Team and Individual Trust Progression for Human-Autonomy Teaming in Next Generation Combat Vehicles

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This study investigated in 22 teams, individual and team trust measures reported by two human participants, recruited from a university populace, as they interacted with each other, robotic combat vehicles (RCVs), a human superior, and their team during a simulated Next Generation Combat Vehicle (NGCV) mission conducted within Minecraft. Trust was measured via survey questions based on established metrics and was found to be high toward the human peer, the human superior, and the overall team throughout the mission. In contrast, overall trust in the RCV was significantly lower in phases of the mission when breakdown in RCV functionality caused a hindrance in mission completion. Trust in the RCV was shown to recover as the mission progressed in phases without RCV maintenance issues. The findings reinforce that trust is distinguishable at the individual level and not necessarily perceived the same at the team level.

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INTRODUCTION

Classical human-automation interaction structures are characterized by machines functioning as tools under human supervision (Parasuraman, Sheridan, & Wickens, 2000). This paradigm is shifting as recent advances in artificial intelligence (AI) have drastically increased the capability of machines for dynamic, autonomous interaction with humans (Endsley, 2017). Current literature defines *human-autonomy teams* (HATs) as comprising human and autonomous machine (i.e., autonomy) members with distinct domains of expertise directed toward common goals (O'Neill, McNeese, Barron, & Schelble, 2020).

In terms of teaming, HATs are more akin to all-human teams because of the degree of distinction and interdependence of roles of individual members (McNeese, Demir, Chiou, Cooke, & Yanikian, 2019). However, the extent to which HATs and human teams are alike is limited. For instance, human teams are characterized by robust socializations (Ahuja & Galvin, 2003) that have not yet been emulated by AI, such that artificial social intelligence for HATs is still considered to be in its infancy (Newton & Fiore, 2020). In spite of the discrepancy between human and autonomy capabilities for social aspects of teaming, the effectiveness of HATs has been described in terms of social constructs like trust (Demir et al., 2021; McNeese et al., 2019). The Next Generation Combat Vehicle (NGCV) is an effort in the Department of Defense that will rely on HAT concepts for mission success (C. Lee, 2017). Within this context, the aim of this study was to investigate trust between members of a HAT using individual and team level subjective measures from previously validated surveys for team trust.

Trust in Human and Autonomy Teammates

Trust is an essential ingredient for team success among human teammates (Costa, Roe, & Taillieu, 2001) and also for tool-like and teammate-like interactions with automation (Chiou & Lee, 2021; J. D. Lee & See, 2004). For human teams, trust has been defined as a multi-component construct, dominated by perceptions of trustworthiness in each teammate and their cooperative behaviors in situations with a considerable degree of risk (Costa et al., 2001). Individual differences in the propensity to trust in other humans and its behavioral manifestations have also been identified as dimensions of interpersonal trust (Mayer, Davis, & Schoorman, 1995). Similarly, J. D. Lee & See (2004) described human trust in less autonomous machines (i.e., automation) as a disposition toward how such agents will aid in accomplishing individual goals that involve some risk.

The relative autonomy of agents in HATs, combined with the complex contexts in which they are typically present, makes human intervention difficult for many of the decisions made by autonomy. Thus, trusting in autonomy is more akin to trusting other human teammates than trusting simple machines (Chiou & Lee, 2021). Although human-human and human-autonomy trust are alike in this regard, how they develop because of long-term interactions has been theorized to proceed in opposite directions. Rempel, Holmes, and Zanna (1985) suggested that trust in human teammates is initially based on circumstantial observations of cooperative behaviors, and upon familiarization, trust becomes more dependent on long-term experiences with each other. In contrast, long-term trust in automated agents begins as more faith-based, then becomes tempered by short-term performance (Muir & Moray, 1996).

Trust in teammates also varies in immediate contexts. Interestingly, Lewandowsky, Mundy, and Tan (2000) showed that short-term fluctuations in trust toward both humans and automation are similar. In simulated process control experiments, they found that the same types of failures produced qualitatively identical patterns of changes in trust levels for both, albeit trust losses toward human counterparts were less pronounced than for automation. De Visser et al. (2017, 2016) also conducted a series of studies which found similar patterns in trust degradation over time for virtual agents with varying levels of anthropomorphism. In this case, decrements in trust were least for agents with the most humanlike appearances. Finally, it has also been reported that for HATs in simulated remotely piloted aircraft systems, quick resolutions of initial trust issues toward human and autonomy teammates were correlated with good team performance in completing a reconnaissance mission (McNeese et al., 2019).

