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Communication and Performance of Command and Control Teams: Results of an Exploratory Team-Shooter Experiment

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Abstract

Command and Control teams in modern military and disaster response organizations work often synchronously and are ad-hoc. We explore communication and performance of synchronous ad-hoc teams in an exploratory experiment study utilizing the team-shooter Battlefield 2 as experiment platform. We identify communication content aspects and communication patterns as the rhythm how communication deals with either the team or with enemy that differ in successful and unsuccessful teams.

Introduction

Today's military and disaster response operations are complex and demand agile organization (Alberts and Hayes 2007; SAS-065 2009). Current scenarios require collaborating organizations to meet mission complexity. This mission complexity calls for new C2 approaches as e.g., *Power to the Edge* (Alberts and Hayes 2003) based on close collaboration of entities. One concept—command and control teams (C2 teams)—is considered to be purposeful to organize collaboration (Salas et al. 2001; Essens et al. 2007). We follow Jones and Roelofsma 2000 in defining a C2 team "as two or more individuals with specialist and interdependent roles who are necessarily brought together to perform a complex decision-rich task in order to achieve goals that are central to those of the organization" (Jones and Roelofsma 2000, p. 1132). C2 teams cope with tasks which are not achievable by individuals. C2 teams "are primarily used to manage moderate to large-scale events within ill-defined situations, where resources are limited" (Salas et al. 2001) and circumstances for operation are often fast-paced and ambiguous. They usually cope with large amounts of ambiguous and frequently changing information from multiple sources according to the dynamics of situations they are operating in (Jones and Roelofsma 2000; Paris et al. 2000; Salas et al. 2001).

Not only mission dynamics and complexity but also team composition exacerbates the task of C2 teams, as they are often ad-hoc—that means composed on short notice for a single mission with no team history (Salas et al. 2001). Work modus is primarily synchronous, as the units in the field require immediate decisions for operation.

We are interested in observing synchronous ad-hoc C2 teams coping with complex tasks in dynamic environments. We want to understand communication behaviors of such teams. Are communication patterns observable, correlating to performance? Which communication behavior is suited to coordinate team actions successfully?

To research such teams we simulated a team environment in an experiment setting to observe and record verbal team communication. We analyze whether communication patterns can distinguish successful and unsuccessful teams.

Theory

Major reviews of scholarly management literature on teams (Cohen and Bailey 1997; Martins et al. 2004; Mathieu et al. 2008) examine teamwork, coordination or leadership in teams. Surprisingly, only few contributions within the aforementioned reviews shed light on the relationship between communication and its content and team performance. None of the mentioned contributions analyze verbal synchronous communication in depth to understand the communication – performance relationship.

In 1973 Paul Hare reviewed several studies about small groups and interaction analysis to recover group development processes (Hare 2009). These studies do not consider the relationship between communication, performance or quality of teamwork and coordination.

One stream of literature on teams' verbal communication deals with aviation teams, i.e., communication in cockpit crews. As communication deficiencies are one major factor in aviation incidents (see e.g. Billings and Cheaney 1981), several studies explore the relationship between communication and cockpit crew performance measured by crews' failure rate in simulated flights (e.g. Foushee and Manos 1981; Foushee et al. 1986; Kanki et al. 1991; Oser et al. 1991). Findings include that captains communicate more commands than first officers (Kanki et al. 1991; Oser et al. 1991), that more communication occur in teams causing less mistakes (Foushee and Manos 1981; Foushee et al. 1986) or that observations communicated without request avoid mistakes (Foushee et al. 1986; Oser et al. 1991).

Aviation team studies indicate positive correlation between communication volume and performance. In contrast, Macmillan et al. (2004) observe in a simulated air and sea-based operation that synchronous C2 teams communicating less, perform better. These researchers argue that verbal communication requires time and cognitive resources and diminishes performance in teams with less efficient team structure defined as "the nature of the team's tasks and the allocation of task responsibilities to individuals on the team" (Macmillan et al. 2004).

The Relationship Between Communication and Coordination

There is some evidence that less communication is better for team performance of C2 teams and there is contradicting evidence that more communication reduces the number of failures. As team communication, as in particular verbal communication seems to be very specific for teams and their contexts, we analyze communication within ad-hoc synchronous teams to understand how communication affects team coordination and if - how it is linked to performance.

