Understanding Team Cognition through Communication Analysis:

Measuring Team Interaction Patterns Using Recurrence Plots

by

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ABSTRACT

By extracting communication sequences from audio data collected during two separate five-person mission-planning tasks, interaction patterns in team communication were analyzed using a recurrence-based, nonlinear dynamics approach. These methods, previously successful in detecting pattern change in a three-person team task, were evaluated for their applicability to larger team settings, and their ability to detect pattern change when team members switched roles or locations partway through the study (Study 1) or change in patterns over time (Study 2). Both traditional interaction variables (Talking Time, Co-Talking Time, and Sequence Length of Interactions) and dynamic interaction variables (Recurrence Rate, Determinism, and Pattern Information) were explored as indicators and predictors of changes in team structure and performance. Results from these analyses provided support that both traditional and dynamic interaction variables reflect some changes in team structure and performance. However, changes in communication patterns were not detected. Because simultaneous conversations are possible in larger teams, but not detectable through our communication sequence methods, team pattern changes may not be visible in communication sequences for larger teams. This suggests that these methods may not be applicable for larger teams, or in situations where simultaneous conversations may occur. Further research is needed to continue to explore the applicability of recurrence-based nonlinear dynamics in the analysis of team communication.

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INTRODUCTION

Many types of effective real-time operations in sociotechnical domains such as military and business depend critically on successful planning. These operations require team members to coordinate and process information quickly. This interdependency between team members requires well-developed coordination that is intrinsically tied to how well the team will perform. Well-coordinated teams learn to provide and request information from their team members at the right time for effective and timely planning.

As the team communicates while completing their task, interaction patterns form (e.g., Bowers, Jentsch, Salas, & Braun, 1998; Fischer, McDonnell, & Orasanu, 2007; Kanki, Lozito, & Foushee, 1989; Miller, Scheinkestel, & Joseph, 2009; Pincus, Fox, Perez et. al., 2008; Sexton & Helmreich, 2000; Xiao, Seagull, Mackenzie et. al., 2008). If interaction patterns develop as teams continue to work together (e.g., Achille, Schultz, & Schmidt-Nielson, 1995; Gorman, Foltz, Kiekel et. al., 2003; Katz, 1982), then changes in team structure and task environment may be reflected by changes in their interaction patterns. This can be revealed in the quantity of patterns, the informational content of those patterns, or in the form of the patterns themselves. Therefore, to further understand the differences between teams, interaction patterns from communication data are analyzed.

One theory of team training suggests that teams who have a shared mental model of a task, as demonstrated by similar knowledge of a task, perform better

(Cannon-Bowers, Salas, Blickensderfer & Bowers, 1998). Although sometimes a shared mental model predicts better performance (Mathieu, Goodwin, Heffner, Salas, & Cannon-Bowers, 2000), sometimes it does not (Stout et. al., 1999).

In contrast with the shared mental model perspective, the Interactive Team Cognition theory states team cognition exists in the interactions among team members (e.g., communication, coordination) rather than in the overlap of team- and task-related knowledge (Cooke, Gorman, & Winner, 2007; Cooke, Gorman, & Rowe, 2009). Support for the Interactive Team Cognition theory includes the finding that mixing in and swapping out different team members has been associated with more flexible coordination, which consequently leads to improved ability to perform in novel situations (Gorman, Cooke, Pedersen, et. al., 2006; Gorman, Cooke, & Winner, 2006).

Based on these two competing perspectives of team cognition, a role-switching, location-switching, and control condition were compared to assess differences in team performance in a team-planning task. Team effectiveness (performance) data from this study has previously been reported (Fouse, Cooke, Gorman, Murray, Uribe, & Bradbury, 2011), showing that role-switching and location-switching teams created better plans than control teams. This increased performance in the role- and location-switching conditions was not reflected in the shared knowledge of the task, as measured using a card-sorting task.

Team interaction patterns recur in time, often in discontinuous bursts and lulls of interactivity (Huberman & Glance, 1998). Because of this, nonlinear dynamics may provide a method for quantifying pattern changes. Based on previous application of nonlinear dynamics to team interaction patterns (Gorman et. al., 2011), a measure of communication determinism drawn from recurrence analysis for nonlinear time series (Weber & Zbilut, 1994) and a measure of communication pattern information drawn from information theory (Shannon & Weaver, 1949) was applied to communication data. Collected in the context of the switching study previously mentioned, interaction patterns from the teams' communication were analyzed to better understand the differences between the team conditions.

Determinism and Pattern Information Measures

A time series consists of observations sampled at regular intervals from a process continuous in both amplitude (variability) and time. In contrast, a discrete sequence is not continuous in either variability or time. Team interaction sequences are considered a discrete code because they are sampled from a nominal set of mutually exclusive codes (e.g., which team member is speaking), and the sequence of codes are ordered in time, but the exact onset or duration times of the individual codes are not used (Quera, 2008). For either type of sequence, the basis for recurrence analysis is a Recurrence Plot (RP).

For time series x of length N, an RP is an $N \times N$ (symmetric) matrix where, if the value of $x(j)$ is sufficiently close (within a threshold) to the value of $x(i)$, then a dot is plotted at $x(i,j)$ (Eckmann, Oliffson Kamphorst, & Ruelle, 1987). The RP of a time series x, represents all pair-wise combinations i,j that are sufficiently close, over all time scales, using a dot. Recurrent points forming unbroken diagonals are time-shifted, recurrent patterns of the time series.

Once the RP is created, recurrence analysis continues by quantifying recurrent patterns of the plot (Webber & Zbilut, 1994). Determinism (DET) is one of the quantifications extracted from the plot. It is the percentage of points forming diagonals divided by all recurrent points in the upper triangle:

$$\text{DET} = \frac{\#\ \text{recurrent points forming diagonals}}{\text{total}\ \#\ \text{of recurrent points}}$$

DET ranges from zero to 100%, where a never repeating time series has determinism zero and a time series that perfectly repeats has determinism 100. For real-world systems, where noise is always present, DET will lie between the deterministic and random extremes. As many processes aim to remain flexible, they are somewhere in between (Van Ordern, Kloos & Wallot, 2009).

It has been argued that to remain flexible and adaptive, teams must maintain a balance between overly structured versus completely random interaction patterns. To quantify this balance, informational content of a sequence of communication codes can be measured by the number of decisions (usually in bits) required to represent the sequence (i.e., the sequence's uncertainty; its "entropy"). However, this analysis does not reflect the *meaning* of the sequence.

Information-theoretic content of a communication pattern (extracted from longer sequence codes) quantifies the average amount that the uncertainty about the overall sequence is reduced, given our knowledge of the pattern. Communication pattern information is quantified as the *mutual information* (Cover & Thomas, 2006; Gallager, 1968) of a short pattern of codes relative to an overall sequence of codes:

$$\text{Pattern Information} = p(\text{pattern}) \times \log\left(\frac{p(\text{pattern})}{\prod_{\text{i}=1}^{\#\text{ codes}} p(\text{codei})}\right)$$

If N = sequence length and L = pattern length, then

$$p(\text{pattern}) = \frac{\text{pattern frequency}}{N - L + 1}$$

$$p(\text{codei}) = \frac{\text{codei frequency}}{N}$$

A pattern that occurs randomly has pattern information equal to zero

If pattern probability is less than the probability of the codes occurring independently, then pattern information will be negative (i.e., if $0 < y = p[\text{pattern}] / \Pi\, p[\text{code}] < 1$, then $\log[y] < 0$).

Negative mutual information (Gallager, 1968) entails that the pattern occurs below random (chance) levels, such that the pattern may provide misleading information regarding the overall sequence. Alternatively, higher, positive information values indicate that when the codes do occur, they tend to occur together as a pattern, providing positive mutual information regarding the process that generates the overall interaction sequence. It is expected that, like a deterministic sequence, high maximum information patterns are associated with a rigidly structured team interaction process. Pattern length does not matter for the random sequence, nor does the order of codes in the pattern because in the random case, any randomly-generated pattern should be just as informative with respect to the overall sequence as any well thought out, *a priori* specified pattern; namely, pattern information ≈ 0. It is expected that teams that remain flexible and adaptive within the constraints of the task will distribute mutual information across interaction patterns, rather than exhibit high maximum pattern information. Sequences have been scanned for patterns to investigate their effectiveness in explaining the process that generates the overall sequence.

