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Interaction with an Autonomous Team Member Determines the Relationship between Team Trust and Team Performance

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***Abstract*—This study examines the effects of individual team members' trust on Human-Autonomy Team (HAT) and all-human team performance in a Remotely Piloted Aircraft System-Synthetic Task Environment (RPAS-STE). Twenty-one three-member teams consisting of two participants – in the roles of navigator and photographer – teaming with either an autonomous agent or a trained human experimenter – a pilot – flew an RPA with the goal of photographing targets. We regressed a measure of team performance, Target Processing Efficiency (TPE), on each team member's trust in their team. We found that both team members' (navigator and photographer) trust in the team predicted TPE, where increases in trust in team predicted increases in team performance. Importantly, we found that the relationship between trust in team and TPE was dependent on the role of the human operator, and team composition, where team composition mediated the relationship for the photographer and moderated the relationship for the navigator. We suggest that heterogeneous interactions with the agent may explain these role-specific differences, which is in line with interactive team cognition's (ITC) proposition that interaction is a dominant factor in team performance. In sum, roles that have more interaction with an autonomous agent will have their team performance affected more so by the presence of an agent than their trust in the team. To alleviate these differing effects, agents should have communication and coordination capabilities comparable to human teammates. Alternatively, forms of interaction that do not depend on natural language could be pursued.**

***Keywords*—Human-Autonomy Teaming, Human-Agent Interaction, Trust, Team Performance, Team Cognition**

I. Introduction

As artificially intelligent agents advance, trust in autonomous agents and Human-Autonomy Teams (HATs) becomes an ever-pressing issue [1]. Trust between humans is the "willingness of a party to be vulnerable to the action of another party based on the expectation that the other will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other party" [2, p. 712]. In Lee and See's [3] view, human-autonomy trust, on the other hand, is the competency (i.e., performance) of the agent and its perceived intentions upon which humans base their trust. When working in a HAT, both definitions of trust are necessary to understand how much an individual trusts their HAT overall.

According to Huang et al.'s [4] Distributed Dynamic Team Trust (D2T2) framework, the trust humans place in autonomous agents is distributed among all related stakeholders. That is, each team member's attitude toward the autonomous agent can shape overall team trust. Further, team trust is transitive and changes through direct interaction with autonomous agents or indirectly through other team member's influence. In this distributed network some people may have more impact on others' attitudes depending on the individual's role and responsibilities. This dynamic view of trust is important because each stakeholder's trust in the team impacts their task performance [4].

According to the theory of interactive team cognition (ITC), team cognition is localized 'between the heads' of team members, meaning it is observable from team interaction. In this way, team cognition is an indicator of team performance and effectiveness [5], [6]. In the present study, we measure team performance by assessing how efficiently teams capture reconnaissance photos in a simulated task environment. This measure has been used in prior research. For example, McNeese et al. [7] found that HATs had poorer target processing efficiency (TPE) than all-human teams, thus we purport it will remain an important dependent measure. Furthermore, a similar study by McNeese et al. [8], found that lower-performing HATs had lower levels of trust in their autonomous agent teammate. However, it was unclear whether lower levels of trust in the autonomous agent led to lower-performing HATs or if the direction of this relationship was reversed [8]. The present study investigates this gap in their findings. Specifically, we examine the effects of individual team members' trust in their team on HATs' versus all-human teams' team performance in a Remotely Piloted Aircraft System-Synthetic Task Environment

(RPAS-STE). We hypothesized that the degree to which individual teammate trust in their team would predict TPE would depend on all-human vs. HAT team composition.

II. Method

A. Participants

Twenty-one three-member teams ($N = 42$) were recruited from Georgia Tech and the surrounding area. Teams consisted of two participants and either an autonomous agent or a trained human experimenter. Participants' ages ranged from 18 to 31 years ($M = 20.55$, $SD = 2.97$) across 21 males, 20 females, and one non-binary person. Participants were required to be fluent in English and have normal or corrected-to-normal vision. Each participant was paid $10/hour or received course credit.

B. Materials

The experiment took place in the Cognitive Engineering Research on Team Tasks-Remotely Piloted Aircraft System-Synthetic Task Environment (CERTT-RPAS-STE) [9]. The system is pictured in Fig. 1 from [8]. The objective was for teams to take photographs of ground targets while avoiding hazards over a series of 40-minute missions. This task was undertaken by three teammates, each using one of three task-role stations.

The three task roles are: (1) photographer – monitors and adjusts camera settings to take target photos and sends feedback to teammates; (2) navigator – creates the dynamic flight plan and sends out information such as waypoint names, airspeed restrictions, altitude restrictions, and effective waypoint radii; (3) pilot – controls and monitors the airspeed and altitude of the Remotely Piloted Aircraft (RPA), vehicle heading, fuel, gears, and flaps, and negotiates with the photographer to adjust airspeed and altitude to take a clear picture of each target.