Communication is vital for coordination functions in teams (e.g. Stout et al. 1999; Salas et al. 2001). Salas et al. 2001 differentiate communication driven explicit coordination from implicit coordination. Implicit coordination refers to the coordinative power of mental models (Klimoski and Mohammed 1994, Rouse et al. 1992; Smith-Jentsch et al. 2001) commonly shared by all team members. Shared mental models represent common expectations about the environment and its near future development (Klimoski and Mohammed 1994). When these expectations are shared within a team and team members know that, talking about expectations is not further necessary and communication decreases (Cannon-Bowers and Salas 2001; Macmillan et al. 2004).

Shared mental models are team knowledge representations referring at least to knowledge about the team—*who knows what*, *who is responsible for what* or *who is specialized to what*—or knowledge about situation – how the environment will develop in future (Cooke et al. 2000). Knowledge about the team enables to coordinate team functions and team member interdependencies (Gronn 2002). This team knowledge is organized in Team Mental Models (TMMs).

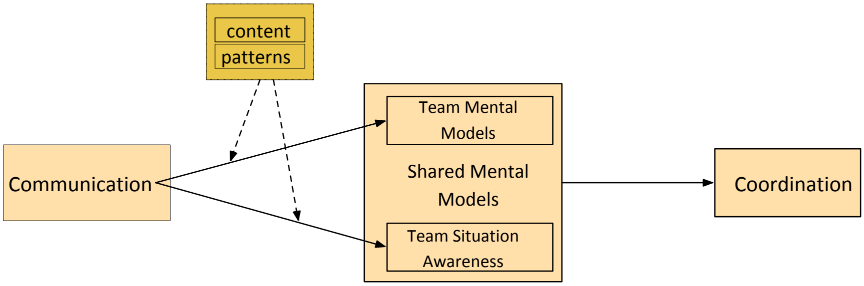

Figure 1. Relationship between Communication, Shared Mental Models and Coordination

Team Situation Awareness (TSA) captures knowledge or awareness about the situation as crucial factor for coordinating team actions according to the environment and its development (e.g. Salas et al. 1995). In situations changing dynamically, communication helps to maintain and develop TSA. Thus, the more dynamic the environment is, the richer communication about situation will be. Figure 1 illustrates the relationship between communication, shared mental models and coordination.

Task complexity increases communication demand so that highly complex tasks require more communication than tasks low in complexity (Van de Ven et al. 1976; March and Simon 1993). This communication establishes and maintains TMM enabling the integration of several specialized team members' functions in accordance to task complexity (Wegner 1995). The management of team members' interdependencies requires coordination and thus communication (Stewart and Barrick 2000; Gronn 2002). This communication supports explicit team coordination. With TMMs developed this communication decreases over time (Kanawattanachai and Yoo 2007).

C2 teams eventually have to cope with rapidly changing environments. Communication is required to recognize, explain and analyze these changes. This communication serves to establish and permanently maintain the situational model of the team – TSA. Thus, the higher the dynamics of the environment is, the more communication about the situation will be required.

We analyze verbal communication in synchronous ad-hoc teams playing a team-shooter computer game. We aim to identify communication patterns according to team-centric communication and situation-centric communication that distinguishes successful from unsuccessful teams. We are interested to observe whether successful teams communicate more or less than unsuccessful teams in these respective communication content classes.

Method

Our experiment platform is the first-person-perspective team-shooter Battlefield 2 (www.ea.com), a simulation of military close combat (Figure 2 depicts a screenshot). Our teams playing Battlefield 2 (BF2) are ad-hoc, play in synchronous mode, consist of five players with distinct roles and cope with a complex and dynamic task.

Figure 2. Screenshot from 'Team EC', Game 1, Round 1, Assault-Soldier 1

In summer 2009 we conducted an exploratory experiment to observe synchronous ad-hoc teams. Following the definitions of Steinle 1998, exploratory experiment settings offer empirical openness and the ability to develop theories—in contrast to theory testing approaches typically common on experiments.

Team Task

Two teams fight each other in *capture the flag* mode to win a BF2 game that consists of two rounds. The theatre is a virtual urban area with four strategic points like e.g. a mosque. Teams' task is to conquer these points to hoist their flags on them. The objective is to capture or recapture as many strategic points as possible to mark them with the team flag.

There are three ways to win a round. First, to conquer all strategic points and to kill all adversary players gives immediate victory. Second, each team has 200 tickets (points) at the beginning. Tickets reduce for a team (1) when it holds fewer flags than the opposing team or (2) when a teammate is killed. A round ends when one team has zero tickets. The team with tickets left wins. The third way to win is to have more tickets after 20 minutes, the maximum round duration.

Note, a five-player team is unable to defend all strategic points concurrently. A round usually seesaws with multiple changes in "ownership" of flags forcing teams to change tactics dynamically—to switch from attack to defence or regroup and act once as unity, once as two sub-teams. All these actions require coordination.