Goals and Predictions

The goal of this project is to demonstrate that the discrete recurrence approach presents valid measures for differentiating nonlinear dynamics using relatively simple, automatically-generated interaction sequences. Communication data from a study in which members of five-person teams either changed roles, changed locations, or stayed the same during a four-operation mission planning task (Fouse et. al., 2011) was analyzed. Based on prior results from this study, as well as previous findings in team communication (Gorman, Cooke, Amazeen, & Fouse, 2011), these new analysis techniques were evaluated for their validity and usefulness. In addition, communication from a similar five-person mission-planning task, collected across four days for each team was analyzed. Although very similar to the switching study, there were no team conditions, but rather this study was conducted with the goal of observing and evaluating the evolution of interaction across a longer time period (28 operations across four days).

I predicted that because control teams had more rigid coordination dynamics, their interaction sequences would be more rigidly patterned, as manifested in relatively high determinism and maximum pattern information. On the other hand, because their coordination dynamics were more flexible, I predicted that the switching teams' interaction sequences would manifest in lower determinism and, relative to their overall interaction process, lower maximum pattern information.

I hypothesized that the longitudinal teams from the second study would become more flexible over time, resulting in less determinism, due to the varied interaction necessary for the 28 operations they completed.

Chapter 2

STUDY 1: SWITCHING STUDY

Methods

Forty-six five-person teams were recruited from Arizona State University and the surrounding community. Participants were unfamiliar with each other before participating. These teams participated in one four-hour session. Due to various hardware or software issues, only 30 teams were able to complete the entire study. Individuals were compensated for their participation by payment of $12 per hour.

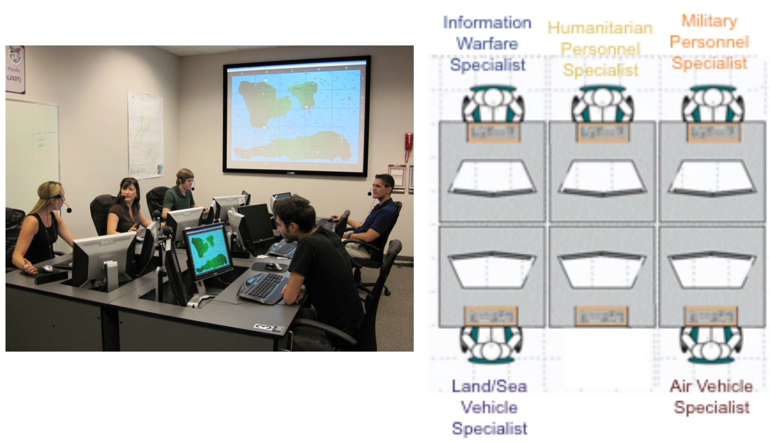

Figure 1: A team performs a non-combatant evacuation scenario is the STE (left); the role setup in the Control condition (right).

Task. A Synthetic Task Environment (STE) (Cooke & Shope, 2005; Duran, Goolsbee, Cooke, & Gorman, 2009; see Figure 1) was used to measure the team planning task. This STE is an object-oriented system that has the ability to host many different scenarios such as emergency management or wartime asset planning. The realism and flexibility of the STE makes it capable to address questions that are important for team collaboration across a variety of task settings.

Based on a scenario constructed by Warner, Wroblewski, and Shuck (2009), participants assumed an individual role to work as a team in order to complete operation plans during a non-combative evacuation scenario. Team members were assigned to one of five roles, which had access to heterogeneous information and were required to work together to be able to aid civilians during a rebel takeover. The roles were Land/Sea Vehicle Specialist, Air Vehicle Specialist, Information Warfare Personnel, Humanitarian Personnel, and Military Personnel. Teams completed four operations, each varying in difficulty. Each operation had four distinct objectives that required the team to work together, utilizing their resources to develop a plan that met the objectives. During Operation 3, participants had to successfully notice a change in a scrolling newsfeed, which would alert them to the possibility that they may need to alter their objectives.

The team did all of their planning through a computer interface called a resource viewer. In the resource viewer, each step of the plan was listed in a collective plan viewer visible to the rest of the team.

Teams were instructed to try and produce the best possible plan by completing as many objectives as possible, while using as little money and time as possible.

Design and measures. Teams were randomly assigned to one of three conditions: role switching (RS), location switching (LS), or control. For the RS condition, each team member switched to a different role for Operation 2 and 3 and back to their origin role for Operation 4, while remaining in the same location throughout all operations. For the LS condition, each team member switched to a different location for Operation 2 and 3 and switched back to their original location for Operation 4, while remaining as the same role throughout all operations. The control condition had participants remain in the same role and location throughout all operations.

Objective team performance, measured for each operation, was a composite outcome score of the plan based on how many objectives were completed, how much money was spent, and how much time was required to complete the plan. Subjective ratings of team performance based on their plan were also collected to validate the objective score. This score was an average of ratings made by two experimenters using a scale from 1-10, 1 being worst possible and 10 being best possible. An intra-class correlation reliability analysis was run under the parallel model assumption across the two experimenter ratings, with reliability at ICC = .912. There was a significant correlation between objective and subjective plan scores ($r(95) = -0.48$, $p<.01$). Because good planners can meet objectives using low time/cost resources, this correlation is negative.

Both audio and video were collected during each operation. A separate microphone and overhead camera recorded each participant's individual audio and video. An additional video camera captured the entire team interacting, which had a composite audio feed (combined audio recording from each participant's microphone).

Procedure. There were nine teams in the RS condition, 11 teams in the LS condition, and 10 teams in the Control condition. Each participant was randomly assigned to one of the five roles before training began. The team watched a short news clip regarding the imaginary task environment and then was given a PowerPoint presentation with an overview of the task and each of the roles, as well as an explanation of the overall objectives for the task. A quiz of that material followed, with correct answers given by an experimenter as needed. Experimenters then explained how to use the interfaces (resource viewer and interactive map). A practice operation followed, during which the experimenters ensured that each participant had an understanding of the basic functions and duties of his or her role. Once the training operation was completed, the experimental sessions began. Teams completed four 30-minute operations. For each operation, an experimenter rated the collaboration process of the team. Teams received feedback after each operation on how well they accomplished their objectives. After completing the fourth mission, teams were compensated and then debriefed.

Analysis

After examination of all recorded audio files, only 21 teams (six Control, nine Role Switching, and six Location Switching) had complete audio for all four operations due to various recording issues.

Audio data for all teams was run through an in-house MatLab program to set threshold levels for each individual. Threshold levels were chosen to maximize the individual's sound, while minimizing sound picked up from other participants. Ordered sequences of codes (one for each operation) were then output. The sequences are composed of mutually exclusive (nominal) codes for each planning operation: 1 – “Air/Vehicle Speaking”; 2 – “Land/Sea Speaking”; 3 – “Military Personnel Speaking”; 4 – “Humanitarian Personnel Speaking”; and 5 – “Information Warfare Speaking”. A code was added to the sequence every time a team member in a different role began speaking, creating a coded sequence of the order of interactions between team members. Total talking time (in seconds) and the total co-talking time (in seconds) for each individual were also outputted.

A discrete RP was constructed for each mission planning operation. DET scores were calculated from recurrent diagonals relative to all recurrent points, for each operation.

Patterns of codes making up recurrent diagonals in the upper triangle of each RP were used to calculate pattern information scores. Pattern information for each distinct pattern was then extracted from each RP. The maximum of those values for each RP is the measure of maximum pattern information.

Analysis of Co-Variance. Total Talking Time, Co-Talking Time, Sequence Length, Recurrence Rate, DET, and Maximum Pattern Information were analyzed using an Analysis of Co-Variance (ANCOVA) with condition as the independent variable and interaction measures for Operations 2, 3, and 4 as the repeated-measures dependent variables. Talking Time, Co-Talking Time, and Sequence Length were also calculated by minute, due to the varied lengths of the four operations. The interaction measures at the pre-switch operation served as the covariates (See Appendix B).

Total Talking Time. A Repeated-Measures Analysis of Co-Variance (ANCOVA) was run with the switching conditions as the between-subjects factor, and Total-Talking Time for the entire team (in seconds) for Operations 2, 3, and 4 as the repeated dependent measure. Total Talking Time for Operation 1 was used as a covariate because it occurred before the experimental manipulation and the assumption of homogeneity of the regression effect was met. There was a main effect of Operation ($F(2, 34) = 9.79$; $p < .05$; Operation 2: mean = 683, SD = 86; Operation 3: mean= 1747, SD= 129, Operation 4: mean = 1276, SD=109). There was no main effect of the switching conditions. There was no significant interaction between Condition and Operation.

A Repeated-Measures Analysis of Co-Variance (ANCOVA) was run with the switching conditions as the between-subjects factor, and Total-Talking Time per Minute for the entire team for Operations 2, 3, and 4 as the repeated dependent measure. Total Talking Time per Minute for Operation 1 was used as a covariate because it occurred before the experimental manipulation and the assumption of homogeneity of the regression effect was met. There was no main effect of Operation. There was no main effect of the switching conditions. There was no significant interaction between Condition and Operation.

