Communication and Decisionmaking in C4ISR Sustained Operations: An Experimental Approach

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C2 Experimentation Track

Abstract

This report describes the approach and initial results of a systematic investigation of individual and team C4ISR communication and performance in complex time-critical targeting scenarios over a sustained period of time. To date, there have been few systematic and experimental programs of research on the effects of fatigue on complex decisionmaking (Mahan, 1992), team communication, coordination, shared awareness, or performance (Mahan, 1994;. Mahan, Elliott, Dunwoody, & Marino, 1998). In this report, we focus our efforts on aspects of C4ISR communication and coordination, and how we can assess impact of fatigue on complex team communication and performance over time.

Introduction

USAF command and control (C2) warfighters face increasingly complex environments that represent the essence of naturalistic decisionmaking-- multiple demands for enhanced vigilance, rapid situation assessment, and coordinated adaptive response (Cohen, 1993; Klein, 1993; Mitchell & Beach, 1990; Orasanu & Salas, 1991; Orasunu & Connolly; 1993; Rasmussen, 1993). In tactical C2 situations, the focus is on dynamic battle management and time-critical targeting. Information updates may be from air or from ground sources. Coordination demand is high-- reconnaissance and resource allocation depend upon close coordination between ground and air forces in a distributed network system of systems. Situations requiring close coordination and adaptive replanning are increasingly prevalent and challenging.

It is clear that challenges within these battle scenarios are critically important to air and ground superiority. Much effort has been focused on the development of advanced technology to provide and represent time-critical information during mission execution. These capabilities are needed to facilitate, even enable, situation awareness and coordinated response in conditions of information complexity and time pressure. However, technology can only support, not replace, the role of the war fighters. In fact, technology increases the role and demands of the human decision maker.

Soldiers and leaders make decisions and responses in time-critical situations. While advanced technology affords paradigm shifts in information technology, it cannot replace C2 decision makers or troops on the ground, who must make tactical decisions under duress, often for long periods of time. Despite any particular advanced technology, individual performance will still vary, depending on the competence of each individual with regard to situation demands. We need to determine how to enhance the processes by which war fighters recognize, interpret and respond effectively in these situations.

Soldiers and leaders make decisions and responses in team situations. In these situations, effective response inevitably involves interaction with others: typically, information and/or resources must be distributed effectively and actions/events must be sequenced. Current military scenarios comprise operators and technology in a complex, dynamic, and interdependent system. Complex coordination must include adaptive problem solving. Prime examples include dynamic re-allocation of assets, for purposes such as retargeting and search-and-rescue.

Soldiers and leaders make decisions and responses in sustained situations. Sustained operations are integral to command and control—combat missions require vigilance over time and adaptive performance under stress. During the early stages of actual scenarios, members of the command center are often up for several days with little if any time for recuperative sleep. Over time, chronic fatigue will affect everyone, and the likelihood of error will increase (Hursh, 1998). This is particularly relevant to C2 situations, which require constant monitoring, even when events are still.

Sustained operations result in acute and chronic fatigue effects. There is extensive documentation on the negative impact of acute and/or chronic sleep loss. In a review of findings, Bonnett (2000) report an array of negative effects. These effects include mood changes, disorientation, irritability, perceptual distortions, hallucinations, difficulty in concentration, and/or paranoid thinking, depending on the extent of sleep loss. Negative effects have also been demonstrated on a range of cognitive tests, such as monitoring tasks, speed/accuracy tests, short-term memory, logical reasoning, and mental subtraction/addition. Physiological effects are reflected in a variety of physiological tests, such as EEG, nystagmus, hand tremor, slurring of speech, sluggish corneal reflexes, hyperactive gag reflex, and increased sensitivity to pain.

The effects of fatigue on complex team communication and performance have not been extensively investigated. While extensive data are available on effects of sleep loss on physiological, attitudinal, and cognitive function (Kryger, Roth, & Demnet, 2000), very few studies reported data regarding sleep loss effects on particular aspects of information processing in complex decision making tasks (Mahan, 1992; 1994).. Even fewer have reported on effects on team performance; however, a few prelimary studies, based on team simulation-based performance, provide some introductory results (Mahan, et al. ,1998; Coovert et al., 2001). To continue this stream of research, the Chronobiology and Sleep Laboratory at Brooks City-Base, San Antonio, TX has initiated a program of research on effects of sleep loss on information processing, communication, coordination, and decision making in complex simulation-based tasks. In this paper we shall focus on fundamental issues related to team communications (elicitation and assessment) and team performance.

