TEAM COORDINATION OF TEAM SITUATION AWARENESS IN HUMAN-AUTONOMY TEAMING

Preprint · October 2019

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In this study, we examined how pushing and pulling information and coordinated perception were associated with Team Situation Awareness (TSA) in both Human-Autonomy (HAT) and all-human teams in simulated Remotely Piloted Aircraft System (RPAS) task environment. Pushing information was positively associated with TSA, and synthetic teams had lower levels of both pushing and pulling information than the all-human teams. In this team task, effective teamwork involves anticipating the needs of teammates, which in turn means pushing information before it is requested. However, in addition to anticipation, effective coordination is also needed during roadblocks. HATs demonstrated significantly lower levels of coordinated perception than all-human teams. These results indicate that HATs' lack of anticipation and coordination resulted in poorer TSA performance. This information then helps HATs to grow its coordination and communication methodologies. HAT is here to stay, but improvements to human-machine interactions must continue if we are to improve team effectiveness.

INTRODUCTION

Advancements in algorithms and technological innovation in high-tech industries (i.e., medical and military) have enabled innovation in highly advanced autonomous agents capable of performing in complex and dynamic tasks (Kownacki, 2018; Singer, 2018). Autonomous agents are partially (or fully) self-directed, and, though they are often designed for specific situations, they have intelligence-based abilities that allow them to operate outside of those situations (Endsley, 2015). In recent studies (Fiore & Wiltshire, 2016; Schulte, Donath, & Lange, 2016), autonomous agents have been playing the role of a team member. The Remotely Piloted Aircraft System (RPAS) task environment is a specific environment that autonomous agents may be useful and have been tested in (Ball et al., 2010). With that in mind, Human-Autonomy Teaming (HAT) is a coordinated unit in which humans and autonomous agents interact with each other to complete a common task or goal (McNeese, Demir, Cooke, & Myers, 2018).

In the last decade, a continuing large project, the Synthetic Teammate Project (Ball et al., 2010), has integrated an Adaptive Control of Thought - Rational (ACT-R, Anderson, 2007) based synthetic teammate into the RPAS task environment. The current version of the synthetic teammate is one of the largest high-fidelity cognitive models containing 2,000 procedural memories and more than 57,000 declarative memories, and it consists of several core components related to team interaction (among the team members and the task environment) and team situation awareness (TSA) (Endsley, 1995). The emphasis on team interaction within the synthetic teammates' core components aligns well with the theory of Interactive Team Cognition, which considers team interaction as team cognition (Cooke, Gorman, Myers, & Duran, 2013).

As part of team cognition, TSA is a critical factor that influences team performance, and is defined as getting the right information from the right person within the right amount of time, in order to overcome an unexpected event (Gorman, Cooke, Pederson, Connor, & DeJoode, 2005). TSA is developed and maintained through team interactions, allowing for the measurement of TSA based on team interaction (Cooke & Gorman, 2009). In the current study, a specific measure, Coordinated Awareness of Situation by Teams (CAST) is used (Cooke & Gorman, 2009; Gorman, Cooke, Pederson, Connor, & DeJoode, 2005). CAST evaluates the effectiveness and efficiency of team interaction under "roadblock" scenarios (Gorman, Cooke, & Winner, 2006). These roadblocks represent novel situations in the task and require effective team communication and coordination. Team members must assess the situation according to their own specialized role and/or resources and coordinate with other team members to overcome each separate roadblock. In this task, effective communication refers to team anticipation. That is, each team member needs to anticipate each other's needs by pushing information rather than pulling information during the task (Demir, McNeese, & Cooke, 2017).

In this study, we specifically focus on the effects of team interaction (*communication*, i.e., pushing and pulling information and *coordination*, i.e., CAST) on TSA during the roadblocks. In this paper, first, we review and describe the current experimental design of this specific study. Next, we highlight the methodology and analytical techniques used to determine the relationship between team interaction and TSA.