Team Trust in HATs

Interactive team cognition (ITC) theory states that successful team performance depends upon team-level cognitive processes manifesting in interactions between team members that are distinct from simple aggregates of individual mental models (Cooke, Gorman, Myers, & Duran, 2013). As such, it has been pointed out that it is not enough to simply assess trust measures in HATs on an individual scale, but also toward teams as a collective unit (Huang et al., 2020). An abundance of research has been conducted on trust toward individual humans and automation in team contexts. However, empirical studies on trust toward the entire team as a unit is limited for HATs.

Huang et al. (2020) proposed a theoretical framework for team trust among HAT members by defining it as a dynamic attribute distributed among human stakeholders. Also hinging their framework on ITC theory, they argued that established methods of measuring trust (i.e., surveys and behavioral markers) may not be as useful for measuring global measures of team trust as they are for individual trust in teammates. They proposed the use of interaction-based social networks to model team trust while acknowledging that experimental data is needed to validate this approach. Nevertheless, this current study aims to provide empirical evidence of whether validated surveys for global and individual trust measures in all-human teams (e.g., Jarvenpaa & Leidner, 1999) can reveal nuances in trust in HATs at both the individual and team levels.

CURRENT STUDY

The current study investigated short-term trust progression at both the individual and team level of a HAT within an NGCV-like environment, using subject survey responses. The following hypotheses are proposed:

Hypothesis 1. It is hypothesized that a varied perception of individual teammates in an NGCV-like environment may result in different levels of trust for each of those individual components. Thus, it is predicted that trust in the automated RCV will be lower in phases when maintenance issues occur which cause the human to adjust action for mission completion.

Hypothesis 2. Based upon the findings of McNeese et al. (2019) that consider team level trust and how, per the ITC theory, the measurement for team success must be at a team level, it is hypothesized that a degradation in the trust of one entity will not necessarily impact overall team trust as long as the mission is successful. It is predicted that though trust in the RCV may degrade at the individual level, the overall team trust will not necessarily degrade in the survey data.

METHODS

A 2x6x4 mixed factorial design was employed with role (Blue 1, Blue 2) as a between-subjects variable and phase (Mission Phases 1 through 6) and entity (RCV, peer, Blue 6, and team) as within-subjects variables. The role variable pertained to participant roles charged with the direct control of an RCV (i.e., Blue 1 and Blue 2). The phases variable had six planned phases occurring over the two missions that participants needed to complete for the study. Each of the six phases followed a strict script with specific maintenance issues that occurred for the RCVs at standardized points. Example maintenance issues faced by the teams included an immobilized RCV during Phase 3 and degraded vision for one RCV in Phase 6. The entity variable compared the reported trust that Blue 1 or Blue 2 had in their other teammates or the team itself. The four levels included: the RCV the operator is controlling (RCV), the counterpart peer operator controlling the other RCV (Peer), the coordinator tracking the mission execution for the team (Blue 6), and the overall team (Team).

Participants

A total of 66 participants were recruited from a large southwestern university and the surrounding community and were grouped into 22 three-person teams. Participants were randomly assigned to one of three roles (Blue 1, Blue 2, or Blue 6). For this study, the design of experiment and analysis focused solely on data collected from Blue 1 ($n = 22$) and Blue 2 ($n = 22$). There were 30 males, 12 females, and two who chose not to report birth gender. The average age was 21.8 with a standard deviation of 3.4 and an age range of 18 to 34. All participants were adults, spoke fluent English, had normal (or corrected to normal) vision and hearing, and had computer gaming experience. In addition, participants had to have a reliable internet connection, a standalone computer, a computer mouse, and a headset or microphone and speakers to complete the study. Only two participants reported prior military experience. Participants were compensated with Amazon gift cards at a rate of $15 per hour.

Materials

Experimental scenario. The study was run through a remote, split, synchronous protocol and all participants and experimenters were in different locations. The primary testbed was a Minecraft-based scenario in which participants controlled an RCV to perform an NGCV-like mission. Specific tasks included reconnaissance to identify targets and friendlies within a set boundary of terrain. The team performing the task included two RCVs with each being controlled by a human operator designated Blue 1 or Blue 2. The two humans worked with a coordinator, called Blue 6, to complete all mission tasks and report required updates to a mission commander who was considered external to the team.