Team Composition

Our teams consist of three assault-soldiers, one medic and one support-soldier:

Assault-soldiers are heavily armored and equipped with an assault-rifle with grenade function and smoke grenades. Assault-soldiers' mobility is limited by armor.

Medics feature heal-bags to restore teammates' health and a heart defibrillator to reanimate teammates. They are not armoured and very mobile. For self-protection medics use a standard assault-rifle and hand grenades.

Support-soldiers supply teammates with ammunition. They fight with a 'heavy' machine gun or an assault-rifle and hand grenades. Their mobility is limited by heavy armor.

Data Acquisition

We captured verbal communication using software called *teamspeak* (www.teamspeak.com), a widely used voice chat software. All players had headphones. We captured the video-stream of each player's screen utilizing software called *Fraps* (www.fraps.com). We merged video and audio as raw material for data analysis.

Participants

All 80 experiment participants were male German Armed Forces officer cadets enrolled as students at the *Universität der Bundeswehr München*. The students volunteered. We offered neither financial remuneration nor credits. Experiment participants were not familiar with research questions.

Experiment Procedure

Before competition, we explained game and task and conducted a single player modus training run to enable all players to handle their game character.

We then conducted two competition rounds (identified as Round 1, Round 2) with two competing teams with randomly assigned players. The two competing teams played in different laboratories (WI-lab and EC-lab). We identify teams according to the lab-token as *Team WI* or *Team EC*.

Communication Coding Scheme

According to the theory-section we analyze differences with regard to team-centric communication and situation-centric communication between successful and unsuccessful teams. Hence, we developed a communication coding scheme to codify all communication acts spoken in our teams to distinguish these communication content classes. The two main categories of the coding scheme are (1) team-centric communication (TCC) and (2) enemy-centric communication (ECC) (Figure 3).

Situation-centric communication in close combat scenarios usually covers more than solely communication about the enemy. Crucial situational aspects for operation are weather and time constraints, neutral forces, underground and many more. However, in our BF2 context these aspects did not play a considerable role. Our teams did not communicate about such aspects. Thus, we decided to name the category enemy-centric communication to clarify that situation-centric communication in our context is about the enemy as the adaptive behavior of the opponent team causes situational change continually which this communication class reflects.

Code Identifier	Sub Codes	Code Definition	Exemplifications
Enemy-centric communication (ECC)	Perception	Unspecific information about enemies' occurrences	"I killed one" "There is one more"
	Comprehension	Information about enemies that helps to maintain the situational picture of each team-mate esp. due to information about location or relationship to own team	"One more at the hotel" "Attention one is sitting on the roof"
	Projection	Communication of possible future actions of enemies	"All will come to the mosque, again..." "Two come towards you, Player One"
	Action	Information about actions to do with regard to the enemy	"I enter the roof to try to fight them from above" "Throw hand-grenades on them!"
Team-centric communication (TCC)		Information about own status, socio-emotional communication, tension release, coordination without enemy relation, etc. All communication not referring to the enemy	"All to the medic" "Medic, can you heal me?" "To the left, to the wall?" "Hey, we have to capture the flags, now!" "I'm dead"

Figure 3. Coding Scheme

To understand ECC better, we apply Endsley's theory of Situation Awareness (Endsley 1995) and its team context application (e.g. Salas et al. 1995). We distinguish perceiving the environment (Perception), comprehending relevant facts perceived (Comprehension), exchanging relevant projections of future environmental states (Projection) and exchanging information on actions (Action). Teams should exchange information about the perception and comprehension of facts, as teammates' views on the battlefield all differ. Projection means processing relevant data and simulating future environmental states. Projections of single teammates have to be communicated and converged to become shared and basis for team based actions. Subcode Action captures communication about team action regarding the enemy as e.g. suggestions or commands. We argue that ECC is required to maintain team situation awareness (TSA) in our teams. The team members' exclusive sensing has to be exchanged via communication to become shared within the team.

The TSA stages perception, comprehension and projection are ordered (Endsley 1995). Projection of future states requires comprehension and beforehand perception of the situation and its changes. Projection is basis for planning and shared team activities. Thus, Action is based on projections and captures coordination attempts with regard to opponents.

Team-centric communication (TCC) is characterized by communication acts about the team, as e.g. status information, requests for healing or socio-emotional communication as, e.g., tension releases or jokes. With this either-or-choice we underline that all information exchanged in the team that is not about the situation (enemy) is about the team. The teammates did not have time to "tell" something that is not relevant for the scenario. That does not mean that all information exchanged is relevant to be effective. The teams were swearing, joking and laughing, of course. But this is also important to understand the teammate—to create a mental model of the team. We argue that TCC is crucial for building a Team Mental Model (TMM).