PROJECT OVERVIEW

Development of a synthetic team member and empirically testing it in the testbed are the two-main foci of the synthetic teammate project. The first focus is to build a synthetic teammate capable of human-like behavior (see Ball, et al. (2010) for details on the synthetic teammate). The current study is an empirical validation of the synthetic teammate's team interaction under degraded circumstances.

In this research, we integrated the synthetic agent to the Cognitive Engineering Research on Team Tasks Remotely Piloted Aircraft Systems - Synthetic Task Environment

(CERTT-RPAS-STE) which was designed to be both a flexible research platform and a realistic task environment with a view to researching team performance and interaction-based measures of team cognition (Cooke, Rivera, Shope, & Caukwell, 1999; Cooke & Shope, 2004). The CERTT-RPAS-STE platform is used to simulate teamwork in RPAS operations. This platform has several features, including text chat capability for communications between human teammates and the synthetic teammate; and eight hardware consoles: four consoles for up to four team members and four experimenters who oversee the simulation, inject roadblocks, and make observations (Cooke & Shope, 2004).

The CERTT platform provides a testbed wherein the objective is to take good photos of target waypoints. The task is performed by three heterogeneous teammates (see Figure 1): (1) the *navigator* who creates a dynamic flight plan and provides *information* about the waypoints, the RPA's airspeed, and altitude restrictions to the pilot; (2) the *pilot*, who controls the RPA's heading, altitude, and airspeed, and *negotiates* about them with the photographer in order to take a good photo; and (3) the *photographer*, who monitors sensor equipment in order to take photographs of target waypoints and sends *feedback* to the other team members about the quality of the photo. This specific coordination between the team members is called Information-Negotiation-Feedback. The communication within the three-agent RPA team occurred over a text-based communications system.

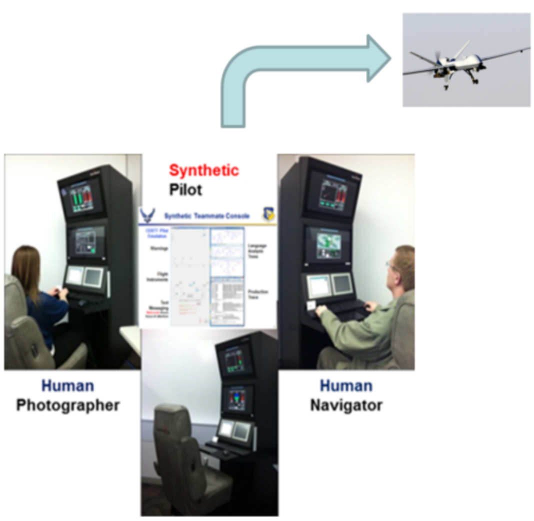

Figure 1. Participant consoles and synthetic teammate

This project aimed to understand how team behaviors and team performance differed between human-autonomy teams, all-human teams, and teams with a pilot experienced in RPAS operations: (1) the *synthetic* condition—the pilot role was given to the synthetic teammate, which was an ACT-R based cognitive model (which had a limited interaction ability, see Ball et al., 2010; Demir et al., 2015); (2) the *control* condition—the pilot was a randomly selected human participant, just like the other two participants; and (3) the *experimenter* condition—one of the experimenters served as an expert pilot. Experimenter condition utilized a Wizard of Oz (WoZ) paradigm in which a trained experimenter (located in a separate room) used a script to imitate a synthetic teammate and communicated with participants in limited communication behaviors but pushing and pulling information in a timely manner (robust coordination).

METHODOLOGY

Participants

Seventy graduate and undergraduate students served as participants in the study; all recruited from a large Southwestern university. English language fluency and normal (or corrected-to-normal) vision were required for participation. Participants were between 18 and 38 years of age (M_{age}=23.7, SD_{age}= 3.29) with 60 males and 10 females.