C4ISR team scenarios were chosen for USAF operational relevance and the need to understand dynamics of communication, shared awareness, coordinated action, and adaptive response to time-critical situations. C4ISR scenarios were crafted such that mission planning, team coordination and dynamic replanning are critical to team success. Scenarios were carefully constructed to ensure equivalence in task demand and difficulty (Elliott, Coovert, & Miller, 2003). We predicted that fatigue will have a detrimental effect on performance, and particularly on indicators of problem identification, communication, task sequencing, and asset redistribution. In this report, we focus on measures of communication as indicators of information exchange and task sequencing, and describe very initial relationships with other measures of team process and performance.

Participants

Research participants were drawn from a pool of USAF officers awaiting Air Battle Management Training at Tyndall AFB, FL. In the first six, three-person teams, there was only one participant, a Captain, who was not a Second Lieutenant. Three of the first six teams were composed of three males, while the other three teams each contained two males and one female. All of the participants had already attended the Aerospace Basics Course, which however provided them with little training or knowledge useful for the current study. The participants were assigned to the 325th Air Control Squadron, Airborne Battle Managers Undergraduate, Ground (325 ACS-ABM-AUG).

Training

Each participant participated in a 40-hour training session occurring during a one-week period. The training included administrative processing (1 hr), training on cognitive test battery (9 hrs.) and training on C4ISR assets, capabilities, and tactics, along with AEDGE interface functions

(30 hrs). Also, the various ergonomic features of the chairs and workstations were explained and demonstrated to the participants. Participants learned principles of these ergonomics and how they can be adjusted to aid with fatigue effects.

Experimental Manipulation

The experimental session began at 6pm on the last day of training (always a Friday) and ended at 11am the following morning. They participated as three-person teams, every other hour, in 8 40-minute team-based C4ISR decision making scenarios, with 20 additional minutes for each session for debriefing, data collection, and mission planning for the next session. Every other hour, between each scenario session, they performed on a standard cognitive test battery that assesses reaction time, working memory, and multitasking. They also provided physiological (e.g. temperature, etc.), mood-state, and sleepiness data. All email and audio communications were digitally captured for transcription. This resulted in extensive cognitive performance and simulation-based performance.

Elicitation of Performance

Criterion measures of simulation-based performance were generated from a PC-based synthetic team task environment developed for investigations of C4ISR team performance. The AWACS AEDGE (Agent Enabled Decision Group Environment) is constructed as a federation of intelligent agent-based functions that enable PC-based scenario construction and emulation of C4ISR information and cognitive task demands (Hicks, Stoyen, Zhu, 2001). These PC-based scenarios operate much like networked videogames. However, the scenarios are scaled (Elliott, Dalrymple, Schiflett, & Miller, in press; Schiflett & Elliott, 2000). Functional and cognitive fidelity was based on cognitive task analyses (Chaiken, Elliott, Dalrymple, & Schiflett, 2001; Elliott, Dalrymple, Regian, & Schiflett., 2001).

C4ISR functions in these scenarios were typified by a strong demand for communication, coordinated action, and adaptive response to time-critical situations. The goals were to (a) capture operational relevance to C4ISR (content fidelity), (b) identification and assessment of individual and team performance (construct fidelity), and (c) development of scenarios that are equivalent in difficulty (cognitive fidelity) and yet (d) are not exact replicas of each other. If participants perform the same scenario over and over, over time, then effects of fatigue will be confounded with effects of practice and recognition-based performance. Scenarios had to be demanding, operationally relevant, equivalent in difficulty, and yet be distinct from each other (Elliott et al., 2003).

The C4ISR functions reflect those of current and future command centers that coordinate across diverse functional, geographic, military, national, and political characteristics. General principles of mission goals and tactics were identified and reflected in the AEDGE Scenarios. At the same time, scenarios must reflect research goals—performance constructs must be identified, elicited, and assessed. In order to (a) capture current and future operational issues, and (b) elicit interdependence, coordinating activities, and problemsolving on the part of the participants, we chose to develop C4ISR scenarios that include unplanned events requiring coordination among team members, problem identification and problem resolution.