The photographer and navigator roles were always occupied by participants. The pilot role was assumed by either an autonomous agent ("synthetic teammate") or a human experimenter [10]. The synthetic teammate was developed using the ACT-R cognitive modeling architecture to simulate human cognition [7]. Based on the dynamic task situation the synthetic teammate can decide its own course of action, but it was not developed with explicit teamwork skills [7]. However, the synthetic teammate is responsible for all aspects of the pilot role and is a critical part of the team that cannot be set aside if the team expects to perform well [7]. The participants were cognizant of when they were working with the human experimenter or the synthetic teammate. All team members used a text-chat interface to communicate with each other.

C. Procedures

Before arriving, each team was randomly assigned to an experimental condition (i.e., HAT or all-human team) and each participant was randomly assigned to a task role (i.e., photographer or navigator). After providing informed consent, participants completed an interactive 30-minute PowerPoint training module focused on their distinct task role, followed by the first trust questionnaire session. Participants then engaged in a 30-minute hands-on training mission. During the training mission, experimenters coached the participants using a script to ensure that each participant understood their role, the task, and the text-chat interface. Teams then began Missions 1 and 2. After Mission 3, the second trust questionnaire session began. During Mission 4 the pilot role was always assumed by a human experimenter as the experiment was intended to assess if human-autonomy task acquisition transfers to all-human teams. However, performance during Mission 4 is not examined in the current study as we sought to examine only HAT vs. all-human trust performance differences. The final questionnaire session was completed after Mission 4. After the six-hour experiment, participants were debriefed and compensated.

D. Measures

1) Target Processing Efficiency (TPE): TPE is a measure of team performance that measures how efficiently the team processes each ground target. It is an outcome-based measure that is scored out of 1,000 and automatically recorded by the CERTT-RPAS-STE. Teams begin with 1,000 points. Points are then deducted based on how long (in seconds) the RPA was in the effective radius of a target and if a bad photo was taken. For the purposes of this study, only TPE scores for targets during Mission 3 were used. These scores were averaged over Mission 3 targets to create an overall TPE score for each team.

2) Trust in Team: Trust in team was measured for both the navigator and photographer roles at each questionnaire session. For the purposes of this study, only the answers from the second questionnaire session were analyzed. The measure is a summed score of trust in team based on two trust questionnaires for each role. The first was a modified trust questionnaire originally developed by Mayer and Gavin [11] and the second was the Checklist for Trust between People and Automation Scale [12]. The Mayer and Gavin [11] questionnaire was modified by Demir et al. [13] to match the HAT context and adopted here. It consisted of 25 items regarding trust towards either human or autonomous teammates with a Likert scale ranging from "1" = Strongly Agree to "5" = Strongly Disagree. The Checklist for Trust between People and Automation Scale had 12 items with a Likert scale ranging from "1" = Not at all to "7" = Extremely. To keep the two questionnaires' Likert scales in the same direction, the modified questionnaire by Mayer and Gavin [11] was reverse scored. There were missing data for two items, 1 out of 777 items for both the navigator and photographer. To correct for the missing data, all missing items were mean replaced with the role-specific average score for the given item.

III. Results

We ran a multiple linear regression where each participant roles' trust in team were predictors for TPE. We found that, regardless of team type, both participant roles' (navigator and photographer) trust in team predicted TPE, $R^2 = 0.79$, $F(2, 18) = 34.52$, $p < .001$. This indicates that an individual team member's trust is related to team performance where the navigator's trust in team, $\beta = 0.60$, $t(18) = 4.57$, $p < .001$, indicates that, on average, each unit increase of trust in team is associated with a .60 *SD* increase in TPE. While the photographer's trust in team, $\beta = 0.39$, $t(18) = 2.93$, $p < .01$, indicates that, on average, each unit increase of trust in team is associated with a .39 *SD* increase in TPE. However, when controlling for team type (HAT vs. all-human team), while still including individual team member trust, only the navigator's trust in team and team type were significant predictors, $R^2 = 0.89$, $F(3, 17) = 43.61$, $p < .001$; $\beta = 0.36$, $t(17) = 2.96$, $p < .01$; $\beta = -0.51$, $t(17) = -3.68$, $p < .01$, whereas the photographer's trust in the team became non-significant, $\beta = 0.18$, $t(17) = 1.54$, $p = .143$. To note, the reference group for team type was set to HATs. Therefore, team type was a possible third variable that accounts for the relationship between individual-level trust in team and TPE.

