Evaluating Communication Effectiveness in Team Collaboration

Julie A. Parisi[1] *and Douglas S. Brungart*[2]

Air Force Research Laboratory
Human Effectiveness Directorate, Wright-Patterson Air Force Base, Ohio, U.S.A.
[1]julie.parisi@wpafb.af.mil, [2]douglas.brungart@wpafb.af.mil

Abstract

Effective team communication is essential for mission success in many complex operational environments. Whereas most previous research has focused primarily on the psychological factors that can cause breakdowns in team communication, this paper introduces a novel procedure designed to systematically evaluate the impact that a degraded communication transmission channel can have on team performance. This procedure measured communication effectiveness in terms of the time necessary for the team to reach a consensus about the proper ordering of unfamiliar images that were viewed in randomized order. Preliminary results indicate that this procedure can identify differences in communication channel quality that would not be detected by traditional evaluation procedures based solely on point-to-point intelligibility.

1. Introduction

Many barriers can lead to ineffective communication, causing multiple difficulties that lead to a decrease in individual task performance. However, these barriers can become dangerous when they inhibit the ability of teams to communicate effectively. Any breakdown in communication increases the risk of accidents and mishaps and poses a serious threat to mission success. The enhancement of communication effectiveness in teams is therefore of primary importance to all organizations that depend on coordinated team action to achieve their mission objectives.

Previous research examining factors that affect both individual and team performance has shown that effective communication is a necessity for mission success [1]. Particularly for team communication, this research has indicated that team performance is affected by the team's cohesiveness and the ability of the members to interact with one another, by the hierarchy of the individuals within the team, and by differences in culture and language among team members [2, 3, 4]. The research done to date emphasizes the psychological aspects of effective team communication, neglecting other factors that might play an important role in effective team coordination. In particular, very little effort has been made to determine how different modes of team communication (i.e. face-to-face, video conferencing, conference calling, etc.) can influence overall performance in team tasks. The goal of this research is to develop a new tool for objectively evaluating how effectively different team communication systems can be used to complete a coordinated team task.

To this point, most of the tools that have been developed to evaluate interactive team communication have been designed primarily to evaluate the effect of propagation delay on the efficiency of two-party conversations [5, 6, 7, 8, 9, 10, 11, 12]. These tests, which are often characterized as "communicability tests", can be broadly divided into two categories: those designed to test the subjective acceptability of a communication channel in totally unstructured conversation (i.e. [5]), and those designed to test the efficiency of a communications channel by forcing the participants to complete a highly structured task in the minimum amount of time possible. For example, such tasks might require participants to play a game of "battleship" [7, 8], compare visual graphs [13], or verify the names of cities [11]. One recent example this kind of collaborative task is the "Blackjack" communicability task developed by TNO [12]. In this task, pairs of subjects were separated into different rooms and asked to participate in a computer-controlled card game. This game required them to jointly decide the order in which to play a series of cards that were labeled with code words drawn either from a set of CVC rhyme words or from the NATO Alphabet. A total of eight same-gender teams were asked to perform this task under eight different communication channel conditions: a standard telephone-bandwidth speech channel with combinations of three different round-trip delay values (0, 800 and 1600 ms) and four different levels of background noise (no noise, 61, 67, or 73 dBA). The results showed that the introduction of a 1600 ms delay increased the average response time per card in the CVC condition by 5 s, from roughly 15 s to roughly 20 s.

The computerized Blackjack game described by TNO clearly represents one possible methodology for evaluating communication effectiveness in a collaborative team task. However, it is not immediately clear how this Blackjack task, or the other tasks that have been used to evaluate two-talker communication, could be expanded to account for teams with more than two members. For the present study, the question of particular interest was developing a reliable method for analyzing communication effectiveness in a larger team and in any number of conditions. Thus, we set out to design a testing procedure that would build on the basic concept of the Blackjack task but would:

1) allow the evaluation of communication effectiveness in a wide variety of conditions with teams comprised of four or more individuals;
2) provide enough sensitivity to distinguish between modestly different communications environments in a relatively short period of time;
3) allow large numbers of trials to be conducted with the same team without shifts in strategy due to "over learning" the task; and
4) encourage communication and collaboration both across the entire team and between individual sub-teams within the team.