Co-Talking Time. A Repeated-Measures Analysis of Co-Variance (ANCOVA) was run with the switching conditions as the between-subjects factor, and Co-Talking Time (in seconds) for the entire team for Operations 2, 3, and 4 as the repeated dependent measure. Co-Talking Time was defined as two or more people speaking simultaneously. Total Co-Talking Time for Operation 1 was used as a covariate because it occurred before the experimental manipulation and the assumption of homogeneity of the regression effect was met. There was a main effect of Operation ($F(2, 34) = 3.67$; $p < .05$; Operation 2: mean = 306, SD = 51; Operation 3: mean= 909, SD= 141, Operation 4: mean = 538, SD=91). There was no main effect of the switching conditions. There was no significant interaction between Condition and Operation.

A Repeated-Measures Analysis of Co-Variance (ANCOVA) was run with the switching conditions as the between-subjects factor, and Co-Talking Time per Minute for the entire team for Operations 2, 3, and 4 as the repeated dependent measure. Co-Talking Time per Minute for Operation 1 was used as a covariate because it occurred before the experimental manipulation and the assumption of homogeneity of the regression effect was met. There was no main effect of Operation. There was no main effect of the switching conditions. There was no significant interaction between Condition and Operation.

Sequence Length. A Repeated-Measures Analysis of Co-Variance (ANCOVA) was run with the switching conditions as the between-subjects factor, and Sequence Length for Operations 2, 3, and 4 as the repeated dependent measure. Sequence length is the number of times team members took turns speaking. Sequence length for Operation 1 was used as a covariate and the assumption of homogeneity of the regression effect was met. There was a main effect of Operation ($F(2, 34) = 17.8$; $p < .05$; Operation 2: mean = 175, SD = 21;

Operation 3: mean= 419, SD= 26, Operation 4: mean = 313, SD=21). There was no main effect of the switching conditions. There was a significant interaction between Condition and Operation ($F(4, 34)= 3.03$, $P<.05$). Simple main effects analysis showed that for Operation 2, the RS had significantly longer sequences than LS ($P<.05$) and Control ($p<.1$). There were no significant differences found between conditions for Operation 3. In Operation 4, the RS had significantly longer sequences than Control ($p<.1$), but no significant difference with LS.

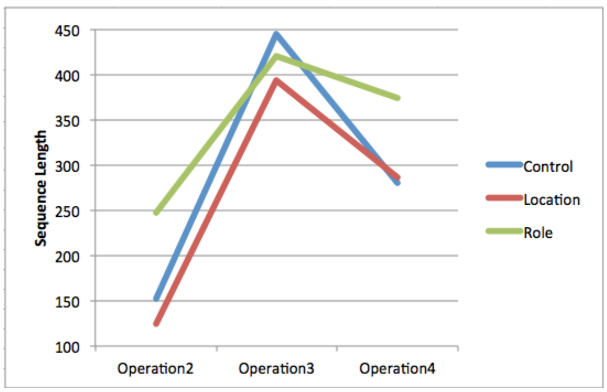

Figure 2: Sequence length by Operation and Condition. Role Switching teams have significantly longer interaction sequences than Location and Control teams in the 2nd and 4th operations.

A Repeated-Measures Analysis of Co-Variance (ANCOVA) was run with the switching conditions as the between-subjects factor, and Sequence Length per Minute for the entire team for Operations 2, 3, and 4 as the repeated dependent measure. Sequence Length per Minute for Operation 1 was used as a covariate because it occurred before the experimental manipulation and the assumption of homogeneity of the regression effect was met. There was no main effect of

Operation. There was no main effect of the switching conditions. There was no significant interaction between Condition and Operation.

Recurrence Rate. A Repeated-Measures Analysis of Co-Variance (ANCOVA) was run with the switching conditions as the between-subjects factor, and Recurrence Rate for Operations 2, 3, and 4 as the repeated dependent measure. Recurrence Rate is the density of recurrent points in a recurrence plot. Recurrence Rate for Operation 1 was used as a covariate and the assumption of homogeneity of the regression effect was met. There was a main effect of Operation ($F(2, 34) = 19.5$; $p < .05$; Operation 2: mean = 39.3, SD = 4.7; Operation 3: mean= 92.7, SD= 5.2, Operation 4: mean = 72.5, SD=4.6). There was no main effect of the switching conditions. There was a significant interaction between Condition and Operation ($F(4, 34)= 5.09$, $P<.05$). Simple main effects analysis showed that for Operation 2, RS had significantly greater Recurrence Rate than LS ($P<.05$) and Control ($p=.05$). No significant differences were found between conditions for Operation 3. In Operation 4, RS had significantly greater Recurrence Rate than Control ($p<.1$), but no significant difference with LS.

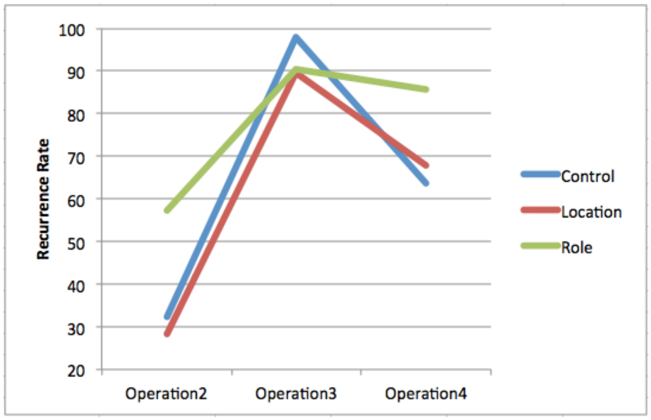

Figure 3: Recurrence Rate by Operation and Condition. Role Switching teams have significantly greater Recurrence Rate than Location and Control teams in the 2nd and 4th operations.

Determinism. A Repeated-Measures Analysis of Co-Variance (ANCOVA) was run with the switching conditions as the between subjects factor, and Determinism for Operations 2, 3, and 4 as the repeated dependent measure. Determinism for Operation 1 was used as a covariate and the assumption of homogeneity of the regression effect was met. There was no main effect of Operation or the switching conditions. There was no significant interaction between Condition and Operation.

Maximum Pattern Information. A Repeated-Measures Analysis of Co-Variance (ANCOVA) was run with the switching conditions as the between subjects factor, and Maximum Pattern Information for Operations 2, 3, and 4 as the repeated dependent measure. Maximum Pattern Information for Operation 1 was used as a covariate and the assumption of homogeneity of the regression effect was met. There was no main effect of Operation or the switching conditions. There was no significant interaction between Condition and Operation.

Correlations. A separate correlation was run on team performance (Objectives Met and the Objective Composite score) and interaction variables (Total Talking, Co-Talking, Sequence Length, Recurrence Rate, Determinism, and Maximum Pattern Information) for each operation (See Appendix C). While significant correlations were found between pairs of interaction variables, no significant correlations between any performance and interaction variables were found.

Additionally, separate correlations were run for each operation, partialling out Co-Talking to attempt to address the multiple-conversation problem inherent in a five-person team setting (See Appendix C). No changes in significant correlations were observed in any of the operations when co-talking was removed.

Surrogate Analysis. A surrogate analysis was also conducted, which is a re-sampling method that tests the null hypothesis that the observed dynamics are due to the temporal (sequential) distribution of the data, rather than its marginal distribution properties (Theiler, Eubank, Longtin et. al., 1992). This was used to ensure DET and, therefore, pattern analysis results, were not artifacts of sequences consisting of only five codes or occurring randomly. One hundred surrogate sequences were generated for each collected sequence by randomly shuffling each collected sequence. DET values of surrogate sequences (M = 40.12; SD = 4.06) and observed sequences (M = 40.34, SD = 4.16) were compared using a sign test (see Van Orden et. al., 2003). Fifty-three out of 84 comparisons yielded a success (observed DET > surrogate DET; $p < .05$), revealing that the observed dynamics were not due to marginal probabilities or lack of codes.

Discussion

A recurrence-based interaction measure (RR), as well as a more traditional interaction variable (Sequence Length), showed some effect of condition, as seen in the significant interactions between Condition and Operation for both Sequence Length and Recurrence Rate. RS having longer sequences and greater Recurrence Rates was the driving factor behind these significant interactions. Typically, in this condition, team member communication-exchange increased due to the team member who was previously in a role helping out the team member who now had to learn that role. This change in communication was reflected in a significant increase in Sequence Length, as well as a greater Recurrence Rate. However, this change was not detected by DET or Pattern Information. Recurrence Rate takes into consideration the density of the recurrence points, or how many times the system returns to a previous state. Determinism relates to the predictability of the system, or being able to predict when the system will return to the previous state. Based on the interactions between Condition and Operation for sequence length and recurrence rate, Role Switching teams had more interactions and returned to the same states more often, but, as reflected by no difference in DET, it is not possible to predict when teams will return to these states. Because these recurring states are not predictable, they are also not forming patterns.