While interface functions were greatly simplified, careful attention was given to capture of core information processing and decisionmaking demands in these C4ISR scenarios. Participants were trained on a variety of enemy and friendly weapons platforms, such as various UAV, ISR, fighter, bomber, SAM and other missile assets. They learned typical armament, speed, and radar characteristics. They learned the relative threat and designated targets of each asset.

Measures

Mission outcomes. Raw measures of mission outcome and team process were captured and time-stamped by the simulation. This includes descriptions and counts of events and actions, which then form the basis for various assessments of performance. For example, mission outcome scores were represented by the type, number, and relative value of assets that were lost, by "friendly" and "hostile" roles. Friendly assets included air bases, cities, surface-to-air missile launchers, uninhabited aerial vehicles, tanker aircraft, high-value reconnaissance aircraft, fighter aircraft, and bomber aircraft. Each asset was given a relative score value, generated by our weapons director expert, and validated by other experienced weapons directors. The loss of any friendly asset detracts from the score of the friendly team, and adds to the score of the enemy. In turn, hostile assets are similar. The loss of hostile assets adds to the score of the friendly team, and detracts from the score of the hostile. For these research participants, the overall mission outcome score was based on the point value obtained after subtracting all friendly “losses” from the total hostile “losses”.

Observation-based measures. These measures provide additional data on individual and team interaction. Scenario observation sheets provide raters with descriptions of events as they evolve in the scenario. For example, in the first 6 minutes each scenario introduces several hostile threats. The observation sheets also describe what each team member should be doing at that time. During the first 6 minutes, the ISR role should be identifying decoys, to enable STRIKE to jam them and target them with bombers. At the same time, SWEEP fighters must protect STRIKE and ISR assets from air-to-air threat. Team members must act swiftly and in coordination with each other, or they will likely lose assets and waste resources.

Behaviorally-anchored rating scales. These scales are based on descriptions of what each person should be doing are provided for time segments chosen based on the flow of events. Therefore, the appropriate and desirable responses to these events are also similar, across scenarios. For each introduction of assets and/or targets, the appropriate behaviors were identified for each role. Descriptions were generated for different levels of performance, leading to anchored scales for observer-based ratings of performance. Figure 1 provides an example of a tailored rating scale, this one tailored to rating the behavior of STRIKE, during the first six minutes of scenario 1.

0-6 min OVERALL rating of STRIKE (Circle)

During this time, Strike should be giving orders to bombers and jammers, jamming SAM sites, and assisting SWEEP and ISR.

1	2	3	4	5
POOR	FAIR	ADEQUATE	GOOD	EXCELLENT

POOR: no actions taken
FAIR: some action, very ineffective
ADEQUATE: some assigning of assets, no attention or assistance to others
GOOD: assets assigned, jamming accomplished, some coordination with others
EXCELLENT: assets assigned, jamming accomplished, assistance and coordination with others

Justify poor or excellent rating:

Figure 1. Observation-based rating scale for Strike, Scenario 1, 1st time period

Observation-based ratings of team communication. For specified time periods, based on events, observers provided ratings as shown in Figure 2:

0-6 min OVERALL rating of Team Communications (Circle)

1	2	3	4	5
POOR	FAIR	ADEQUATE	GOOD	EXCELLENT

POOR: No comm (or inaccurate comm) on conditions of friendlies / no comm on coordination needs or activities
FAIR: Partial comm on conditions of friendlies / hostiles; some comm on simple coordination needs / activities
ADEQUATE: Some comm on conditions of friendlies / hostiles; some comm on ordinary coordination needs/activities
GOOD: Comm on conditions of friendlies/hostiles covered the majority of the situation; comm on more complex coordination needs/activities
EXCELLENT: Comm on conditions of friendlies covered the entire situation; comm on conditions of hostiles covered the entire situation; comm on the most complex coordination needs; comm to accomplish the most complex coordinations

Justify poor or excellent rating:

Figure 2. Rating scale for team communications

Audio capture of communications. Digitally ecorded communications are another critical source of assessment. Communications were initially coded for indications of teamwork, such as sharing of information or assets, sequencing actions, acknowledgements, requests for repeats, task-related encouragement, expressions of fatigue, and social comments (positive and negative). All comments were coded as to whether they requested or provided information.