The first author coded all communication using the transcribed audio files. After coding all communication first author reassessed the coding and recoded a very small number of communication acts. The main hypotheses and approaches to analyze data were developed after the coding inspired by the interpretation of codes in an explorative approach (Glaser and Strauss 2008).

Results

The first part of the result section provides an overview of all games. Differences between successful and unsuccessful teams with regards to communication volume and communication categories are discussed.

The second part compares communication patterns and analyzes how successful and unsuccessful teams differ in TCC and ECC communication sequence length and oscillation. Subsequently a Linear Discriminant Analysis (LDA) is presented testing whether identified variables discriminate successful from unsuccessful teams.

Communication and Performance

Table 1 outlines the overall experiment result including duration of rounds (column 2; 8); successful teams (*X* mark winners in column 4; 10) or ticket margin for each round (column 5; 11; if a round finished ahead of time team tickets of unsuccessful teams are marked -). Additionally, Table 1 depicts the number of communication acts of a particular round (column 6; 12). Columns 7 and 13 overview communication frequency, giving the calculation of communication acts per minute (CA/min). Following calculations use CA/min to compare communication volume despite of different rounds' length.

Table 1 reveals differences in games. We shortly describe peculiarities in rounds' duration, ticket differences and communication volume. Only Games 1 and 6 took maximum duration of 40 minutes (two rounds à 20 minutes). However, only in Game 3 both rounds finished ahead of time. Nine rounds (from 16) took the maximum of 20 minutes. The shortest round took 5:20 minutes.

Table 1. Games Overview

	Round 1						Round 2					
Game	Duration (min)	Team	Winner	Tickets at Round's End	Communication Acts	Communication Acts per Minute	Duration (min)	Team	Winner	Tickets at Round's End	Communication Acts	Communication Acts per Minute
1	20:00	EC	X	166	392	19.6	20:00	EC		114	418	20.9
		WI		79	360	18		WI	X	155	468	23.4
2	20:00	EC		50	445	22.25	5:35	EC		-	108	19.34
		WI	X	158	398	19.9		WI	X	194	130	23.28
3	16:35	EC		-	253	15.26	8:00	EC		-	127	15.88
		WI	X	114	444	26.77		WI	X	194	244	30.5
4	20:00	EC	X	168	396	19.8	18:15	EC		-	391	21.42
		WI		49	478	23.9		WI	X	130	447	24.49
5	14:20	EC	X	186	248	17.3	20:00	EC	X	172	387	19.35
		WI		-	238	16.6		WI		81	392	19.6
6	20:00	EC	X	177	385	19.25	20:00	EC		155	392	19.6
		WI		65	350	17.5		WI	X	160	415	20.75
7	20:00	EC		90	144	7.2	5:20	EC		-	42	7.88
		WI	X	161	349	17.45		WI	X	199	114	21.38
8	5:35	EC	X	197	66	11.82	20:00	EC	X	165	369	18.45
		WI		-	96	17.19		WI		114	524	26.2

The ticket difference for the 20 minutes-rounds (for the other rounds ticket difference is senseless) is considerably different. For example Team EC in Game 4, Round 1 had a "walkover" with the highest overall ticket margin of 119. Surprisingly, this team lost the second round. The slimmest margin (Game 6, Round 2) was 5 tickets and this round's successful Team WI had previously lost Round 1. In Games 1, 4 and 6 the successful team changed between Round 1 and 2. In the other five games the same team won both rounds.

Communication volume either differs. Team WI in Game 3 was the most talkative team (CA/min in Round 1: 26.77 and Round 2: 30.5 CA/min) and also the most successful team winning both rounds ahead of time. The least talkative team, Team EC in Game 7 (CA/min in Round 1: 7.2 and Round 2: 7.88), lost both rounds.

According to our research questions, we are interested in communication patterns and behaviors differentiating successful from unsuccessful teams. Table 2 depicts the number of CA/min and round for each relevant coding category (overall CA/min, TCC and ECC—both main coding categories and the sub-codes of ECC). It contrasts mean and standard deviation (SD) for successful and unsuccessful teams. The last column reveals the results of a one-way ANOVA comparing means for successful and unsuccessful teams in the respective category.