Two participants were recruited for each of the 20 teams in either the Experimenter or Synthetic conditions and three participants for each of the 10 teams in the Control condition. Each participant could be randomly assigned to the navigator or photographer roles in all three experimental conditions, but it was only possible to be randomly assigned the pilot position in the control condition.

Equipment and Materials

The current study included three participant consoles, one for each of the three roles: pilot (control condition only), photographer, and navigator. Additionally, experimenters used two other consoles: the "texting" and "non-texting" console. The "texting" experimenter console had two embedded computers and included a chat window for sending messages to the three team members, a master control window to control the power of all other consoles/computers and was also used for giving ratings on taskwork relatedness, behavior, and situational awareness. The "non-texting" experimenter console was used for rating coordination, taskwork relatedness, and was equipped with a camera for following the participants.

PowerPoint slides were developed to train participants along with custom software for data collection. Participants also received a "cheat sheet" and supplemental materials: role-tailored rule summaries, annotated display screenshots, a list of the waypoints signs (navigator only), and a list of camera settings/folder of good and bad photos (photographer only).

Task and Roles

The CERTT-RPAS-STE task needs three different and interdependent team members (each with a unique task position: pilot, navigator, and photographer) in order to achieve the goal of photographing critical waypoints. Before arriving at the session, participants in the control condition were randomly assigned to one of the three roles for the duration of the experiment (in the Synthetic and Experimenter conditions, participants could only be assigned to either the navigator or photographer roles). Within each of the five missions, teams were required to photograph 11 to 20 targets in less than 40 minutes. Teams were told to obtain as many "good" photos as possible while avoiding alarms and rule violations. Missions terminated either after 40 minutes had elapsed or when team members believed that the mission goals—taking a good photo for each target—had been completed.

Experimental Session

Before the task, each team conducts 60 minutes of role-related training (30-minute interactive PowerPoint slides and a 30-minute hands-on training mission). During the hands-on training mission, the experimenters use a checklist to ensure that the participants are comfortable with their roles and that the condition-based training manipulations are conducted. The first 40-minute mission following the training is used as a baseline and contains no roadblocks. The experiment was approximately eight hours in duration which consisted of five 40-minute missions. Between each mission, there was a 15-minute break. Throughout the experiment, the navigator and photographer were seated in a room and separated by partitions that prevented face-to-face contact. The pilot was alone in another room. These teams photographed targets during each of five 40-minute missions for the duration of the eight-hour experimental session (see Table 1).

Table 1. Experimental Session

Sessions		
1) Consent forms	**6)** Mission 2	**10)** NASA TLX/ Knowledge
2) PowerPoint Training	**7)** Mission 3	**11)** Demographic questions/ debriefing
3) Hands on Training	**8)** Mission 4	**12)** Post Checklist
4) Mission 1	**9)** Mission 5	
5) NASA TLX / Knowledge		

Measures

Team Situation Awareness (TSA). Proportion of overcoming the roadblock per mission was considered an outcome measure of team situation awareness. During each mission, teams were presented with "roadblocks" by the introduction of a new, *ad hoc* target waypoint (for example scenario see Table 2). In this case, when team enters a new zone (e.g., between PRK and ASH waypoints), the intel (i.e., experimenter) sends the following message (in Table 2) to the navigator regarding the embedded waypoints, e.g., KGM, M-STR, S-STR and FRT. The triggering mechanism for these roadblocks is based on each team's position relative to the waypoints in the mission; as such, the number of waypoints triggered in each mission may vary from team to team.