Equipment. The software used to implement the experiment included Minecraft, Parsec, Open Broadcaster Software (OBS), Zoom, PowerPoint slides shared through a Google Drive, and Qualtrics. The missions were designed to be carried out in a Minecraft world created with Minecraft Java Edition (2020) and Minecraft Forge (2020). Participants controlled the RCV through a Parsec connection that was recorded via OBS screen share (Dickson, 2016). Coordination of the mission tasks was completed via audio communication recorded in Zoom. In addition, screen sharing was employed on Zoom for the coordinator to see the mission map and track what the RCV operators reported. Qualtrics was used to administer the informed consent documentation and collect survey and demographic information from participants.

Team construct. Participants assigned to the roles of Blue 1 and Blue 2 connected to Zoom and Parsec to supervise the RCVs in Minecraft. Those assigned to Blue 6 only connected to Zoom. Three experimenters administered the experiment with one hosting the Minecraft server on his or her computer. A Wizard of Oz construct was used with two experimenters acting as confederates in the study by shadowing the RCV controls to perform its autonomous functions (Riek, 2012). These included notifying the RCV operator when a potential infantry was in the field of view or performing an auto zoom function to locate and view potential infantry. The third experimenter served as the mission commander.

Surveys. Self-reported trust was captured through survey questions presented to the participants after each of the six phases completed in the experiment. The trust questions were modeled on a question from Jarvenpaa and Leidner's (1999) research, which the authors validated to have a reliability of α = 0.90. From a trust dimension perspective, the emphasis was on an individual's perceived reliance upon the four different entities: RCV, peer, Blue 6, and team. Table 1 shows the four questions presented to participants after each phase. These questions were administered on a seven-point Likert scale ranging from strongly agree to strongly disagree. The Cronbach's α of 0.928 indicates that these questions have excellent internal consistency. Additional surveys administered during the study included the situation awareness global assessment technique (Endsley, 1988) and a team workload questionnaire (Sellers, Helton, Näswall, Funke, & Knott, 2014). These additional surveys were not analyzed here as they are beyond the scope of this research. The demographic information included participant age, birth gender, educational attainment, military experience, and computer gaming experience.

Table 1. Trust questions administered by role after each phase

Entity	*Blue 1*	*Blue 2*
Team	I can rely on my team	I can rely on my team
RCV	I can rely on my RCV	I can rely on my RCV
Peer	I can rely on Blue 2	I can rely on Blue 1
Blue 6	I can rely on Blue 6	I can rely on Blue 6

Procedure

For experiment trials, all participants were admitted at the same time in a common Zoom room. They then completed the informed consent and were randomly assigned to one of the three test participant roles (Blue 1, Blue 2, or Blue 6). Participants then completed role-specific training via a shared PowerPoint screen before finishing hands-on training that was directed by the confederate mission commander. In the 45-minute hands-on training, each participant practiced their role in a short mission phase. Afterwards, the participants completed two missions with three phases per mission. Phases lasted approximately 12 to 16 minutes each and were each preceded by a three-minute brief for the team to plan their phase execution. The only break in the experiment was between Phase 3 and Phase 4 when participants were given a three- to five-minute break. Following both missions, responses to more in-depth survey questions were collected. After all the final survey questions, demographic information was solicited from the participants. Finally, prior to concluding, an experimenter read a debrief statement. In total, the experiment took approximately three hours to complete.

RESULTS

A lack of sphericity resulted in using the Greenhouse-Geisser adjustment for all analyses. For *post hoc* analysis, a Bonferroni correction was applied for family-wise error.

Analysis began with a mixed factor 2 (between-subjects role) x 6 (within-subjects phase) x 4 (within-subjects entity) analysis of variance (ANOVA) to explore effects on the reported trust scores. The overall ANOVA revealed significant main effects of phase, $F(3.78, 158.65) = 3.62$, $p = .009$, $\eta_p^2 = .079$, and entity, $F(1.89, 79.29) = 6.68$, $p = .003$, $\eta_p^2 = .137$. There was no three-way interaction, but significant effects were found in two two-way interactions: phase x entity interaction, $F(5.22, 219.19) = 5.38$, $p < .001$, $\eta_p^2 = .113$, and entity x role interaction, $F(1.89, 79.29) = 3.74$, $p = .030$, $\eta_p^2 = .082$.

