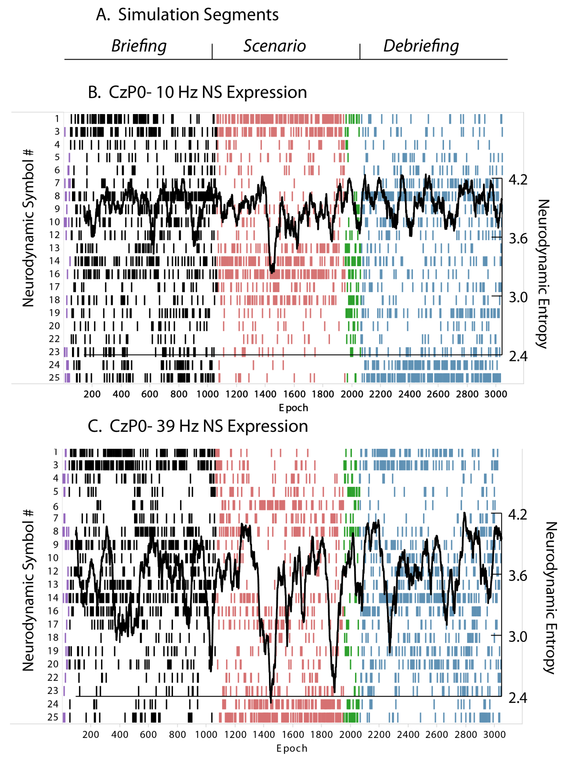

Figure 2. Neurodynamic symbol expression during simulation training. A) Markers highlight the simulation segments. B, C) The NS symbol being expressed each second in the 10 Hz (B) or 39 Hz (C) data streams was marked in the appropriate NS symbol row (y-axis). The line traces overlaying Figs. B and C are the Shannon entropy values of the 10 Hz and 39 Hz NS data.

The neurodynamic organizations (i.e. low NS entropy) were primarily distributed across two EEG frequency regions, 8-10 Hz and 30-40 Hz, with the exception of a region between 1300s-1500s where the decreased NS entropy bridged across the alpha and gamma bands into the beta band (~20 Hz). As a control, randomization of the NS symbol stream prior to calculating the NS entropy removed the patterns (Fig. 3B).

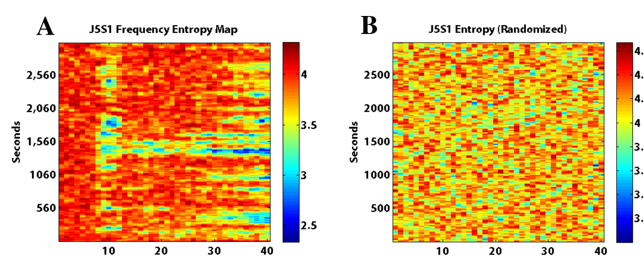

Figure 3. Neurodynamic entropy topology map generated from the 1-40 Hz frequency bins of the CzP0 sensor. A) This map plots the NS entropy levels as a function of performance time and EEG frequency. B) The same data following NS randomization prior to calculating entropy.

Linking Neurodynamic Fluctuations with Simulation Events

To relate the changing neurodynamics to simulation activities the speech of the team was transcribed and segmented into event-related Scenario activities (Fig. 4). During the first five minutes (performance epochs 1000s-1300s) the team conducted a primary patient survey, began administering oxygen, delivered the initial intravenous saline bolus and began ventilating the patient but with difficulty (1380s). From 1460-1560s respiratory failure was detected and a second endotracheal intubation was attempted and completed by 1675s.

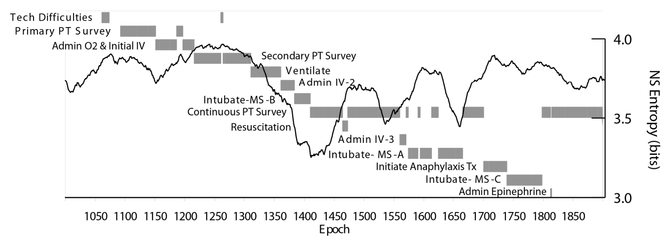

Figure 4. Episodes of team activity during the scenario portion of the first simulation. The speech transcript was reviewed by two raters and segments were coded that represented different stages of patient care during the Scenario.

The NS entropy declined with the start of the endotracheal intubation by medical student ‘B’ (MS-B) and continued through the second IV administration. The NS entropy was the lowest when team member ‘B’ stated: “I am not sure if I made it in. Does somebody want to check breath sounds?” The entropy levels fluctuated at low levels (i.e. high neurodynamic organization) for the next 4 minutes while medical student ‘A’ (MS-A) attempted to intubate. The team then reassessed the idea of anaphylaxis and administered epinephrine (1812s). The entropy levels began to rise to those levels seen at the beginning of the Scenario.

Linking Team Neurodynamics with Team Communication and Proficiency Ratings

We next examined the changes in NS entropy at 10 Hz and 39 Hz as a function of performance number (Fig. 5). Figure (5A) shows that as the team performed the simulations, the entropy levels increased; i.e. the team was becoming less neurodynamically organized which we interpret as being more flexible (Stevens & Galloway, 2015). The parallel curves for alpha and gamma power suggest this was occurring with both attention and working memory activities. The second figure (5B) correlates the NS entropy and TeamSTEPPS® ratings. Included in this figure are the 10 Hz NS entropy levels for three experienced teams (labeled “E”), which had higher entropy levels than the medical student team. The relationship between the LSA metrics and overall TPOT scores is shown in Fig. 6 for the novice and experienced team performances. What these pilot data demonstrate is that the communication metrics behave as expected for discriminating teams of different experience and skill levels in the medical domain, with more skilled teams (high TPOT rating) having more densely-packed domain-specific communication (large vector lengths) as well as a tendency to cover more domain-specific topics (smaller cosine) over the course of a conversation. It is important to note, however, that whereas the TPOT ratings provide a broader analysis of teamwork dimensions over time, the communication metrics pinpoint very specific cognitive and behavioral factors that differentiate between more skilled and less skilled teams. Taken together, our results suggest that these communication and performance differences are further reflected in neurodynamic changes during team performance.