These methods of communication analysis somewhat follow the same pattern seen by the analysis of team performance (Fouse et. al., 2011) in which

RS and LS conditions performed better when compared to the Control condition. However, only the RS condition showed any significant differences in Recurrence Rate and Sequence Length. Because these differences were not found in the LS condition, it is unclear what longer Sequence Length and greater Recurrence Rate can inform us about the performance of these teams.

While some of these interaction variables were correlated with each other, they did not show significant correlations with the performance measures. There were significant differences in Total Talking, Co-Talking, Sequence Length, and Recurrence Rate between different operations, but these differences did not show a continuous trend across operations.

Chapter 3

STUDY 2: LONGITUDINAL STUDY

Methods

Ten five-person teams were recruited using a temporary service agency. Participants were unfamiliar with each other before participating. These teams participated in one four-day session.

Task. The task environment was equivalent to Study 1, extended from four operations completed in one day, to 28 operations completed over four days.

Teams completed one mission each day, each with seven operations for a total of twenty-eight operations, each varying in difficulty. Each operation had four distinct objectives that required the team to work together. During eight operations (two during each mission) participants had to notice a change in a scrolling newsfeed, which would alert them to the possibility that they may need to alter their objectives.

Design and Measures. Objective team performance, measured for each operation, was a composite outcome score of the plan based on how many objectives were completed, how much money was spent, and how much time was required to complete the plan.

Both audio and video were collected during each operation. A separate microphone and overhead camera recorded each participant's individual audio and video. An additional video camera captured the entire team interacting, which had a composite audio feed (combined audio recording from each participant's microphone).

Procedure. Each participant was randomly assigned to one of the five roles before training began. The team watched a short news clip regarding the imaginary task environment and then were given three PowerPoint presentations: one with an overview of the task, another that was specific to their assigned role, and a third which provided training on the interfaces. An electronic quiz was administered following each of the presentations, with immediate feedback as to the correct answers. Participants were required to achieve a score of 70% or greater before moving on to the next set of training. A practice operation followed, during which the experimenters ensured each participant had an understanding of the basic functions and duties of his or her role. Once the training operation was completed, the experimental sessions began. Teams completed 28 30-minute operations. For each operation, an experimenter rated the collaboration process of the team. Teams received feedback after each operation on how well they accomplished their objectives. After completing their final mission, teams were debriefed.

Analysis

The longitudinal communication sequences were analyzed using regression. A regression was conducted for Total Talking Time, Co-Talking Time, Sequence Length, Recurrence Rate, Determinism, and Maximum Pattern Information, with Operation and Team as fixed factors, to view changes over time. Talking Time, Co-Talking Time, and Sequence Length were also calculated by minute, due to the varied lengths of the 28 operations (teams became much faster at completing an operation by the fourth day). Separate regressions were run to examine Objectives Met and Objective Composite Performance score as the dependent measure (See Appendix E). In addition, due to the exploratory nature of this analysis, a step-wise regression was conducted over all interaction variables and both performance scores, at the mission level (See Appendix F).

Ten teams completed the entire four-mission study. Audio data for all teams was run through an in-house MatLab program to set threshold levels for each individual. Threshold levels were chosen to maximize the individual's sound, while minimizing sound picked up from other participants. Ordered sequences of codes (one for each operation) were then output. The sequences are composed of mutually exclusive (nominal) codes for each planning operation: 1 – "Air/Vehicle Speaking"; 2 – "Land/Sea Speaking"; 3 – "Military Personnel Speaking"; 4 – "Humanitarian Personnel Speaking"; and 5 – "Information Warfare Speaking". A code was added to the sequence every time a team member in a different role began speaking, creating a coded sequence of the order of interactions between team members. Total talking time (in seconds) and the total co-talking time (in seconds) for each individual were also outputted.

A discrete RP was constructed for each mission planning operation. DET scores were calculated from recurrent diagonals relative to all recurrent points, for each operation.

Patterns of codes making up recurrent diagonals in the upper triangle of each RP were used to calculate pattern information scores. Pattern information was then computed for each distinct pattern extracted from each RP. The maximum of those values for each RP is the measure of maximum pattern information.

Regression. A regression, with Team and Operation as fixed factors, was conducted for Total Talking Time, Total Talking Time per Minute, Co-Talking Time, Co-Talking Time per Minute, Sequence Length, Sequence Length per Minute, Recurrence Rate, DET, and Maximum Pattern Information.

Total Talking Time. A regression was conducted across all teams, with Objectives Met for each of the 28 operations as the dependent measure and Total-Talking Time as the predictor. Both Team and Operation were included as fixed factors. Talking was a significant predictor of Objectives Met across Operations [$F(1,27) = 4.21$, $p<.05$ $\beta = -3.35 \times 10^{-4}$, $t(9)= -2.05$, $p=.41$]. A decrease in talking time is associated with an increase in performance.

A regression was conducted across all teams, with the Objective Composite score for each of the 28 operations as the dependent measure and Total-Talking Time as the predictor. Both Team and Operation were included as fixed factors. Total-Talking Time was not a significant predictor of the Composite score.

A regression was conducted across all teams, with Objectives Met for each of the 28 operations as the dependent measure and Talking Time per Minute as the predictor. Both Team and Operation were included as fixed factors. Talking per Minute was not a significant predictor of Objectives Met across Operations.

A regression was conducted across all teams, with the Objective Composite score for each of the 28 operations as the dependent measure and Talking Time per Minute as the predictor. Both Team and Operation were included as fixed factors. Talking Time per Minute was not a significant predictor of the Composite score.

Co-Talking. A regression was conducted across all teams, with Objectives Met for each of the 28 operations as the dependent measure and Co-Talking Time as the predictor. Both Team and Operation were included as fixed factors. Co-Talking was a significant predictor of Objectives Met across Operations [$F(1,27) = 3.94$, $p<.05$ $\beta = -4.95 \times 10^{-4}$, $t(9)= -1.99$, $p=.048$]. A decrease in Co-Talking Time is associated with an increase in performance.

A regression was conducted across all teams, with the Objective Composite score for each of the 28 operations as the dependent measure and Co-Talking Time as the predictor. Both Team and Operation were included as fixed factors. Co-Talking Time was a not significant predictor of the Composite score.

A regression was conducted across all teams, with Objectives Met for each of the 28 operations as the dependent measure and Co-Talking Time per Minute as the predictor. Both Team and Operation were included as fixed factors. Co-Talking Time per Minute was not a significant predictor of Objectives Met across Operations.

A regression was conducted across all teams, with the Objective Composite score for each of the 28 operations as the dependent measure and Co-Talking Time per Minute as the predictor. Both Team and Operation were included as fixed factors. Co-Talking Time per Minute was not a significant predictor of the Composite score.

Sequence Length. A regression was conducted across all teams, with Objectives Met for each of the 28 operations as the dependent measure and Sequence Length as the predictor. Both Team and Operation were included as fixed factors. Sequence Length was a significant predictor of Objectives Met across Operations [$F(1,27) = 5.331$, $p<0.05$; $\beta = -1.83 \times 10^{-3}$, $t(9)= -2.31$, $p=.022$]. A decrease in Sequence Length is associated with an increase in performance.

A regression was conducted across all teams, with the Objective Composite score for each of the 28 operations as the dependent measure and Sequence Length as the predictor. Both Team and Operation were included as fixed factors. Sequence Length was not a significant predictor of the Composite score.

A regression was conducted across all teams, with Objectives Met for each of the 28 operations as the dependent measure and Sequence Length per Minute as the predictor. Both Team and Operation were included as fixed factors. Sequence Length per Minute was not a significant predictor of Objectives Met across Operations.

A regression was conducted across all teams, with the Objective Composite score for each of the 28 operations as the dependent measure and Sequence Length per Minute as the predictor. Both Team and Operation were included as fixed factors. Sequence Length per Minute was not a significant predictor of the Composite score.

Recurrence Rate. A regression was conducted across all teams, with Objectives Met for each of the 28 operations as the dependent measure and Recurrence Rate as the predictor. Both Team and Operation were included as fixed factors. Recurrence Rate was a significant predictor of Objectives Met across Operations [$F(1,27) = 4.32$, $p<0.05$; $\beta = -7.47 \times 10^{-3}$, $t(9)= -2.08$, $p=.039$]. A decrease in Recurrence Rate is associated with an increase in performance.