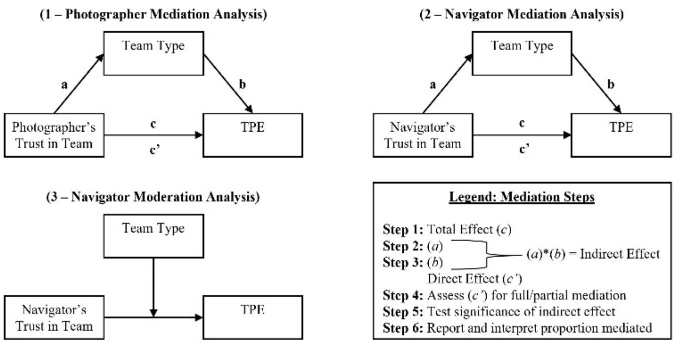

Fig. 1. Path diagrams for the mediation and moderation analyses.

To examine this exploratory hypothesis, we followed Baron and Kenny's [14] method for testing third variable models. First, we sought to determine if team type acted as a mediator for the relationship between photographer's trust in team and TPE (see diagram (1) in Fig. 1). The first step is to estimate and test the total effect, path (*c*). A linear regression was significant wherein photographer's trust in team was a predictor of TPE, $R^2 = 0.55$, $F(1, 19) = 23.57$, $p < .001$; $b = 6.00$, $\beta = 0.74$, $t(19) = 4.86$, $p < .001$. The total effect (*c*) was therefore significant and equal to 6.00. The second step is to estimate and test path (*a*). A logistic regression wherein photographer's trust in team predicts team type was analyzed. The full model was a significantly better fit than the null, $\chi^2(1, N = 21) = 12.76$, $p < .05$. To derive path (*a*), a goodness-of-fit test using the Cox and Snell [15] R^2, was used because it is a close analog to the linear regression R^2. This value was $R^2_{(CS)} = 0.46$, indicating that adding the photographer's trust in team significantly accounted for the increase in proportion of information accounted for in the model; $-2LL_{(Null)} = 29.07$; $-2LL_{(Full\ Model)} = 16.30$. Based on this model, the main effect of photographer's trust in team and the estimate for path (*a*) is $b = -0.07$, $z(1) = -2.38$, $p < .05$; path $(a) = -0.07$. The purpose of step 3 is to estimate and test path (*b*) and derive the direct effect path (*c'*). A multiple linear regression wherein photographer's trust in team and team type were predictors of TPE was analyzed and was significant, $R^2 = 0.83$, $F(2, 18) = 42.68$, $p < .001$. Team type was a significant predictor of TPE, $b = -421.45$, $\beta = -0.73$, $t(18) = -5.30$, $p < .001$ and the relationship between photographer's trust in team and TPE was not significant, $b = 1.89$, $\beta = 0.23$, $t(18) = 1.70$, $p = .11$; $(b) = -421.45$; $(c') = 1.89$.

In step 4, the direct effect (*c'*) was not significant, indicating a full mediation based on [14]. The indirect effect, $(a)*(b) = 27.60$, was significant according to the Baron and Kenny [14] modified Sobel test, $z = 2.17$, $p < .05$ [16]. Based on [17] we calculated the proportion of mediation and found that the proportion of the effect that photographer's trust in team through team type has on TPE is .94, or 93.60%. According to Kenny in [18], if the proportion mediated is at least .80, complete mediation can be claimed. Therefore, we claim that team type acts as a full mediator for the relationship between photographer's trust in team and TPE. In sum, we found that accounting for team type eliminated the relationship between photographer's trust in team and TPE. Since our reference group was HATs, the full mediation suggests that the photographer's role was impacted more by the presence of the autonomous pilot than the level of trust they had in their team.

We then examined if team type acted as a mediator for the relationship between navigator's trust in team and TPE (see diagram (2) in Fig. 1). In accordance with step 1, a linear regression wherein navigator's trust in team was a predictor of TPE was analyzed and was significant, $R^2 = 0.69$, $F(1, 19) = 43.18$, $p < .001$; $b = 8.39$, $\beta = 0.83$, $t(19) = 6.51$, $p < .001$; $(c) = 8.39$. For step 2, a logistic regression wherein navigator's trust in team predicts team type was a significantly better fit than the null model, $\chi^2(1, N = 21) = 14.97$, $p < .05$. The goodness-of-fit test using the Cox and Snell R^2 [15], $R^2_{(CS)} = 0.51$, indicated that adding the navigator's trust in team predictor significantly accounted for the increase in proportion of information accounted for in the model; $-2LL_{(Null)} = 29.07$; $-2LL_{(Full\ Model)} = 14.10$. Thus, the main effect of navigator's trust in team and the estimate for path (*a*) was, $b = -0.10$, $z(1) = -2.36$, $p < .05$; $(a) = -0.10$. In step 3, a multiple linear regression wherein navigator's trust in team and team type were predictors of TPE, was significant, $R^2 = 0.87$, $F(2, 18) = 59.74$, $p < .001$. Team type was a significant predictor of TPE, $b = -352.22$, $\beta = -0.61$, $t(18) = -4.90$, $p < .001$ as well as navigator's trust in team, $b = 3.92$, $\beta = 0.39$, $t(18) = 3.13$, $p < .01$; $(b) = -352.22$; $(c') = 3.92$. Although, the direct effect, $(c') = 3.92$, was smaller than the total effect, $(c) = 8.39$, the direct effect was still significant, indicating that team type partially mediates the relationship between navigator's trust in team and TPE. Thus, we then explored team type as a moderator since [14] requires a non-significant direct effect for full mediations.