The next section describes the "Interactive Team Dialogue Effectiveness" (ITDE) task that was developed in an attempt to meet these evaluation objectives.

1. Method

1.1. ITDE Task

The ITDE task was developed to allow flexibility for repeated trials in a variety of different conditions. The task consisted of an interface that was presented to the four team members, who were each seated at a computer. At the start of a trial, an interface consisting of five columns appeared on each team member's computer. The columns, each labeled by a color, such as *Blue*, contained four different images of human faces, arranged in a random order. The images within each column were randomly drawn from one of 78 different categorized lists of similar image files (i.e. faces of individuals of the same sex in the same pose) within a database containing a total of more than 1500 images of human faces (provided by the Computer Vision Laboratory at the University of Ljubljana, Slovenia [14] and by the Psychological Image Collection at Stirling, University of Stirling Psychology Department [15]).

The same two columns appeared on the display of all four team members, and each team member had one additional column in common with each of the other three team members. This resulted in a total of five columns for each individual team member, and a total of eight unique columns distributed across the four team members. The columns were randomly ordered on each team member's display, and the pictures were randomly ordered within each column (see *Figure 1*).

The object of the task was for all team members with the same column of images in common (as identified by the color) to place the images within that column in the same order. This ordering was achieved by using the computer mouse to select one of four check boxes displayed beneath each image in the visual interface. The subjects were instructed to perform this task as quickly as they could without sacrificing accuracy, and to press a "finish" button when they were confident that all five of the columns on their displays were ordered in the same way as those of the other team members with whom they had columns in common.

The dependant variables measured included the time to complete the task (measured from the time that the first subject clicked on one of the images to the time the last subject pressed the finish button) and the accuracy with which the task was completed (i.e., how consistently the images were ordered across team members). The experimenter controlled the execution of each trial and was able to monitor the team's progression and final time and score.

1.2. Communications Environment

The ITDE task relies on communication and, as a result, variations in communications quality were expected to have a direct impact on the time required to complete the ITDE task. In order to validate this assumption, a preliminary experiment was conducted that required a team of four subjects with normal hearing and vision (2 males and 2 females, ranging in age from 20 to 50) to perform the task in five different environments with systematically decreasing levels of communication quality.

The first communication environment (Face-to-Face) was a control condition that allowed for the fullest amount of team interaction. In this configuration, the team was arranged in a quiet room such that all members were in full view of each other and could easily communicate both verbally and visually (see *Figure 2*).

Figure 1: Interfaces for two team members at the start of a trial. *Black* and *Beige* columns were shared by all team members; this pair of team members uniquely shared the *Green* column. Images were in a different order for the pair; to complete the task they needed to mark all of the images in each column in the same order.

The second communication environment (Cubicle) decreased the amount of team member contact. All team members in this condition were in the same room; however, they were arranged in a row with dividers separating their views of each other (i.e. they were seated in a “row of cubicles”). This condition was designed to test how team members are able to interact when visual contact has been limited. Team members were not given any devices to aid in communicating with their team members.

The third, fourth, and fifth communications environments further limited team contact by placing each team member in a separate room, therefore preventing any direct auditory or visual contact. In the third environment (Conference Call), team members communicated by means of a commercial conference call (placed by direct dial with a standard handset telephone to the FreeConference.com service). In the fourth environment (VoIP), team members communicated via TeamSound, a publicly available shareware application that provides a voice-activated telephone-bandwidth full-duplex VoIP conference call with a variable delay time of approximately 1 second. Finally, in the fifth communication environment (Chat), team members communicated nonverbally through the Microsoft NetMeeting chat program by typing and sending messages to each other through their computers. During all three of these trials, any communication made by one team member was received by the other three members. A team member could not selectively send messages to a particular team member.