Analysis of communications (computer-mediated and verbal). In addition, all audio is digitally captured, and will be coded to ascertain the degree to which the team (a) shared information and (b) discussed sequencing their activities, for each phase of performance. We plan to capture the number of times each team member: 1) requests information about a target, asset, or unknown type of entity; 2) provides information about a target, asset, or unknown type of entity; 3) engages in strategy communications; 4) requests acknowledgements; 5) provides acknowledgements; 6) requests repeats, 7) provides repeats; 8) communicates fatigue; 9) communicates encouragement; 10) communicates on the time remaining in the scenario; and 11) has other communications. The concept map tool provides a useful means of representing these communications, as shown in Figure 3.

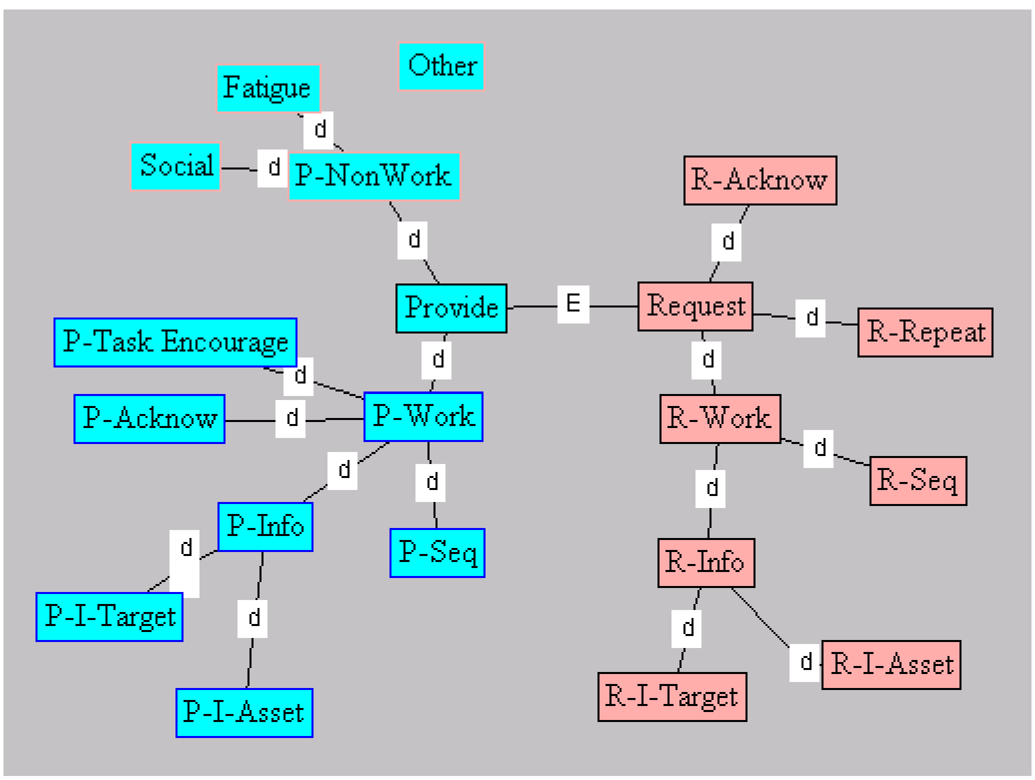

Figure 3. Representation of communication concepts

The first two types above deal with information activities (non-sequencing communications, such as queries, alerts, reminders, friendly and hostile conditions, lessons learned, strategies and tactics, etc.), while the third involves coordinating activities (sequencing tasks, sharing assets, requests for transfers, orders to transfer, coordination of transfers, sending transfers, receiving transfers, denying transfers, aborting transfers, etc). We will then correlate with quantitative indices of events, such as the number of times a handoff request or "push" (when a teammember offers an asset to another) is accepted or denied (from who to whom). Other quantitative indices include the number of times team members scope in or out (related to SA), the number of times they open information windows on assets, the number of times a decoy is correctly identified, assets are refueled and/or rearmed, penetration of friendly area by enemy; and of course, all outcome measures (targets destroyed by whom, etc). Figure 4 represents how patterns of communication among team members can be determined. In this particular example we show how different patterns regarding provision and request of information (by type) can be conceptualized. In this case, teams that have high amounts of providing information and low amount of requests are demonstrating *implicit coordination*, a very efficient means of communication that is associated with expert coordination under time pressure.