Following the methods outlined in [19] and depicted in diagram (3) in Fig. 1., we first used the previous regression wherein navigator's trust in team significantly predicted TPE. For the second step, we conducted a hierarchical regression. The predictor model, a multiple regression with the centered variable navigator's trust in team and team type as predictors of TPE, was significant, $R^2 = 0.87$, $F(2, 18) = 59.74$, $p < .001$. The moderator model, which added an interaction term, was also significant, $R^2 = 0.92$, $F(3, 17) = 62.49$, $p < .001$, and explained significantly more variance than the predictor model, $\Delta R^2 = 0.05$, $F(1, 17) = 9.77$, $p = .006$. This indicates that team type moderates the relationship between navigator's trust in team and TPE.

The coefficient of navigator's trust in team (centered) was not significantly different from zero; $b = -0.08$, $t(17) = -0.05$, $p = .960$, whereas the coefficients of team type and the interaction term were significantly different from zero; $b = -388.73$, $t(17) = -6.47$, $p < .001$; $b = 6.58$, $t(17) = 3.13$, $p = .006$. For navigators in all-human teams, the slope of the navigator's trust in team to TPE was -0.08 with a y-intercept of 954.34; $b = -0.08$, $t(17) = -0.05$, $p = .960$. Alternatively, for navigators in HATs, the slope of the navigator's trust in team to TPE was 6.49, and the y-intercept was 565.62; $b = 6.49$, $t(17) = 4.93$, $p < .001$. In sum, for HATs, higher levels of navigator trust in team were associated with higher TPE, but in all-human teams, the relationship between trust in team and TPE was negligible.

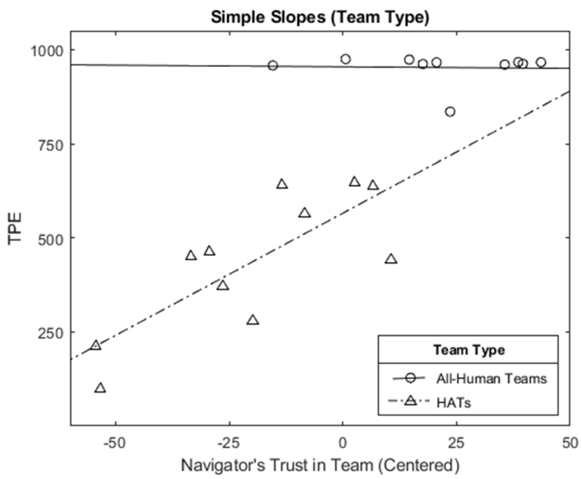

Fig. 2. Simple slopes analysis of the relationship between navigator's trust in team and TPE across team type.

IV. Discussion

This study provides insight into how team composition can impact the relationship between team members' trust in their teams and team performance. In support of our hypothesis, we found that both the navigator and photographer's trust in their team predicted TPE, wherein higher levels of trust were associated with increased team performance. Importantly, we found that the relationship between trust in team and TPE was dependent on the role the human operator played, and team composition, where individuals on HATs and all-human teams had different relationships between these two variables.

The observed differences between trust, TPE, and team composition reflect the different responsibilities of each role. The navigator and photographer engage in different forms of interaction with the pilot: the navigator sends target information to the pilot, while the photographer negotiates with the pilot. These heterogeneous interactions with the pilot likely explain the role-specific differences in the relationship between trust in team and TPE across team types. The autonomous pilot's limited communication and planning abilities compared to the expert human pilot also determined how trust and performance interacted in the present study, in addition to team role [20]. Given these limited abilities, our findings suggest that roles that have more interaction with an autonomous agent will have their team performance affected more so by the presence of an agent than their trust in the team. The finding is consistent with ITC's proposition that team cognition as interaction is a dominant factor in team performance. Even in the absence of an autonomous agent, however, trust remains a central variable to team performance. To alleviate these differing effects by role and team type we suggest that autonomous agents have communication and coordination capabilities comparable to human teammates. Alternatively, forms of interaction that do not depend on natural language could be pursued.

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