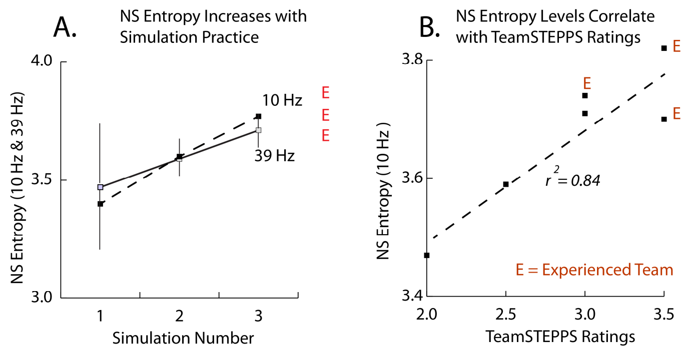

Figure 5. Neurodynamic entropy increases with experience A) The NS entropy levels during the Scenario are plotted for the 10 Hz and 39 Hz data streams against the simulation number. B) The NS entropy levels (10 Hz) of the three medical student and experienced teams are plotted vs. the TeamSTEPPS® ratings; red ‘E’ letters indicated experienced team measures.

DISCUSSION

In this study we followed teams of medical students and hospital practitioners through simulations emphasizing patient ventilation to better understand the relationships between the team’s neurophysiology and their behavioral, communication and performance dynamics.

One consistent across-performance feature was the neurodynamic reorganization that occurred at the Scenario – Debriefing junction. The switch from low alpha power during the Scenario to high alpha power in the Debriefing indicated a reversal in the attentional state of the team (Klimesch, 2012; Stevens, Galloway, Wang, Berka, Tan, Wohlgemuth, Lamb & Buckles, 2012). The lower alpha power levels during the Scenario suggests the team members were closely attending to the unfolding events and activities in the environment. These activities would simultaneously include attention to each of the other team members as well as the task events.

During social coordination, vision of the partner substantially lowers alpha power, with the degree of the fluctuations reflecting the complexity of behavioral information acquired about the partner (Tognoli & Kelso, 2013). This complexity is likely mediated by multiple social coordination markers in the 8-11 Hz region including the Phi complex (Tognoli, Lagarde, de Guzman & Kelso, 2007) and the medial, left, and right central mu rhythms that are regulated by movement, or imagined movements (Menoret, Varnet, Fargier, Cheylus, Curie, desPortes, Nazir & Paulignan, 2014; Caetano, Jousmaki & Hari, 2007; Pineda, 2008).

A second consistent feature was the increased neurodynamic organization of the teams that occurred intermittently throughout the performance and was reflected in the changes in the magnitude and duration of entropy fluctuations. In this study the largest entropy drops occurred during periods of difficulty or uncertainty as highlighted by the performance described in Fig. 2 and Fig. 4. This was seen when the team needed multiple attempts to successfully ventilate the patient. The association between reduced entropy levels and periods of team stress has been seen in all teams we have studied (Stevens & Galloway, 2014, 2015; Stevens, Galloway, Lamb, Steed & Lamb, 2015). As expert navigation teams generally experienced fewer periods of stress, their entropy levels during the Scenario were higher than for junior officer teams undergoing training to become navigators and boat operators (Stevens et al, 2012). More recently, a positive correlation was seen between the entropy levels and team resilience as measured by an observational instrument recently adopted by the submarine fleet (Stevens et al, 2015). For expert teams, high entropy levels (flexibility) correlated with increased resilience indicating expert teams are more adaptive to changing situations and recover quicker to the unexpected.

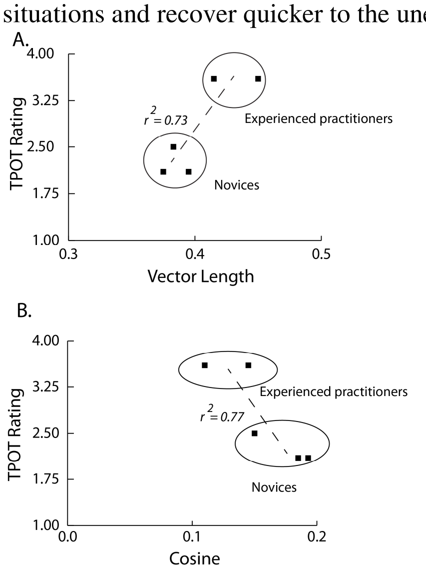

Figure 6. Association between TeamSTEPPS® TPOT ratings and speech measures. A) Vector length; B) Speech cosine.

Similarly in this study, NS entropy levels were correlated with ratings of TeamSTEPPS® evaluators. These preliminary results should be viewed with caution given the 'fair' inter-rater reliability, which may have resulted from the lack of consensus discussions between the two raters. Nevertheless, these studies suggest a path forward for developing more detailed descriptions of teamwork across observable, cognitive, and neurophysiologic levels, including more granular construct descriptions for TeamSTEPPS® ratings and perhaps new directions for simulation training.

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