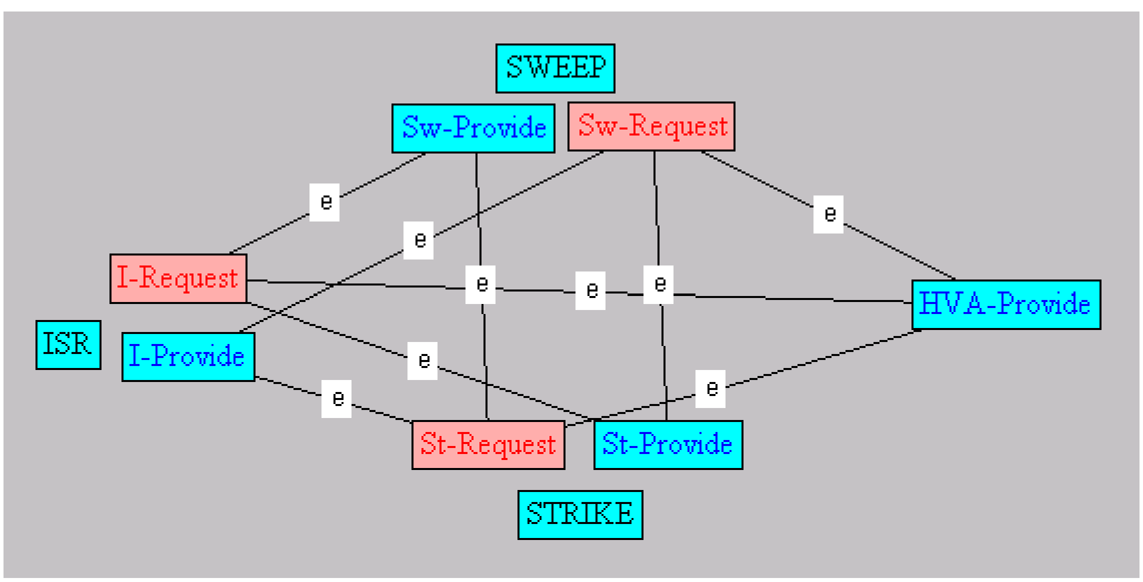

Figure 4. Representation of communication patterns regarding provision and request of information among team members.

We predict these indices of coordinating behavior, anticipatory behavior, and SA-related behavior will decline with fatigue. People will tunnel in, not notice the predicaments of others, not care (share resources), and not realize when new bandits arise, or when additional friendly resources are available. They are also expected to fail in sequencing activities, such that decoys are not identified, vulnerable friendly assets are lost, and hostile targets not executed. They are also expected to lose friendly assets due to fuel outs. Data collection is underway, and preliminary results will be available on an ongoing basis.

Discussion

Data collection is still underway. Coding of communications have resulted in acceptable reliability (over 90% agreement), and refinements will likely increase agreement. Preliminary analyses on limited data have already revealed significant direct effects of fatigue on some criterion measures, even when power is very low (N = 4 teams, within-subjects time series analyses). Data from all sources will be ultimately analyzed using a multi-level hierarchical modeling approach that enables consideration of performance data of individuals, clustered in teams, to ascertain relationships and trends over time (Kreft, & De Leeuw, 2000). We will over time, focus on how individual performance affects team performance, and how both are affected by fatigue.

References

Bonnet, M. H. (2000). Sleep Deprivation. In M. Kryger, T. Roth, & W. Dement (Eds.) Principles and Practices of Sleep Medicine, 53-68 Philadelphia, W.B. Saunders Company.

Chaiken, S., Elliott, L., Dalrymple, M., & Schiflett, S. (2001). Weapons Director intelligent agent-assist task: Procedure and findings for a validation study. Proceedings of the International Command and Control Research and Technology Symposium, June, 2001.

Cohen, M. S. (1993). The naturalistic basis of decision biases. . In G. Klein, J. Orasanu, R. Calderwood, & C. Zsambok (Eds.) Decision Making in Action: Models and methods. Norwood, NJ: Ablex Publishing Corporation.Coovert, M., Riddle, D., Gordon, T., Miles, D., Hoffman, K., King, T., Elliott, L., Schiflett, S., & Chaiken, S. (2001). The impact of an intelligent agent on weapon directors behavior: Issues of experience and performance. Proceedings of the International Command and Control Research and Technology Symposium, June, 2001. US Naval Academy, Annapolis.