Table 2. Successful and Unsuccessful Teams' Communication per Round

	All Teams (N=32)		Successful Teams (N=16)		Unsuccessful Teams (N=16)		ANOVA (df 1= 1; df 2= 30)	
	Mean	SD	Mean	SD	Mean	SD	F	p
CA/min	19.44	4.81	20.84	4.27	18.05	5.04	2.87	n.s.
TCC Acts/min	12.80	3.28	13.11	2.74	12.5	3.8	0.27	n.s.
ECC Acts/min	6.64	2.45	7.74	2.41	5.54	2.01	7.81	<.01
Perception/min	1.25	0.68	1.33	0.75	1.17	0.61	0.42	n.s.
Comprehension/min	2.70	1.14	3.15	0.85	2.26	1.24	5.63	<.05
Projection/min	1.02	0.52	1.15	0.53	0.88	0.49	2.28	n.s.
Action/min	1.67	1.01	2.11	1.06	1.24	0.75	7.27	<.05

CA: Communication Acts; TCC: Team-Centric Communication; ECC: Enemy-Centric Communication

Teams communicated on average 19.44 CA/min per round. With 12.8 TCC-acts versus 6.64 ECC-acts per minute the share of team-centric communication is nearly twice as high as that of enemy-centric communication.

The high standard deviation values (cf. Table 2) in all rows indicate communication differences within teams. Successful teams communicated slightly but insignificantly more than unsuccessful ones (20.84 vs. 18.05 CA/min). Whereas no difference in TCC is observable, successful teams communicated significantly more ECC (7.74 vs. 5.54 CA/min; $F(1,30)=7.81$; $p<0.01$). Differences in subcategories Perception (1.33 vs. 1.17 CA/min) and Projection (1.15 vs. 0.88) are not significant. The number of CA/min in categories Comprehension (3.15 vs. 2.26 CA/min, $F(1,30)=5.63$; $p<0.05$) and Action (2.11 vs. 1.24; $F(1;30)=7.27$; $p<0.05$) however, differs significantly with successful teams communicating more in both categories.

Our analysis neither validates a positive correlation between performance and communication volume as observed in cockpit communication (e.g. Foushee and Manos 1981; Foushee et al. 1986) nor a decline in communication as in different team studies with decision intensive tasks (Macmillan et al. 2004; Kanawattanachai and Yoo 2007; van der Kleij et al. 2009). Latter researchers argue that communication declines due to TMM development. We observe no difference for successful and unsuccessful teams in team-centric communication (TCC) which supports TMM building. We argue that successful teams communicate significantly more about the enemy and invest more communication and time in developing TSA. Successful teams were able in that situation 1) to communicate slightly more and 2) to concentrate with that more on communication on "the enemy" (ECC) to maintain TSA.

Building and maintaining TSA is crucial in our team task as the team environment always changes due to actions by the opponent team. Here our research differs from research on teams in less dynamic environments as general management teams in simulated business environments (e.g. Kanawattanachai and Yoo 2007), teams playing quiz-game (e.g. van der Kleij et al. 2009) or C2 teams in simulated air-sea operations (e.g. Macmillan et al. 2004).

As the number of ECC-acts is significantly higher for successful teams than for unsuccessful, we further investigate in ECC sub-categories. Communication acts coded Perception are fairly equal in number for successful (1.33 CA/min) and unsuccessful teams (1.17 CA/min). In contrast, the higher level communication acts coded Comprehension are communicated significantly more often by successful teams (3.15 vs. 2.26 CA/min, $F(1,30)=5.63$; $p<0.05$). Both categories classify fairly similar communication acts. The main difference is that Comprehension coded communication acts relate different information about the enemy and enriches the situational picture in a more comprehensive way [e.g. "An enemy" (Perception) vs. "An enemy at the stairs" (Comprehension) relates the occurrence of an enemy to its location]. Thus, successful teams' communication is more efficient, supporting with more comprehensive information able to maintain TSA. Surprising was the insignificant difference in number of communication acts in category Projection (1.15 vs. 0.88 CA/min). We argue that movements of the enemies and thus the development of the situation is too fast to communicate future states without communicating consequences for the own team as giving orders to do something or information what the communicating player is doing himself (which we coded Action) in that same communication act. Thus, the significant higher number of CA/min coded Action in successful teams (2.11 vs. 1.24; $F(1;30)=7.27$; $p<0.05$) again characterizes the more efficient communication behavior by successful teams as does the higher number of Comprehension coded communication acts.

Communication Patterns and Performance

We want to specify communication patterns discriminating successful and unsuccessful teams. We argue, the pattern of change in communication content (team-centric or enemy-centric) and thus, the communication content supporting TMM building or TSA maintenance differs between successful and unsuccessful teams. To measure "change" we identify the length of communication acts sequences either coded TCC or ECC (cf. Figure 4).