Table 2. Example Comments from Intelligence to Navigator and Pilot

When	From Intel TO:	Message	WP
RPA enters Restricted Operation Zone Coded PRK-ASH	Navigator	"DEMPC this is Intelligence. I have a critical update: There are two unplanned targets, waypoints M-STR and S-STR that also have to be photographed in this mission a*nd they are located just beyond* the current Restricted Operations Zone (ROZ) box exit. The corresponding ROZ entry and exit waypoints are KGM (the entry) and FRT (the exit)."	KGM (Entry), M-STR & S-STR (Targets), FRT (Exit)
enters Restricted Operation Zone	Navigator	"A new PRIORITY target is in the ROZ area you have just entered. That is all the information we have."	WP8
	Pilot	"Enemy forces have just left target WP8. You are clear to enter area and photo."	

Coordinated Awareness of Situation (CAST). Each roadblock target was measured via the sequence of team interaction across the team members, called Coordinated Awareness of Situation by Teams (CAST, Gorman et al., 2005), and the texting experimenter coded team interaction through the situation awareness logger which is depicted in the following figure.

Accordingly, perception of the roadblock is measured by considering who responded independently to the unusual circumstance, and then, coordinated perception was measured by considering which team members tell other team members of their experience. Each of these levels of TSA were coded one (as response) or zero (as non-response) by clicking any of the boxes in Figure 2. Because there were three team members in this study, the optimal response will be, at maximum, a six-element vector for shared perspectives. However, ideal coordinated perception takes place between the minimum numbers of persons needed to resolve the roadblock.

Coding as one or zero corresponds to hits and false alarms from signal detection theory. In this study, perception and coordination are considered with the focus on whether the team overcame the roadblock or not. In the current study, we considered number of hits (i.e., coordinated perception) as a CAST measure.

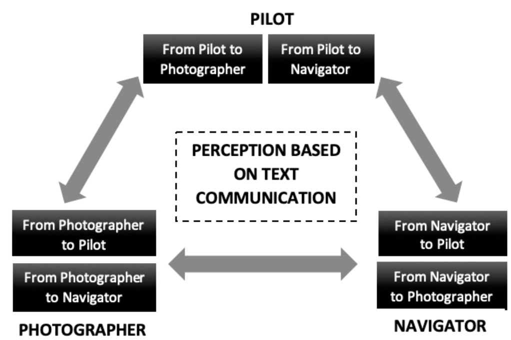

Figure 2. Team Communication Channels

Team Communication. Team communication was measured by classifying four team verbal behaviors into two groups: pushing or pulling information (see the following table). In this study, we only considered the behaviors that happened during the roadblocks.

Table 3. Example of Team Verbal Behaviors with Their Classification (Demir, McNeese, & Cooke, 2017)

Behavior	Push /Pull	Description of the behavior
General Status Updates	*Push*	Informing other team members about current status, *e.g., airspeed for the current target is 300*.
Suggestions	*Push*	Making suggestions to the other team members, *e.g., increase the altitude above 2000 for the current target*.
Planning Ahead	*Push*	Anticipating next steps and creating rules for future encounters, *e.g., the next target is F-AREA: the altitude 2000, the airspeed 200, the radius is 5*.

Repeated Requests	*Pull*	Requesting the same information or action from other team member(s) *e.g. what is the next waypoint?*
Inquiry about status of others	*Pull*	Inquiring about current status of others, and expressing concerns, *e.g., do we have a good photo for the current target?*

RESULTS

MANOVA Results

To analyze the number of pushing and pulling information, number of hits (CAST), and number completed roadblocks, we performed a 3 (condition) x 5 (mission) x 4 (factor: hits, pushing and pulling information, and number of completed situation awareness roadblocks) repeated measures Multivariate Analysis of Variance (MANOVA). Mauchly's test indicates that the assumption of sphericity for the factor ($\chi^2(5) = .024$, $p < .001$, $\varepsilon = .48$), repeated measure (mission: $\chi^2(9) = .41$, $p < .05$, $\varepsilon = .71$), and factor by mission ($\chi^2(77) = .001$, $p < .001$, $\varepsilon = .41$) were viloated. Therefore, degrees of freedom were corrected using the Greenhouse-Geisser correction and reported in Table 4 which presents the results of the MANOVA.