A regression was conducted across all teams, with the Objective Composite score for each of the 28 operations as the dependent measure and Recurrence Rate as the predictor. Both Team and Operation were included as fixed factors. Recurrence Rate was not a significant predictor of the Composite score.

Determinism. A regression was conducted across all teams, with Objectives Met for each of the 28 operations as the dependent measure and Determinism as the predictor. Both Team and Operation were included as fixed factors. Determinism was not a significant predictor of Objectives Met across Operations.

A regression was conducted across all teams, with the Objective Composite score for each of the 28 operations as the dependent measure and Determinism as the predictor. Both Team and Operation were included as fixed factors. Determinism was not a significant predictor of the Composite score.

Maximum Pattern Information. A regression was conducted across all teams, with Objectives Met for each of the 28 operations as the dependent measure and Maximum Pattern Information as the predictor. Both Team and Operation were included as fixed factors. Maximum Pattern Information was not a significant predictor of Objectives Met across Operations.

A regression was conducted across all teams, with the Objective Composite score for each of the 28 operations as the dependent measure and Maximum Pattern Information as the predictor. Both Team and Operation were included as fixed factors. Maximum Pattern Information was not a significant predictor of the Composite score.

Step-wise Regression. A step-wise regression was conducted over all interaction variables and both performance scores, at the mission level (See Appendix F). Significant models were produced for only Mission 1 and Mission 4.

Mission (day) 1. A step-wise multiple regression for Mission 1 was conducted with Total Talking Time, Co-Talking Time, Sequence Length, Recurrence Rate, Determinism, and Maximum Pattern information as the potential predictor variables, with Objectives Met as the dependent variable. No significant model was produced.

A step-wise multiple regression for Mission 1 was conducted with Total Talking Time, Co-Talking Time, Sequence Length, Recurrence Rate, Determinism, and Maximum Pattern information as the potential predictor variables, with the Composite Performance score as the dependent variable.

Talking Time was the only predictor included as a significant predictor for the Composite Performance score [$F(1,8) = 6.02$, $p<.05$; $\beta = .655$, $t(9)= 2.45$, $p<.05$]. As Talking Time increased, the Composite Score increased. Better teams are associated with smaller Composite scores.

Mission (day) 4. A step-wise multiple regression for Mission 4 was conducted with Total Talking Time, Co-Talking Time, Sequence Length, Recurrence Rate, Determinism, and Maximum Pattern information as the potential predictor variables, with Objectives Met as the dependent variable. Co-Talking Time was the only predictor included as a significant predictor for Objectives Met [$F(1,8) = 6.02$, $p<.05$; $\beta = -.775$, $t(9)= -3.46$, $p<.01$]. As Co-Talking decreased, the number of Objectives Met increased.

A step-wise multiple regression for Mission 4 was conducted with Total Talking Time, Co-Talking Time, Sequence Length, Recurrence Rate, Determinism, and Maximum Pattern information as the potential predictor variables, with the Composite Performance score as the dependent variable. No model was produced.

Surrogate Analysis. Another surrogate analysis was to conducted to ensure that DET and, therefore, pattern analysis results, were not artifacts of sequences consisting of only five codes or occurring randomly. One hundred surrogate sequences were generated for each collected sequence by randomly shuffling each sequence. DET values of surrogate sequences (M = 40.91; SD = 4.50) and observed sequences (M = 40.89, SD = 5.05) were compared using a sign test (see Van Orden et. al., 2003). Only 126 out of 278 comparisons yielded a success (observed DET > surrogate DET; $p = .13$). Additionally, a separate sign test was conducted over each mission, to examine whether sequences became more structured over time. Because all four missions did not yield a success, it cannot be assumed that the observed dynamics were not due to marginal probabilities or paucity of codes.

Discussion

The repeated-measures regressions found that Total Talking Time, Co-Talking Time, Sequence Length, and Recurrence Rate were all significant predictors for Objectives Met. This suggests that traditional interaction variables, such as Total Talking Time, Co-Talking Time, and Sequence Length, were reflecting the changes in performance, and that dynamic interaction variables, such as Recurrence Rate, were also showing this relationship. However, when length of the operation was accounted for, the interaction variables were no longer significant predictors. For Total-Talking Time, when operation length was not taken into account, teams were accomplishing more objectives and had less Total-Talking Time, which was the driving force behind the significant effect. When operation length was taken into account, the team's amount of talking per minute remained relatively stable, but their performance greatly increased by the end of the 28 operations, so that Talking Time was no longer a predictor. Sequence length followed this same pattern - teams had consistent amounts of interactions per minute, but the sequences became shorter as the operations went on because teams accomplished their missions quicker.

Due to the results from the sign test, it was not surprising that Determinism and Pattern Information were not significant predictors of performance, since it could not be concluded that the values of the Determinism and Pattern Information predictors were anything more than chance, random occurrences. Again, Determinism relates to the predictability of the system, or being able to predict when the system will return to a previous state. Recurrence Rate takes into consideration the density of the recurrence points, or how many times the system returns to a previous state, which is not based on sequence or patterns. Recurrence Rate was found to be a significant predictor of performance because the sequences could still be in a random order, but have many points in which the team has returned to a previous state. The sign test was conclusive that the sequences were random, or that these recurring states were not predictable and were not forming any consistent patterns.

In addition, the stepwise regressions did not result in any consistent pattern of predictors for performance differences, thus it is not yet clear how these variables may interact as predictors of performance.

Chapter 4

CONCLUSION

It has been argued that familiarity can breed habituation of interaction patterns and rigidity for teams and groups (Gersick & Hackman, 1990; e.g., groupthink; Janice, 1972). However, this project did not provide further evidence in relation to this idea. In fact, based on the results from the sign test for the longitudinal study, the team communication sequences continued to be close to random across all four days of the study.

In addition, this analysis did not provide clear evidence for the validity of the discrete recurrence measures. While some of the interaction variables showed significant effects as predictors of condition (Study 1) and performance (Study 2), others did not. Since this analysis was based upon examining communication sequences and dynamic interaction variables, it is encouraging to find that Sequence Length and Recurrence Rate were found to reflect communication changes between conditions in the Switching Study, and to be significant predictors of performance in the Longitudinal Study. However, due to the inconsistent results on all of the interaction measures found across these two studies, more exploration is needed.

The goal of this project was to explore these methods, and specifically, to determine if they could characterize the interaction of five-person teams in terms of communication Determinism and Pattern Information, all using relatively simple, discrete interaction sequences, which could lead to automated data analysis, including real-time interaction analysis. The interaction sequences were used because content coding can be highly resource intensive and (most often) requires human expertise (e.g., Emmert & Barker, 1989; but see Foltz & Martin, 2009).

While previous research has applied these techniques of Determinism and Pattern Information to team interaction sequences with success (Gorman et. al., 2011), those teams consisted of three individuals performing a fairly structured task. An increase is team size (to five team members), as well as a more open task, can both have large impacts on the amount of structure required for good performance, and the formation of communication patterns. In the three-person task (Gorman et. al., 2011), the range of Determinism values found across teams (both intact and mixed) was much higher than for this less rigid five-person task (Determinism range for Study 1: 39-44; Study 2: 40-45; Three-person UAV task: 58-62). In addition, the range of Maximum Pattern Information values was also much higher for the three-person task (Max Info range, Study 1: .04-.07; Study 2: .03-.07; Three-person UAV task: 06-.09).

These differences in Determinism and Maximum Pattern Information values across studies suggests that there are differences in how the teams are communicating and interacting based on the task and/or the team size. The five-person mission planning and resource allocation task allows for many different ways to accomplish the objectives. Besides the fact that successful plans could be composed of completely different steps in moving resources, the communication required to obtain all the information necessary to successfully move those resources could also take on many forms. Perhaps this task is too flexible and unstructured to require teams to form structure and patterns in their communications.

In addition, the interaction of three team members is essentially different than the interaction of five team members because a three-person team does not allow for simultaneous conversations to occur. Because the teams in Study 1 and Study 2 consist of five people, concurrent conversations occur frequently throughout the team task. However, this nested structure of the conversations cannot be reflected in the communication sequences without indication by either the team members while they are speaking (which would be intrusive to the team task), or manual coding by the experimenters (which eliminates the possibility of an automatic analysis). Even the measure of co-talking does not necessarily indicate two conversations, because co-talking could indicate talking over one another within a single conversation. In addition, two different conversations could be occurring and not be included in the co-talking measure at all if the speakers from the two concurrent conversations are not speaking at the same exact time. It is possible that more intricate patterns are occurring within a five-person team, but that our method of simple sequential communication sequence cannot capture this higher dimension of interactions.