Communication Example:
Game 3; Round 2; Team EC

Player	Communication Acts (Translation) S 1 - S 3 = Assault-Soldier 1 - 3 M = Medic S = Support-Soldier	Code	Sequence-Length
...	...	...	...
S 1	We need here... Do we need a medic here?	TCC	1
S 1	I go off-site around	TCC	2
M	NJAAACH	TCC	3
S 1	Naaa, where is this goddamn wall over?	TCC	4
M	Backwards is the entry! Right behind the mosque.	TCC	5
S 1	Oh yeahh, I see, I see, Isee	TCC	6
S 1	Ok, am now...	TCC	7
S	Caution!	TCC	8
M	Is the spawn-point... Ah it's still there.	TCC	9
S 2	Oh goddamn ... Where...	TCC	10
M	Oh I love it. Right under his nose...	TCC	11
S 1	I got him! I got him! I got him	ECC	1
S 1	Where is this jerk?	ECC	2
S	Is the medic with you?	TCC	1
M	Yes, he is...	TCC	2
S 1	Well, at the flag is no one left. No one at the flag.	ECC	1
S 2	I lay down right around the corner at the stairs	TCC	1
S	I know that feeling	TCC	2
S 2	Yeahh...	TCC	3
S 1	I entered the machine gun. Can bar the main entrance to the mosque.	TCC	4
...	...	...	...

Sequence of eleven team-centric communication acts

Sequence of four team-centric communication acts

Communication Example:
Game 3; Round 2; Team WI

Player	Communication Acts (Translation) S 1 - S 3 = Assault-Soldier 1 - 3 M = Medic S = Support-Soldier	Code	Sequence-Length
...	...	...	...
M	Right	ECC	1
M	Yes!	ECC	2
M	gone	ECC	3
M	Left	ECC	4
M	*narf*	TCC	1
S 2	Uooh there is one lying at the street	ECC	1
M	Don't run, don't run there all. On the left is a small way, too	TCC	1
S 1	Left of what	TCC	2
M	They don't think of that	ECC	1
S 2	Ehh, one with a machine gun on the street	ECC	2
M	Left of our position...	TCC	1
S 1	Where we are all more or less dead. Or don't know how many are still alive.	TCC	2
S 3	Yes, well...	TCC	3
S	Huhhh	TCC	4
S 1	Directly in front of the wall	ECC	1
S 3	He is behind the barracks	ECC	2
M	Behind us...	ECC	3
S	Thanks	TCC	1
S 3	Yes, I have	TCC	2
S	There is one more...	ECC	1
...	...	...	...

Figure 4. Communication Example

Figure 4 exemplifies communication sequence and sequence length with a translated transcript of 20 communication acts of Game 3, Round 2. Team EC, this round's unsuccessful team (Figure 4, left column), communicated five sequences with a maximum length of eleven communication acts coded ECC. The four other sequences are two, two, one, and four communication acts long. Team WI communicated nine sequences with a maximum sequence length of four. According to the change between TCC and ECC, Team WI switches communication content more frequently than Team EC. In very dynamic situations this communication content switch enables the team to maintain and build situational aspects and team-based aspects of shared mental models in parallel.

Figure 5 illustrates all communication sequences of Game 3, Round 2. We choose this example as Team WI was the most successful team exclusively winning both rounds ahead of time and was the most talkative team in our experiment. Communication *oscillates* between TCC (above y-axis) and ECC (below y-axis). The thickness of bars on top and bottom correspond to the length of TCC or ECC sequences. Team EC communicated 127, Team WI 244 acts. Communication content changed much more frequently in Team WI and accordingly the bars in Figure 5 are *thinner* for Team WI.