Table 4. MANOVA Results for Each Factor: CAST, Pushing and Pulling Information, and Completed Roadblocks

Source	*df*	*F*	*p*	η^2
Mission	2.82	3.78	0.02	0.12
Mission by Condition	8	1.98	0.06	0.13
Factor	1.43	119.8	0.00	0.82
Factor by Condition	6	7.13	0.00	0.35
Factor by Mission	4.94	1.87	0.10	0.07
Factor by Mission by Condition	24	4.96	0.60	0.62

According to the significant intereaction effect, factor by condition ($F(6, 81)= 7.13$, $p < .001$, $\eta^2= .35$), the team members in the synthetic condition anticipated less each other needs than the experimenter teams ($p < .001$), but this amount of this anticipation was equal to the control teams ($p= .20$). On the other hand, the team members in the synthetic condition significantly pulled less information from each other during the roadblocks than the control teams ($p < .001$), but close to the experimenter teams ($p= .06$; see Figure 3). Also, the experimenter teams did equal amount of pulling information to the control teams ($p = .47$).

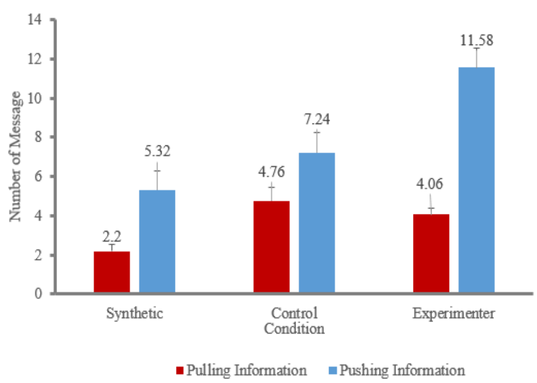

Figure 3. Pulling and Pushing Information across the Conditions.

Synthetic teams also demonstrated significantly lower levels of coordinated perception (i.e., CAST) than the experimenter teams ($p < .001$), but equal with the control teams ($p= .19$, see Table 4 and Figure 2). Similarly, the synthetic teams completed significantly less roadblocks than the experimenter teams ($p < .001$), close to the control teams ($p= .11$; see Figure 4).

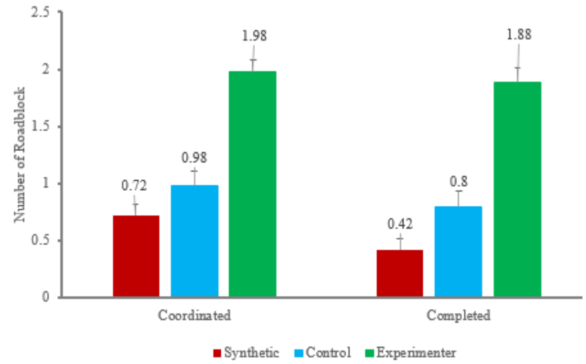

Figure 4. Coordinated and Completed Roadblocks across the Conditions.

Predicting Team Situation Awareness via CAST and Team Verbal Behaviors

In order to predict the roadblock achievement via team coordination and team anticipation, first Growth Curve Modelling was applied (because of five missions) (Mirman, 2014). However, because there was no significant time effect, we continued with multiple regression analysis. The results of the regression indicated that the three predictors explained 64.7% of the variance (R^2=.65, $F(3,146)= 89.1$, $p < .001$). It was found that coordinated perception and team anticipation (i.e., pushing information) were positively and significantly associated with roadblock achievement. That is every one-standard deviation increase in coordinated perception (holding constant other variables) is related to a .74 standard deviation increase in roadblock achievement. Similarly, one-standard deviation increment in team anticipation (holding constant other variables) is related to a .16 standard deviation increase in roadblock achievement (see Table 5). These significant findings indicate that well0-coordinated teams with anticipation of each other needs achieved more roadblocks. However, pulling information was not significantly associated with roadblock completion. This overall team verbal behavior results also confirm the previous study which investigates the relationship between mission level pushing and pulling information with team situation awareness and team performance (Demir et al., 2017).