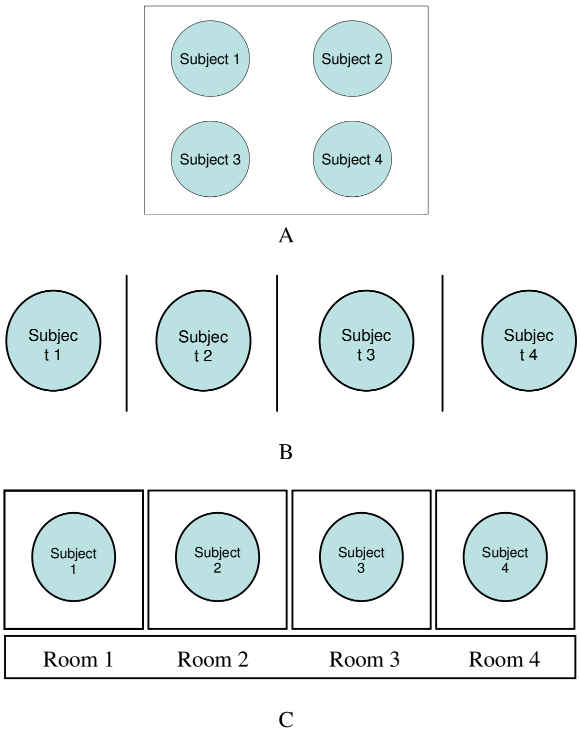

Figure 2: Team member arrangement in the different communications environments: Face-to-Face (A); Cubical (B); Conference Call, VoIP, and Chat (C)

All subjects received five hours of training in the task (one hour per day for five days) prior to formal data collection. Training was conducted in the Face-to-Face condition only.

For each trial, the task completion time was recorded as well as a numeric score reflecting the team’s accuracy. Scores were given to all team members, and then added for a team score. One point was awarded to each team member who had an image in the same order as another team member. For the columns shared by all team members, each member could receive a maximum of 12 points if all members had the images in the same order; for the columns shared between only two team members, the maximum score would be four if the two team members shared the same order. The maximum total score was 144.

2. Results

Table 1 shows the results collected from ten trials in each of the five communications environments described in the previous section. The results show the predicted systematic increase in task completion time, resulting from the systematically decreasing quality of the communication links between the team members in the five different communications environments examined. The standard error results also indicate that the ITDE task is relatively sensitive to even small changes in communication quality: even with only ten trials in each condition, the differences between the means in the five communications environments were never separated by fewer than 2.2 standard errors. The accuracy scores were very high (> 139 out of 144 possible points) in all of the conditions tested except the Chat condition, where it fell to 135.4.

Table 1: Results

Communication Environment	Mean Time (s)	Std. Error of Time (+/- s)	Score
(1) Face-to-Face	97.1	3.2	140.6
(2) Cubical	106.2	2.9	144.0
(3) Conference Call	119.3	6.0	142.4
(4) VoIP	212.1	8.0	139.8
(5) Chat	426.8	34.2	135.4

3. Discussion

The purpose of this study was to develop a new methodology for objectively assessing communications effectiveness in collaborative team tasks. In this regard, the ITDE task seems to be very successful. It produced a clear difference in performance time across all five of the communications environments tested, despite the fact that all five of these conditions would be expected to produce near 100% performance in a conventional point-to-point intelligibility test such as the Modified Rhyme Test. The ITDE task also seemed to be more sensitive to communications degradation than the two-subject computerized Blackjack task described in the TNO study [12]. In that task, the addition of a 1600 ms communication delay increased the average response time per card in the CVC condition by roughly 25%, while the addition of a comparable delay in the VoIP condition of this task increased completion time by roughly 80% relative to the Conference Call condition.

In part, the large differences across the conditions in this study may be attributed to the fact that its eight-column structure encouraged parallel conversations between the team members in the high-quality communication conditions. Because each team member in the ITDE task shares one column with each other team member, the optimal strategy in the task required one pair of team members to be communicating about one set of images at the same time that the other pair of team members was communicating about a different set of images. In listening configurations where the communication quality was poor, such parallel conversations became difficult and the subjects were more likely to conduct these conversations in series rather than in parallel, thus substantially increasing communication time in the task.