In conclusion, this analysis has resulted in mixed support for the use of dynamic interaction variables in categorizing aspects of team communication and performance. Further research is needed to determine for which kinds of tasks and what sizes of teams these methods are applicable.

Future Directions

Because Determinism and Pattern Information were not successful in reflecting pattern changes or performance in this five-person team task, this analysis has suggested that perhaps these dynamic variables might be more applicable in a smaller team setting (two to three people), where simultaneous conversations would not occur, and patterns would be more easily detectable. To address this issue, data is currently being collected using this same mission-planning task, reduced to three participants, to allow for a closer comparison to the three-person team task that previously used these methods. This will allow for comparison with the same number of team members, and to explore whether communication patterns still form in less structured team environments.

With a better understanding of when these methods could be useful, their effectiveness can continue to be evaluated in understanding team communication, and evaluating a team's process in real-time. Ultimately, with a better understanding of the implications of determinism and certain communication patterns on the process and effectiveness of a team, this method of analysis could lead to the ability to provide interventions for teams during their tasks. With more research on team communication, it might be possible to pinpoint patterns that emerge during specific team problems, like conflict, loss of situational awareness, or bad leadership. It might be possible to illuminate these occurring problems to a team in real time, to aid in better team performance.

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APPENDIX A

DESCRIPTIVE STATISTICS FOR STUDY 1

Table 1

Mean Talking Time, Co-Talking Time, and Sequence Length by Operation and Condition

Variable	Condition		
	Control (*n* = 6)	Location (*n* = 6)	Role (*n* = 9)
Talking Time			
Operation 1	1201.5 (465.72)	1589 (526.87)	882.56 (463.49)
Operation 2	625 (289.51)	579.83 (248.8)	893.11 (531.5)
Operation 3	1848.17 (462.64)	1701 (444.97)	1746.33 (723.89)
Operation 4	1152.67 (362.63)	1318.17 (427.85)	1430.89 (667.91)
Co-Talking Time			
Operation 1	473.22 (263.09)	785.75 (477.1)	435.49 (360.81)
Operation 2	246.98 (172.88)	249.08 (126.68)	441.02 (339.42)
Operation 3	894.85 (451.87)	874.33 (545.47)	987.84 (800.76)
Operation 4	427.85 (237.47)	528.72 (363.66)	680.6 (547.06)
Sequence Length			
Operation 1	288.33 (107.5)	367 (116.19)	217.33 (103.41)
Operation 2	154.33 (68.52)	149.67 (68.5)	228.89 (121.73)
Operation 3	445.83 (100.58)	402.83 (75.99)	413 (141.71)
Operation 4	283.67 (76.78)	323.33 (87.72)	346.44 (126.05)

Note. Standard deviations are in parentheses.

Table 2

Mean Talking Time per Minute, Co-Talking Time per Minute, and Sequence Length per Minute by Operation and Condition

	Condition		
Variable	Control (*n* = 6)	Location (*n* = 6)	Role (*n* = 9)
Talking Time per Minute			
Operation 1	0.73 (0.25)	0.92 (0.23)	0.69 (0.34)
Operation 2	0.73 (0.37)	0.63 (0.28)	0.77 (0.38)
Operation 3	0.98 (0.34)	0.95 (0.27)	1.01 (0.35)
Operation 4	0.78 (0.31)	0.78 (0.3)	0.86 (0.29)
Co-Talking Time per Minute			
Operation 1	0.29 (0.17)	0.44 (0.25)	0.34 (0.26)
Operation 2	0.3 (0.22)	0.26 (0.13)	0.39 (0.32)
Operation 3	0.49 (0.28)	0.5 (0.38)	0.56 (0.41)
Operation 4	0.3 (0.18)	0.32 (0.25)	0.4 (0.27)
Sequence Length per Minute			
Operation 1	10.56 (3.56)	12.7 (3.08)	10.23 (4.74)
Operation 2	10.74 (4.91)	9.68 (4.53)	11.98 (4.63)
Operation 3	13.98 (3.97)	13.44 (2.38)	14.34 (4.07)
Operation 4	11.33 (4.01)	11.29 (3.19)	12.7 (2.89)

Note. Standard deviations are in parentheses.

Table 3

Mean Recurrence Rate, Determinism, and Maximum Pattern Information by Operation and Condition

Variable	Condition		
	Control (*n* = 6)	Location (*n* = 6)	Role (*n* = 9)
Recurrence Rate			
Operation 1	67.64 (26.08)	84.01 (22.58)	47.11 (20.5)
Operation 2	33.74 (14.68)	35.07 (17.67)	51.81 (26.86)
Operation 3	98.59 (18.32)	92.49 (20.13)	88.16 (26.87)
Operation 4	65.42 (15.4)	76.3 (15.68)	79.02 (28.51)
Determinism			
Operation 1	42.56 (3.46)	43.87 (5.8)	40.28 (5.77)
Operation 2	39.87 (4.58)	43.85 (4.2)	43.74 (6.01)
Operation 3	42.59 (1.93)	43.27 (4.14)	40.11 (1.85)
Operation 4	44.07 (4.97)	43.91 (4.9)	42.42 (4.45)
Maximum Pattern Information			
Operation 1	0.04 (0.02)	0.05 (0.02)	0.07 (0.04)
Operation 2	0.06 (0.01)	0.06 (0.02)	0.05 (0.02)
Operation 3	0.04 (0.01)	0.05 (0.02)	0.04 (0.01)
Operation 4	0.05 (0.02)	0.05 (0.02)	0.04 (0.02)

Note. Standard deviations are in parentheses.

APPENDIX B

REPEATED MEASURES ANCOVA TABLES FOR STUDY 1

Table 1

Repeated Measures Analysis of Covariance for Total Talking Time

Effect	MS	df	F	p
		Within subjects		
Operation	647343	2	9.79**	<.001
Operation x Covariate	32168	2	.49	.62
Within-Group Error	66111	34		
		Between subjects		
Condition	806121	2	1.37	.28
Condition x Operation	90998	4	1.38	.26
Between-Group Error	806121	17		

*p<.05 **p<.01

Table 2

Repeated Measures Analysis of Covariance for Total Talking Time Per Minute

Effect	MS	df	F	p
		Within subjects		
Operation	8.2×10^{-2}	2	2.4	.11
Operation x Covariate	3.5×10^{-2}	2	.52	.60
Within-Group Error	1.16	34		
		Between subjects		
Condition	2.52×10^{-2}	2	1.40	.27
Condition x Operation	4.2×10^{-2}	4	.31	.87
Between-Group Error	3.05	17		

*p<.05 **p<.01

Table 3

Repeated Measures Analysis of Covariance for Co-Talking Time

Effect	MS	df	F	p
Within subjects				
Operation	333888	2	3.69*	.04
Operation x Covariate	33290	2	.39	.70
Within-Group Error	90567	34		
Between subjects				
Condition	478250	2	1.08	.36
Condition x Operation	12943	4	.14	.87
Between-Group Error	442854	17		

*p<.05 **p<.01

Table 4

Repeated Measures Analysis of Covariance for Co-Talking Time per Minute

Effect	MS	df	F	p
Within subjects				
Operation	4.1×10^{-2}	2	1.03	.37
Operation x Covariate	1.5×10^{-2}	2	.38	.68
Within-Group Error	.04	34		
Between subjects				
Condition	.11	2	.78	.47
Condition x Operation	4.0×10^{-3}	4	.11	.98
Between-Group Error	.14	17		

*p<.05 **p<.01

Table 5

Repeated Measures Analysis of Covariance for Sequence Length

Effect	MS	df	F	p
		Within subjects		
Operation	49530	2	17.88**	<.001
Operation x Covariate	5255	2	1.90	.17
Within-Group Error	2770	34		
		Between subjects		
Condition	26314	2	1.04	.38
Condition x Operation	8415	4	3.04*	.03
Between-Group Error	26314	17		

*p<.05 **p<.01

Table 6

Repeated Measures Analysis of Covariance for Sequence Length per Minute

Effect	MS	df	F	p
Within subjects				
Operation	4.0×10^{-3}	2	2.6	.09
Operation x Covariate	1.0×10^{-3}	2	.60	.55
Within-Group Error	5.1×10^{-2}	34		
Between subjects				
Condition	.01	2	1.29	.30
Condition x Operation	1.0×10^{-3}	4	.35	.84
Between-Group Error	8.0×10^{-3}	17		