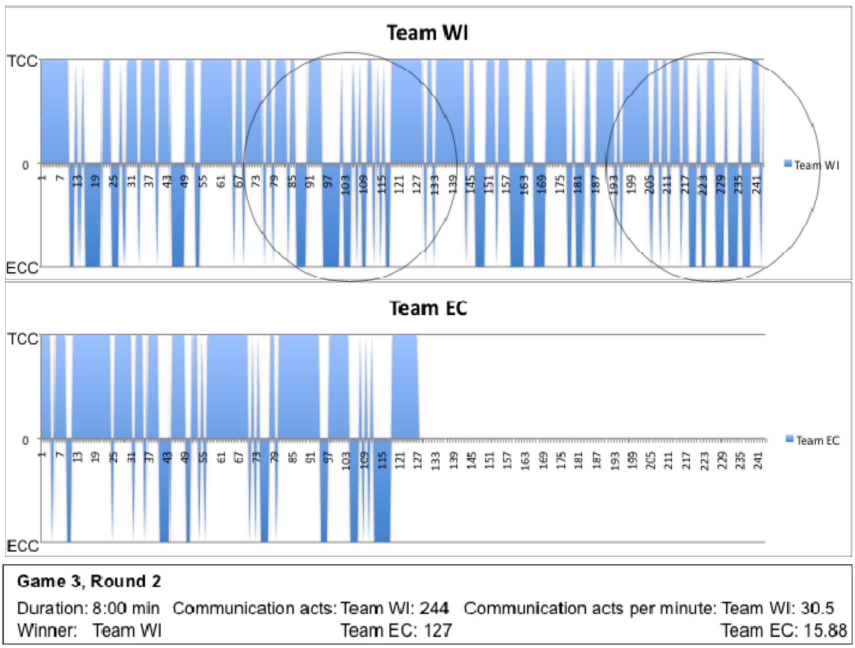

Figure 5. Sequence Changes

Both circles mark phases in which Team WI's ECC outweigh TCC and team's communication concentrates on the enemy. This pattern is appropriate to maintain TSA continuously. It helps the team to act progressively in order to defeat Team EC. In particular at the end of that fight ECC is merely *interrupted* by short TCC-sequences. TMM is developed so far that team members know what to do such that communication concentrates on the enemy until Team EC is defeated.

This pattern of shorter sequences and more frequent changes is observable throughout the whole data sample. We determine the Average Sequence Length (ASL) of communication sequences in category TCC and ECC and compare ASL of successful and unsuccessful teams (Table 3).

Table 3. Comparison of Communication Sequences

ASL: Average Sequence Length						
	Successful Teams (N=16)		Unsuccessful Teams (N=16)		ANOVA (df 1= 1; df 2= 30)	
	Mean	SD	Mean	SD	F	p
ASL TCC	3.37	0.77	4.40	1.72	4.82	<.05
ASL ECC	1.94	0.32	1.91	0.27	0.10	n.s.
Difference of ASL TCC and ASL ECC	1.43	0.99	2.49	1.79	4.35	<.05

Table 3 depicts the comparison of communication content change for successful and unsuccessful teams. The 16 unsuccessful teams communicated TCC-sequences on average 4.4 communication acts long. Successful teams, however, communicated significantly shorter TCC-sequences on average 3.37 acts long ($F(1,30)=4.82$; $p<0.05$).

In contrast to ASL of ECC little differences in ASL of ECC-sequences are observed (Table 3). Successful teams communicated on average slightly but not significantly longer sequences (1.94 vs. 1.91). Thus, with shorter TCC-sequences (3.37) and longer ECC-sequences (1.94) communication is more evenly distributed over both categories in successful teams. The difference between ASL of team-centric communication and ASL of enemy-centric communication is significantly shorter for successful than for unsuccessful teams (1.43 vs. 2.49; $F(1,30)=4.35$; $p<0.05$). Successful teams switch more uniformly and more evenly between communication content. This communication pattern enables to maintain TMM and TSA concurrently.

Unsuccessful teams, however, tend to communicate TCC sequences very long and time consuming. This indicates performance loss through bad information how the enemy acts during these communication sequences.

Successful vs. Unsuccessful Teams - Communication Behavior and Patterns

The last two sections revealed that successful teams communicated significantly more about the enemy and adopted more efficient communication behavior than unsuccessful teams by communicating more communication acts coded Comprehension and Action. Additionally, successful teams had shorter sequences of communication acts in TCC and the difference between ASL of TCC and ASL of ECC is significantly smaller. Successful teams' communication is more evenly distributed over content classes ECC and TCC.

However, our analysis so far includes only one variable at a time. As these variables might be correlated it is widely unclear (1) whether the analyzed variables in common differentiate successful from unsuccessful teams and (2) if so, which impact which variable has for such differentiation. We utilized Linear Discriminant Analysis (LDA) to answer these questions as the appropriate design for LDA calls for nominally scaled dependent and metrically scaled independent variables as in our design (e.g. Backhaus et al. 2006).

Table 4. Description of function discriminating successful from unsuccessful teams

Description of Discrimination Function				
Eigenvalue	Wilks !	″^{2}	df	p
0.50	0.67	11.14	5	<.05

Discriminant Coefficients		
	Canonical Discriminant Coefficients	Standardized Discriminant Coefficients
ECC/min	-0.45	.72
Action/min	1.05	.70
Comprehension/min	0.88	.61
ASL TCC	-3.12	-.57
Difference of ASL TCC and ASL ECC	3.19	-.54

Table 4 depicts the results of LDA. Note, it is not our goal to predict future results for teams playing BF2. Moreover, we try to test whether the communication of more (1) enemy-centric CA/min, and (2) communication acts coded Action and Comprehension on one side and the pattern of (3) shorter sequence lengths of team-centric communication, and (4) a smaller difference of ASL of TCC and ASL of ECC on the other side are suited to differentiate successful from unsuccessful teams.