Elliott, L. R., Coovert, M., & Miller, J. C. (2003). Ascertaining effects of sleep loss and experience on simulation—based performance. Proceedings of the 2003 Conference of the Society of Industrial/Organizational Psychology, Orlando, FL.

Elliott, L. R., Dalrymple, M. A., Schiflett, S. G., & Miller, J. C. (in press). Scaling Scenarios: Development and Application to C4ISR Sustained Operations Research. In S. Schiflett, L. Elliott, E. Salas, & M. Coovert (Eds.) Scaled Worlds: Development, Validation, and Applications. Ashgate Publishing Limited, Surrey, England.

Elliott, L. R., Dalrymple, M., Regian, J. W., Schiflett, S. (2001). Scaling Scenarios for Synthetic Task Environments: Issues Related to Fidelity and Validity. Proceedings of the 2001 Meeting of the Human Factors and Ergonomics Society, September. Minneapolis, MN.

Hicks, J., Stoyen, A., Zhu, Q. (2001). Intelligent agent-based software architecture for combat performance under overwhelming information inflow and uncertainty. Seventh IEEE International Conference on Engineering of Complex Computer Systems, 200-210.

Hursh, S.R. (1998) Modeling Sleep and Performance within the Integrated Unit Simulation System (IUSS). Final Report for the United States Army Soldier Systems Command; Natick Research, Development and Engineering Center, Natick, Massachusetts 01760-5020; Science and Technology Directorate; Technical Report: Natick/TR-98/026L.

Klein, G. A. (1993). A Recognition-Primed Decision (RPD) model of rapid decisionmaking. . In G. Klein, J. Orasanu, R. Calderwood, & C. Zsambok (Eds.) Decision Making in Action: Models and methods. Norwood, NJ: Ablex Publishing Corporation.

Kreft, I, & De Leeuw, J. (2000). Introducing Multilevel Modeling. Thousand Oaks, Sage.

Kryger, M., Roth, T., & Dement, W. (2000). Principles and Practices of Sleep Medicine, 3rd Edition. Philadelphia: W. B. Saunders Company.

Mahan, R. P. (1992). Effects of task uncertainty and continuous performance on knowledge execution in complex decision making. International Journal of Computer Integrated Manufacturing, 5 (2), 58-67.

Mahan, R. P. (1994). Stress-Induces strategy shifts toward intuitive cognition: A cognitive continuum framework approach. Human Performance, 7, (2), 85-118.

Mahan, R. P., Elliott, L.R., & Dunwoody, P.T. (April, 1998). Team Decisionmaking under Stress: The Effects of Sleep Loss, Continuous Performance, and Absense of Feedback on Team Decision Process and Performance. Presented at the Aerospace Medical Panel Symposium on Collaborative Crew Performance in Complex Operational Systems, Edinburgh, United Kingdom, April, 1998.

Mitchell, T. R. & Beach, L. R. (1990). ...Do I love thee? Let me count ... Toward an understanding of automatic decision making. Organizational Behavior and Human Decision Processes, 417, 1-20.

Orasanu, J. & Salas, E. (1991). Team decision making in complex environments. In G. Klein, J. Orasanu, R. Calderwood, & C. Zsambok (Eds.) Decision Making in Action: Models and methods. Norwood, NJ: Ablex Publishing Corporation

Orasunu, J. & Connolly (1993). The reinvention of decision making. In G. Klein, J. Orasanu, R. Calderwood, & C. Zsambok (Eds.) Decision Making in Action: Models and methods. Norwood, NJ: Ablex Publishing Corporation.

Petrov, P., & Stoyen, A. (2000). An intelligent-agent based decision support system for a complex command and control application. Proceeding of the sixth IEEE international Conference on Engineering of Complex Computer Systems, Tokyo, Japan.

Rasmussen, J. (1993). Deciding and doing: Decision making in natural contexts. In G. Klein, J. Orasanu, R. Calderwood, & C. Zsambok (Eds.) Decision Making in Action: Models and methods. Norwood, NJ: Ablex Publishing Corporation.

Schiflett, S. G. & Elliott, L. R. (2000). Synthetic Team Training Environments for Command and Control. In Dee Andrews and Mike Mcneese (Eds.), Aircrew Training Methods. Mahwah, NJ: Lawrence Erlbaum Associates.