Simple effect analysis was used to interpret the two-way interactions. For the first two-way interaction, a 6 (phase) x 4 (entity) ANOVA was run. Once again, there were significant main effects for entity, $F(1.85, 79.51) = 6.27$, $p = .004$, $\eta_p^2 = .127$, and phase, $F(3.78, 162.40) = 3.69$, $p = .008$, $\eta_p^2 = .079$. As before, these were qualified by a phase x entity two-way interaction, $F(5.26, 226.04) = 5.44$, $p < .001$, $\eta_p^2 = .112$. To understand the interaction, pairwise t-tests comparisons were run. In comparing the Phase 3 RCV entity to the other phases, it was revealed that the RCV entity, Phase 3 trust score is significantly lower than Phase 1, $t(43) = -3.80$, $p < .001$, Phase 2, $t(43) = -3.82$, $p < .001$, and Phase 5, $t(43) = -3.51$, $p = .001$. Additionally, within Phase 3, the RCV entity was significantly lower than all three other entities: team, $t(43) = -3.51$, $p = .001$, peer, $t(43) = -3.28$, $p < .002$, and Blue 6, $t(43) = -3.69$, $p < .001$. The overall phase x entity interaction is illustrated in Figure 1, showing that trust toward the RCV during Phase 3 was distinct from the other phases; this figure does not break the data out by role but looks at overall averages.

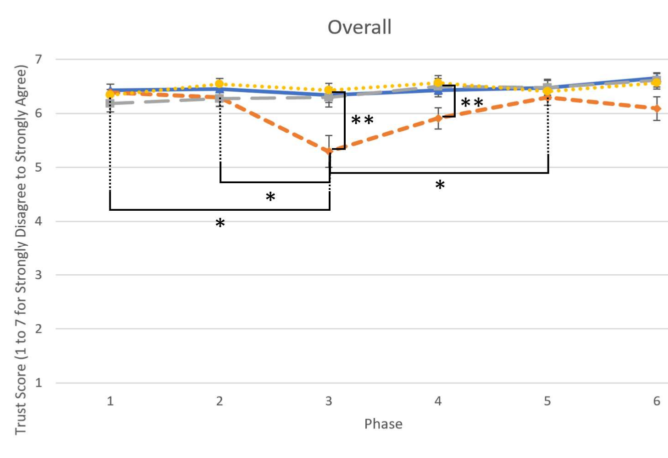

Figure 1. Entity (Team, RCV, Peer, Blue 6) by Phase (1 to 6) Trust Scores. Note that an * annotates $p \leq .001$ and ** is $p \leq .002$.

We note from the results of the preceding analysis that trust toward the RCV in Phase 5 was significantly higher than in Phase 3 and no different than Phases 1 and 2, indicating that trust had recovered to baseline levels after Phase 5. To explore the recovery of trust for the RCV entity, the Phase 4 RCV entity score was reviewed. In Phase 4, trust toward the RCV was also found to be significantly lower than the other three entities: team, $t(43) = -3.32$, $p = .002$, peer, $t(43) = -3.36$, $p = .002$, and Blue 6, $t(43) = -3.38$, $p = .002$. Thus, recovery of participant trust in the RCV was not yet achieved in Phase 4 but happened during Phase 5.

The Phase 6 RCV entity was also compared with the other Phase 6 entities. Here, the results are not significant because of the Bonferroni correction but may illustrate another case of the interaction effect to keep in mind. Comparison of the Phase 6 RCV entity with the other entities in Phase 6 resulted in the following results: team, $t(43) = -2.68$, $p = .010$, peer, $t(43) = -2.24$, $p = .030$, and Blue 6, $t(43) = -2.25$, $p = 0.029$.

For the entity x role interaction, which was the second two-way interaction identified in the initial ANOVA, 6 (phase) x 4 (entity) ANOVAs were again run, but this time broken down according to the individual roles, Blue 1 and Blue 2. For the Blue 1 ANOVA, there was a significant main effect of entity, $F(1.14, 23.88) = 8.77$, $p = .005$, $\eta_p^2 = .295$, but not for the Blue 2 ANOVA. This indicates that entity results varied between the two roles that supervised the RCVs. See Tables 2 and 3 for means and standard deviations of the trust scores reported for the Blue 1 and Blue 2 roles, respectively.

Table 2. Trust score means and standard deviations (italics) for Blue 1.

Entity	Phase 1	2	3	4	5	6
Team	6.50	6.55	6.50	6.45	6.45	6.73
	(0.80)	*(0.74)*	*(0.74)*	*(0.96)*	*(1.14)*	*(0.70)*
RCV	6.23	6.14	4.95	5.73	6.18	5.91
	(1.34)	*(1.13)*	*(2.06)*	*(1.35)*	*(1.01)*	*(1.57)*
Peer	6.36	6.55	6.50	6.64	6.59	6.73
	(0.66)	*(0.60)*	*(0.74)*	*(0.79)*	*(1.10)*	*(0.88)*
Blue 6	6.36	6.55	6.36	6.55	6.41	6.50
	(0.66)	*(0.60)*	*(0.85)*	*(1.14)*	*(1.14)*	*(1.01)*

Table 3. Trust score means and standard deviations (italics) for Blue 2.