Data in Table 4 support the assumption that all factors revealed discriminate both groups significantly. The table shows the standardized discriminant coefficients ordered according to their absolute value. The higher the absolute value is, the more important the coefficient is for discrimination. All differences between absolute values of standardized discriminant values are pretty low, indicating that all factors are influential in discriminating both groups of teams.

As the results reveal, communication content adoption and communication patterns are qualified to distinguish successful from unsuccessful synchronous ad-hoc teams playing BF2. We think Shared Mental Models are of great concern for such complex and dynamic task. TMM and TSA development require communication (Rouse et al. 1992; Salas et al. 1995; Cannon-Bowers and Salas 2001; Kanawattanachai and Yoo 2007). Ad-hoc teams cannot build on developed TMMs as longer living teams with common history. Instead, these teams are obliged to develop TMMs initially (Kanawattanachai and Yoo 2007) and to scrutinize the shared views during the common task to increase productivity. Thus, ad-hoc teams require team-centric communication for initial TMM development. However, a dynamic environment like BF2 permanently changes. Teams are required to inform about these changes and to communicate situation specific communication (as in our setting was enemy-centric communication), comprehend facts, project future environmental states and act. When teams communicate long TCC-sequences it takes them much time in that the team cannot maintain TSA as no information about the situation (in our setting about the enemy) was exchanged.

A uniform and relatively short content switching communication pattern like that observed for successful teams is suited for synchronous ad-hoc teams in dynamic environments coping with complex tasks. This pattern supports concurrent TMM building and TSA maintenance. Successful teams' shorter TCC-sequences indicate that successful teams (1) develop TMMs efficiently and (2) use their cognitive capacity to switch content frequently helping to maintain TSA. TSA maintenance is supported by frequent short ECC-sequences. Thus, successful teams talk more often about the enemy. We do not state that these patterns point to personality traits or psychological constructs at the individual level. We argue that these patterns are team level constructs. When a team is able to find processes suitable to handle the situation in a quick manner, the team can concentrate more on the enemy. Whether a team can adopt such processes depends on the team but also on the quality of the enemy. Thus, team communication patterns can change over time depending on the situation.

Following, the question about communication volume is not whether more or less communication is better. The studies of Kanawattanachai and Yoo 2007 and van der Kleij et al. 2009 research teams in rather stable environments. Here communication decreases over time as

TMMs develop (Cannon-Bowers and Salas 2001; Kanawattanachai and Yoo 2007). However, our teams act in a very dynamic environment. Thus, our observed patterns differ. Uniform communication content *oscillation* between TCC and ECC emerges. Successful teams emphasize enemy-centric communication much more than unsuccessful teams. With ongoing TMM development successful ad-hoc BF2 teams are able to shift communication from TCC to ECC and become more competitive.

Discussion and Limitations

Limitations of our results are, as in any experimental setting, induced by sample size, selection of participants and generalizabilty of findings in the experiment setting. Experiment and analyses are exploratory and we developed a coding scheme and measurements for synchronous ad-hoc teams acting in complex and dynamic settings. Future research should analyze TCC in more detail. We decided to code one main category to describe TCC. A more elaborate coding scheme might give better insights into team communication. To validate theory developed with this contribution the coding process should be organized differently. Independent coders and a test of inter-coder reliability increase internal validity.

The use of the computer game BF2 as experiment platform to research synchronous ad-hoc teams was promising. We think in future military and disaster response operations synchronous C2 teams become more important and leaders and trainers require knowledge about appropriate team communication. Our results presented here reveal that communication content adoption and communication patterns are qualified to distinguish successful from unsuccessful synchronous ad-hoc teams playing BF2 highlighting the exclusive role of team communication in complex tasks in dynamic environments. We furthermore identified communication patterns supporting concurrent team mental model building and team situation awareness maintenance. We observed that successful teams communicated more team-centric communication and in particular more communication acts coded Comprehension and Action than unsuccessful teams. Moreover successful teams switch communication content between team-centric communication and enemy-centric communication more often. This pattern enables concurrent TMM building and TSA maintenance.

The identified relationship between communication patterns and team performance and building and maintaining Shared Mental Models and team performance stress that synchronous ad-hoc C2 teams require particular instruments and methods for assessing and developing communication and performance. More research is needed here, in particular since ad-hoc C2 teams are a crucial element of modern mission scenarios.

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