5. Conclusion

The results of this study indicate that the ITDE method is a valid and reliable evaluator for communication effectiveness in teams. The ITDE task produced reliably different completion times in communications environments that would likely not have been identified as significantly different in conventional measures of communication quality based on point-to-point intelligibility. Furthermore, the image ordering task used in the ITDE task seems likely to be a reasonably good predictor of performance in tasks that require distributed team members to achieve a "common operating picture" based on different perspectives of the same underlying information (for example, two air traffic controllers identifying the same aircraft on radar screens centered at different geographic locations, or two law enforcement officers trying to identify a common suspect on the basis of two different photographs). As improving and expanding communications networks produce an ever greater expectation that widely distributed teams will be able to work together effectively, evaluation methods such as the ITDE will be essential to ensure that future communication systems are able to meet the growing expectations of the user community. The ITDE task is also easily adapted to the evaluation of communication effectiveness in environments with spatially co-located team members. For example, the ITDE task could be used to determine the extent to which large computer consoles might impair the use of visual communication cues in a command center, or the extent to which environmental noise might impair collaboration in an airborne conference room.

6. Acknowledgements

The authors of this paper would like to thank Alex Kordik, Frank Mobley, Nandini Iyer, Brian Simpson, Sander van Wijngarden, and Dianne Popik for their recommendations, critiques, and help.

7. References

[1] Cushing, Steven. *Fatal Words: Communication Clashes and Aircraft Crashes* (Chicago: University of Chicago Press, 1994).

[2] McKinney, E.H. & Barker, J. (1999). Communication, team values, and quickstart teams. In *Proceedings of the Tenth International Symposium on Aviation Psychology* (pp. 229-334). Columbus, OH: The Ohio State University.

[3] Achille, L.B. & Schulze, K.G. (1996). Content analysis of communication in a hierarchical navy team, NRL Report NRL/FR/5510—96-9775.

[4] Sexton, J.B., & Helmreich, R.L. (1999). Analyzing cockpit communication: The links between language, performance, error, and workload. In *Proceedings of the Tenth International Symposium on Aviation Psychology* (pp. 689-695). Columbus, OH: The Ohio State University.

[5] Butler, L.W. & Kiddle, L. *The rating of delta sigma modulating systems with constant errors, burst errors, and tandem links in a free conversation test using the reference speech link*, (Rpt. No. 69014, Feb. 1969 (Signals Research and Development Establishment, Ministry of Technology, Christchurch, Hants, 1969.

[6] Voiers, W.D. *Exploratory research on the feasibility of a practical and realistic test of speech communicability*, (Final report, April 1978). Dynastat Inc, 1978.

[7] Schmidt-Nielsen, A. & Everett, S.S. *A conversational test for comparing voice systems using working two-way communication links*, (NRL Report No. 8583, June 1982) Washington, DC, USA: Naval Research Laboratory, 1982.

[8] Woodard Kreamer, E., & Tardelli, J.D. "Communicability testing for voice coders," *Proc. IEEE International Conference on Acoustics, Speech and Signal Processing* 1996.

[9] Kitawaki, N. & Itoh, K. "Pure delay effects on speech quality in telecommunications," *IEEE Journal on Selected Areas in Communication,* 9(4): 586-593, 1991.

[10] Kitawaki, N. & Itoh, K. "Delay effect assessment taking into account human factors in telecommunications," *Proc. 13th Symposium on Human Factors in Telecommunication:* 555-562, 1991.

[11] Kitawaki, N., Kurita, T. & Itoh, K. (1991). Effect of delay on speech quality. *NTT Review* 3(5), 88-94, 1991.

[12] Wijngaarden, S.J. van Smeele, P.M.T., & Steeneken, H.J.M. (2001): "A new method for testing communication efficiency and user acceptability of speech communication channels", In *EUROSPEECH-2001*, 1675-1678.

[13] Krauss, R.M. & Bricker, P.D., "Effects of transmission delay and access delay on the efficiency of verbal communication," *J. Acoust. Soc. Amer.,* 41(2): 286-292, 1966.

[14] CVL Face Database: <http://www.lrv.fri.uni-lj.si/facedb.html>

[15] Psychological Image Collection at Stirling (PICS), University of Stirling Psychology Department: <http://pics.psych.stir.ac.uk/>