*p<.05 **p<.01

Table 7

Repeated Measures Analysis of Covariance for Recurrence Rate

Effect	MS	df	F	p
		Within subjects		
Operation	2084	2	19.47**	<.001
Operation x Covariate	182	2	1.70	.20
Within-Group Error	107	34		
		Between subjects		
Condition	1199	2	.93	.41
Condition x Operation	545	4	5.09**	.003
Between-Group Error	1199	17		

*p<.05 **p<.01

Table 8

Repeated Measures Analysis of Covariance for Determinism

Effect	MS	df	F	p
		Within subjects		
Operation	.43	2	.02	.98
Operation x Covariate	.48	2	.03	.97
Within-Group Error	18.45	34		
		Between subjects		
Condition	5.47	2	.37	.70
Condition x Operation	20.91	4	1.13	.36
Between-Group Error	14.86	17		

*p<.05 **p<.01

Table 9

Repeated Measures Analysis of Covariance for Pattern Information

Effect	MS	df	F	p
Within subjects				
Operation	8.50×10^5	2	.35	.71
Operation x Covariate	0	2	.51	.61
Within-Group Error	0	34		
Between subjects				
Condition	.04	2	.75	.40
Condition x Operation	3.47×10^5	4	.14	.96
Between-Group Error	0	17		

*p<.05 **p<.01

APPENDIX C

CORRELATION TABLES FOR STUDY 1

Table 1

Interaction and Performance Variable Correlations For Operation 1

	Total Talk	Co-Talk	Seq Len	RR	DET	Pattern Info	Obj Met	Comp Score
Total Talk	1.00							
Co-Talk	.91**	1.00						
Seq Len	.99**	.90**	1.00					
RR	.94**	.79**	.94**	1.00				
DET	.13	-.09	.16	.33	1.00			
Pattern Info	-.29	-.16	-.31	-.30	-.23	1.00		
Obj Met	-.30	.04	-.06	.04	-.30	-.03	1.00	
Comp Score	.09	-.03	.11	.12	.34	.01	.29	1.00

*p<.05 **p<.01

Table 2

Interaction and Performance Variable Correlations For Operation 2

	Total Talk	Co-Talk	Seq Len	RR	DET	Pattern Info	Obj Met	Comp Score
Total Talk	1.00							
Co-Talk	.96**	1.00						
Seq Len	.96**	.92**	1.00					
RR	.92**	.70**	.96**	1.00				
DET	0.13	0.09	0.09	0.29	1.00			
Pattern Info	-0.41	-0.30	-.50*	-.55**	-0.08	1.00		
Obj Met	-0.30	-0.38	-0.28	-0.25	0.01	0.10	1.00	
Comp Score	0.13	0.17	0.15	0.11	-0.35	-0.10	-.62**	1.00

*p<.05 **p<.01

Table 3

Interaction and Performance Variable Correlations For Operation 3

	Total Talk	Co-Talk	Seq Len	RR	DET	Pattern Info	Obj Met	Comp Score
Total Talk	1.00							
Co-Talk	.91**	1.00						
Seq Len	.96**	.89**	1.00					
RR	.90**	.77**	.94**	1.00				
DET	.01	-.06	-.02	.16	1.00			
Pattern Info	.40	.38	.34	.25	.32	1.00		
Obj Met	.36	.29	.30	.28	.47*	.31	1.00	
Comp Score	.14	.03	.18	.23	-.01	-.05	-.58**	1.00

*p<.05 **p<.01

Table 4

Interaction and Performance Variable Correlations For Operation 4

	Total Talk	Co-Talk	Seq Len	RR	DET	Pattern Info	Obj Met	Comp Score
Total Talk	1.00							
Co-Talk	.96**	1.00						
Seq Len	.92**	.84**	1.00					
RR	.84**	.75**	.93**	1.00				
DET	-.14	-.17	-.17	.02	1.00			
Pattern Info	-.18	-.05	-.18	-.15	.48*	1.00		
Obj Met	.18	.20	-.12	-.12	.03	-.05	1.00	
Comp Score	-.04	.04	.13	.07	-.20	.09	-.65**	1.00

*p<.05 **p<.01

Table 5

Interaction and Performance Variable Correlations for Operation 1 without Co-Talk

	Total Talk	Seq Len	RR	DET	Pattern Info	Obj Met	Comp Score
Total Talk	1.00						
Seq Len	.99**	1.00					
RR	.94**	.94**	1.00				
DET	.14	.16	.33	1.00			
Pattern Info	-.29	-.31	-.30	-.23	1.00		
Obj Met	-.03	-.07	.04	-.30	-.03	1.00	
Comp Score	.09	.11	.12	.34	.01	-.25	1.00

*p<.05 **p<.01

Table 6

Interaction and Performance Variable Correlations for Operation 2 without Co-Talk

	Total Talk	Seq Len	RR	DET	Pattern Info	Obj Met	Comp Score
Total Talk	1.00						
Seq Len	.96**	1.00					
RR	.92**	.96**	1.00				
DET	.13	.09	.29	1.00			
Pattern Info	-.41	-.50*	-.55**	-.08	1.00		
Obj Met	-.30	-.28	-.25	.01	.10	1.00	
Comp Score	.13	.15	.11	-.35	-.10	-.62**	1.00

*p<.05 **p<.01

Table 7

Interaction and Performance Variable Correlations for Operation 3 without Co-Talk

	Total Talk	Seq Len	RR	DET	Pattern Info	Obj Met	Comp Score
Total Talk	1.00						
Seq Len	.97**	1.00					
RR	.90**	.94**	1.00				
DET	.01	-.02	.16	1.00			
Pattern Info	.40	.34	.25	.32	1.00		
Obj Met	.36	.30	.28	.47*	.31	1.00	
Comp Score	.14	.18	.23	-.01	-.05	-.58**	1.00

*p<.05 **p<.01

Table 8

Interaction and Performance Variable Correlations for Operation 4 without Co-Talk

	Total Talk	Seq Len	RR	DET	Pattern Info	Obj Met	Comp Score
Total Talk	1.00						
Seq Len	.92**	1.00					
RR	.84**	.93**	1.00				
DET	-.14	-.17	.02	1.00			
Pattern Info	-.18	-.18	-.15	.48*	1.00		
Obj Met	.18	-.12	-.12	.03	-.05	1.00	
Comp Score	-.04	.13	.07	-.20	.09	-.651*	1.00

*p<.05 **p<.01

APPENDIX D

DESCRIPTIVE STATISTICS FOR STUDY 2

Table 1
Mean Talking Time, Co-Talking Time, and Sequence Length by Mission and Operation

Variable	Mission 1	2	3	4
Talking Time				
Operation 1	1691.59 (762.7)	1674.43 (537.45)	1512.13 (373.29)	568.74 (318.98)
Operation 2	2010.32 (444.63)	1254.39 (514.08)	1983.17 (541.8)	1042.39 (511.07)
Operation 3	1890.77 (561.01)	1844.01 (296)	1060.17 (304.87)	1325.04 (644.99)
Operation 4	1704.33 (449.07)	1238.31 (479.13)	1066.5 (417.39)	1013.4 (297.18)
Operation 5	1921.16 (382.78)	993.39 (360.21)	932.34 (302.91)	1340.51 (490.47)
Operation 6	1617.54 (587.66)	1528.19 (552.72)	1715.85 (617.31)	1050.33 (507.89)
Operation 7	1494.17 (714.19)	1734.36 (256.86)	1576.72 (579.45)	807.43 (365.8)
Co-Talking Time				
Operation 1	764.66 (478.84)	665.47 (411.26)	623.8 (237.92)	188.21 (126.82)
Operation 2	870.26 (361.82)	553.36 (286.7)	887.64 (505.87)	375.78 (258.61)
Operation 3	798.03 (429.45)	730.06 (249.7)	405.63 (188.22)	484.42 (318.53)
Operation 4	646.96 (259.36)	519.78 (305.06)	389.76 (238.44)	372.37 (170.74)
Operation 5	788.46 (288.09)	358.02 (158.68)	356.43 (176.65)	598.7 (464.31)
Operation 6	718.05 (459.94)	595.17 (384.05)	778.24 (367.63)	357.35 (253.93)
Operation 7	666.61 (569.5)	629.98 (207.39)	673.85 (417.52)	272.07 (164.31)
Sequence Length				
Operation 1	364.6 (161.22)	392.9 (107.4)	345.6 (72.87)	139.67 (68.01)
Operation 2	438.2 (74.26)	283.6 (106.34)	457.67 (88.71)	248.2 (113.46)
Operation 3	407.6 (88.92)	411 (76.01)	251.6 (65.43)	320.4 (148.91)
Operation 4	390.3 (91.71)	305.6 (123.89)	255.8 (93.47)	252 (66.41)
Operation 5	439.8 (63.94)	250.2 (84.85)	226.1 (65.41)	317.3 (96.3)
Operation 6	381.6 (119.1)	371.1 (106.16)	394.8 (123.92)	258.5 (111.83)
Operation 7	331.4 (117.56)	420.8 (59.21)	372.2 (124.98)	207.67 (86.68)

Note. Standard deviations are in parentheses.