Entity	Phase 1	2	3	4	5	6
Team	6.36	6.36	6.18	6.41	6.50	6.59
	(0.66)	*(0.66)*	*(1.05)*	*(0.67)*	*(0.60)*	*(0.59)*
RCV	6.55	6.45	5.64	6.09	6.41	6.27
	(0.60)	*(1.06)*	*(1.81)*	*(1.23)*	*(0.91)*	*(1.35)*
Peer	6.00	6.00	6.09	6.36	6.36	6.50
	(1.23)	*(1.15)*	*(1.44)*	*(1.14)*	*(0.95)*	*(0.80)*
Blue 6	6.32	6.55	6.50	6.59	6.41	6.64
	(0.72)	*(0.74)*	*(0.86)*	*(0.59)*	*(0.73)*	*(0.49)*

Based on the hypothesis regarding whether team trust would change, a one-way ANOVA was run to check if team trust scores changed over the phases, $F(3.52, 151.25) = 1.97$, $p = .111$, $\eta_p^2 = .044$, yielding nonsignificant results.

DISCUSSION

The significant findings illustrate how individuals may distinguish perceptions of reliability or trust toward their teammates or entities for the same scenario. In addition, they provide evidence that a loss in trust at the individual level toward an autonomous teammate does not mean the overall trust in the team will have a corresponding drop.

Hypothesis 1 was supported by the drops in trust found in Phase 3 and Phase 6, which were when one of the RCVs had a maintenance issue. The largest trust degradations were observed in Blue 1 having significantly less trust in the RCV after Phase 3. One of the RCVs experienced a maintenance issue in Phase 3 that required the other RCV to rendezvous with the broken RCV for repair. Interestingly, the operator reporting the loss in trust was not necessarily the one controlling the RCV with the maintenance issue. For 18 of the 22 teams, Blue 2's RCV is the one that experienced a maintenance issue in Phase 3. However, in exploring the two-way interaction between entity and role, it was found that the trust degradation was isolated to Blue 1 and did not statistically carry over to Blue 2's trust in the RCV. The recovery RCV—i.e., the functional RCV working in tandem with Blue 1 for most participant teams—shouldered the mission in Phase 3 by going out of its way to assist the broken RCV. This may have contributed to Blue 1's lower perceptions of reliability about the RCV as a whole.

Another major maintenance issue to occur during the mission was in Phase 6, when an RCV lost the ability to see beyond three blocks and had to be led to an extraction point by the other RCV and RCV operator. Unsurprisingly, this is where another dip in trust scores is seen for the RCV entity; however, this drop is not at the same level of degradation as in Phase 3. This may be due to the maintenance issue being comparably less severe, such that the affected RCV was not completely incapacitated from completing the mission.

Hypothesis 2 was also supported by this study's findings: overall team trust remained relatively high and did not change throughout the missions. This might indicate that overall team trust is more than just the simple addition of trust in individual team components. Hence, the drop in trust toward the RCV did not appear to drive a drop in the participants' trust scoring toward their entire team.

There are limitations to this study. Participants for the study were university students and paired together for the first time during this experiment. Future NGCV operations will likely include teams that have operated with others and each other over a prolonged period. The operators will also have a longer history of working with the NGCV system. The results here are for initial trust measurements of interacting with the system. An additional consideration is how the humans perceived the RCV. It may be that the relationship with the RCV was more supervisory than team-like within the construct of this study. Future work should consider this distinction in data collection to understand how participants view the RCV.

CONCLUSION

The ability to manipulate trust to a significant level was associated with major maintenance issues, which aligns with past trust studies that considered human and machine trust as initially faith-based in the short term (Muir & Moray, 1996). Findings from this study allude to trust in robotic teammates correlating with how reliable the robotic teammate was perceived to be in accomplishing a specific phase's objective without necessarily extending to later in the mission. This study also showed that diminished trust in robotic teammates can recover if the robotic teammate can consistently accomplish future mission goals without further issues. Although this research looked at robotic teammates in a military environment, findings from this research also have implications for other industries such as medicine and autonomous commercial vehicles. Further studies are needed to better understand the implications of teaming with autonomy beyond dyadic interactions and should continue to look at the relationship between trust in machine teammates and maintenance issues across a broad spectrum of industries.

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