Table 5. Summary of Regression Analysis for CAST and Team Anticipation Predicting Team Situation Awareness

	B	*SE B*	*β*	*t*	*p*
Intercept	0.25	0.01	0.00	22.71	0.000
Coordination	0.18	0.02	0.74	11.83	0.000
Pushing Inform.	0.01	0.16	0.16	2.00	0.047
Pulling Inform.	-0.01	-0.10	-0.10	-1.53	0.129

DISCUSSION & CONCLUSION

Effective team communication and coordination are crucial for roadblock achievement (TSA). In this team task, effective teamwork involves anticipating the needs of teammates, which in turn means pushing information before it is requested. However, in additon to anticipation, effective coordination is also needed during roadblocks. In this study, we examined how pushing and pulling information and coordinated perception were associated with TSA in both synthetic and human-human teams. Pushing information was positively associated with TSA, and synthetic teams had lower levels of both pushing and pulling information than the all-human teams. In addition, synthetic teams demonstrated significantly lower levels of coordinated perception than human-human teams. These results indicate that synythetic teams' lack of anticipation and coordination resulted in poorer TSA performance. When synthetic teams are contrasted to experimenter teams, one sees a meaningful difference in all results with experimenter teams performing better. These results also align with recent work that identified that experimenter teams performed better on many teamwork measures (McNeese, Demir, Cooke, Myers, 2017).

The question becomes why? Why are experimenter teams more effective at pushing information and completing roadblocks than synthetic teams? The answer to this may point to a difference in the ability to coordinate information at a team level. In the experimenter condition, the pilot was a trained confederate with specializations in teamwork and team interaction. In particular, the confederate pilot focused on properly coordinating information across the team in a timely manner which facilitates TSA. As noted before, coordination is critical to effective team interaction and TSA, and thus team performance. Quality coordination is knowing when to communicate information. A team member could constantly push or pull information but that information only becomes meaningful if it is pushed or pulled at the correct time.

In addition, effective team coordination has the potential to allow for anticipation of information. If a coordindation structure (that is adept at adapting) is in place then team members have the availability to learn the pattern of coordination, which then may lead to anticipation or prediction. This, in turn, may also lead to more effective team interaction and better TSA.

A goal moving forward should be to better develop and design affordances that allow for the synthetic teammate to better coordinate pushing and pulling of information and thus benefit from improved TSA. If the synthetic teammate becomes more adept at this back and forth, coordination then improves, which may result in TSA and team performance improving. One (of many) potential solution to advancing the synthetic teammate could be further investigating the utilzation of embedding artifical intelligence algorithms (using big data) into the synthetic teammate that allow for learning and improvement based on more interactions. For instance, as the synthetic teammate continues to interact, it develops intelligence on which interactions are good and which are bad. This information then helps the synthetic teammate to develop its coordination and communication methodologies.

Finally, future studies might examine the relationships highlighted in this study via nonlinear measures in terms of team stability and flexibility based on their communication and coordination patterns during the roadblocks. HAT is here to stay but improvements to human-machine interactions must continue if we are to improve team effectiveness.

ACKNOWLEDGEMENT

This research was partially supported by ONR Award N000141110844 (Program Managers: Marc Steinberg, Paul Bello) and ONR Award N000141712382 (Program Managers: Marc Steinberg, Micah Clark). We also acknowledge the assistance of Steven M. Shope, Sandia Research Corporation who integrated the synthetic agent and the testbed.

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Reference and Citation Information:

Demir, M., McNeese, J., She, M. & Cooke, N. (2019, October). Team Coordination of Team Situation Awareness in Human Autonomy Teaming. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting (in press). Los Angeles, CA: SAGE Publications.