Table 2
Mean Talking Time per Minute, Co-Talking Time per Minute, and Sequence Length per Minute by Mission and Operation

	Mission			
Variable	1	2	3	4
Talking Time per Minute				
Operation 1	1.07 (0.43)	1.02 (0.24)	1.01 (0.17)	0.77 (0.25)
Operation 2	1.14 (0.25)	1.14 (0.18)	1.11 (0.3)	0.85 (0.2)
Operation 3	1.1 (0.27)	1.08 (0.18)	0.96 (0.25)	0.88 (0.3)
Operation 4	1.04 (0.14)	1.02 (0.22)	0.87 (0.22)	0.9 (0.17)
Operation 5	1.11 (0.21)	0.92 (0.14)	0.92 (0.15)	1 (0.26)
Operation 6	1.03 (0.26)	0.92 (0.25)	1.06 (0.31)	0.82 (0.16)
Operation 7	1.03 (0.3)	0.99 (0.13)	1.02 (0.35)	0.81 (0.14)
Co-Talking Time per Minute				
Operation 1	0.48 (0.26)	0.4 (0.21)	0.42 (0.15)	0.27 (0.16)
Operation 2	0.49 (0.2)	0.49 (0.15)	0.5 (0.28)	0.3 (0.17)
Operation 3	0.46 (0.23)	0.42 (0.14)	0.38 (0.19)	0.31 (0.18)
Operation 4	0.39 (0.13)	0.42 (0.21)	0.32 (0.15)	0.33 (0.13)
Operation 5	0.46 (0.17)	0.33 (0.1)	0.35 (0.14)	0.43 (0.27)
Operation 6	0.45 (0.24)	0.36 (0.21)	0.48 (0.2)	0.27 (0.12)
Operation 7	0.44 (0.29)	0.36 (0.12)	0.44 (0.25)	0.27 (0.11)
Sequence Length per Minute				
Operation 1	13.73 (5.15)	14.36 (2.42)	13.9 (2.05)	11.41 (2.79)
Operation 2	14.91 (2.49)	15.4 (1.2)	15.38 (2.98)	12.34 (2.17)
Operation 3	14.18 (2.32)	14.3 (2.25)	13.62 (2.73)	12.87 (4.48)
Operation 4	14.29 (1.47)	14.93 (2.51)	12.52 (2.93)	13.51 (2.01)
Operation 5	15.19 (2.12)	13.93 (2.17)	13.61 (2.14)	14.21 (2.63)
Operation 6	14.63 (2.76)	13.5 (2.64)	14.77 (3.9)	12.22 (1.94)
Operation 7	13.91 (2.57)	14.41 (1.83)	14.35 (4.54)	12.62 (1.64)

Note. Standard deviations are in parentheses.

Table 3
Mean Recurrence Rate, Determinism, and Maximum Pattern Information by Mission and Operation

	Mission			
Variable	1	2	3	4
Recurrence Rate				
Operation 1	83.08 (36.28)	91.15 (21.48)	78.13 (15.6)	32.84 (17.44)
Operation 2	100.63 (14.56)	65.9 (27.25)	99.85 (20.13)	60.42 (27.48)
Operation 3	95.75 (18.19)	92.51 (15.61)	57.82 (15.1)	75.85 (33.65)
Operation 4	92.61 (21.65)	70.07 (28.04)	59.15 (20.19)	58.23 (14.45)
Operation 5	106.52 (11.42)	59.14 (24.56)	50.74 (15.59)	72.61 (18.14)
Operation 6	88.73 (25.72)	86.63 (25.56)	85.75 (25.33)	59.53 (22.47)
Operation 7	79.83 (24.65)	99.03 (10.27)	85.66 (26.75)	49.82 (19.54)
Determinism				
Operation 1	41.07 (6.44)	42.56 (2.68)	41.69 (3.65)	42.59 (3.64)
Operation 2	42.59 (3.05)	42.31 (3.79)	40.11 (2.72)	44.33 (9.5)
Operation 3	42.37 (3.74)	41.5 (2.4)	41.68 (4.02)	43.3 (4.16)
Operation 4	44.15 (3.63)	41.98 (4.22)	42.13 (5.12)	42.61 (4.16)
Operation 5	44.83 (2.76)	41.15 (3.62)	40.66 (2.56)	41.72 (2.96)
Operation 6	42.48 (2.33)	42.94 (4.79)	41.96 (5.62)	42.04 (3.84)
Operation 7	45.36 (4.08)	43.48 (3.81)	43.16 (3.8)	45.22 (8.45)
Maximum Pattern Information				
Operation 1	0.07 (0.08)	0.04 (0.01)	0.04 (0.02)	0.07 (0.02)
Operation 2	0.03 (0.01)	0.05 (0.02)	0.03 (0.01)	0.04 (0.03)
Operation 3	0.03 (0.01)	0.04 (0.01)	0.04 (0.01)	0.05 (0.02)
Operation 4	0.05 (0.01)	0.04 (0.01)	0.04 (0.01)	0.05 (0.01)
Operation 5	0.04 (0.01)	0.04 (0.01)	0.05 (0.02)	0.04 (0.01)
Operation 6	0.04 (0.01)	0.04 (0.02)	0.04 (0.02)	0.05 (0.01)
Operation 7	0.05 (0.02)	0.04 (0.03)	0.05 (0.02)	0.05 (0.03)

Note. Standard deviations are in parentheses.

APPENDIX E

REGRESSION TABLES, STUDY 2

Table 1

Summary of Regression Coefficients for predicting Objectives Met

Variable	B	SE B	β	t	p
Talking Time	-3.35×10^{-4}	1.64×10^{-4}	-0.12	-2.05*	.04
Talking Time/Min	-.19	.33	-0.03	-.58	.56
Co-Talk Time	-4.95×10^{-4}	2.49×10^{-4}	-0.11	-1.99*	.05
CoTalk Time/Min	-.35	.43	-0.04	-.79	.43
Sequence Length	-1.83×10^{-3}	7.91×10^{-4}	-0.14	-2.31*	.02
Seq Length/Min	-2.9×10^{-2}	2.9×10^{-2}	-0.05	-1.02	.31
Recurrence Rate	-7.47×10^{-2}	3.59×10^{-3}	-1.29	-2.08*	.04
Determinism	1.34×10^{-2}	2.08×10^{-2}	0.04	.65	.52
Pattern Information	-2.15	3.29	-0.03	-.65	.51

*p<.05 **p<.01

Table 2

Summary of Regression Coefficients for predicting Composite Performance

Variable	B	SE B	β	t	p
Talking Time	142.41	194.68	0.05	.73	.41
Talking Time/Min	99413.22	389722	0.02	.26	.80
Co-Talk Time	203.54	296.6	0.05	.69	.49
Co-Talk Time/Min	214587.78	513636.98	0.03	.42	.68
Sequence Length	359.48	944.92	0.03	.38	.70
Seq Length/Min	-4647.92	33827.06	-0.01	-.14	.89
Recurrence Rate	1787.16	4278.83	0.03	.42	.68
Determinism	-10374.53	24589.29	-0.03	-.42	.67
Pattern Information	-2436581.3	3885744.12	-0.03	-.87	.53

*p<.05 **p<.01

APPENDIX F

STEP-WISE REGRESSION TABLES, STUDY 2

Table 1

Step-Wise Regression Results for Mission 1 for Predicting Composite Performance

Model	MS	df	F	p	
Regression	4.5×10^{11}	1	6.02*	.04	
Residual	7.48×10^{10}	8			
Variable	B	SE B	β	t	p
Total Talking	630.06	256.8	.655	2.45	.04

*p<.05 **p<.01

Table 2

Step-Wise Regression Results for Mission 4 for Predicting Objectives Met

Model	MS	df	F	p	
Regression	3.39	1	11.99**	.009	
Residual	.28	8			
Variable	B	SE B	β	t	p
Co- Talking	-.004	.001	-.775	-3.46	.009

*p<.05 **p<.01

BIOGRAPHICAL SKETCH

Shannon Fouse received her BA in Cognitive Science from the University of Pennsylvania in 2008 and is an MA candidate in Applied Psychology at Arizona State University and Graduate Research Assistant at the Cognitive Engineering Research Institute. She will join the PhD program in Simulation, Modeling, and Applied Cognitive Sciences in the Fall of 2012 at Arizona State University.