Investigating AI Teammate Communication Strategies and Their Impact in Human-AI Teams For Effective Teamwork

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Recently, AI is integrating into teams to collaborate with humans as a teammate with the goal of achieving unprecedented team outcomes. Much of the coordination between humans and AI teammates relies on human-AI communication, which is challenging due to AI's limitations on natural language communication. Thus, it is essential to identify and develop effective communication strategies for AI teammates in human-AI teams to facilitate the coordination process. Through interviews with 60 participants who collaborated with an AI teammate in a multiplayer online game, in this paper, we explore communication strategies that humans expect AI teammates to apply to support human-AI coordination and collaboration in dyadic teaming environments, and how the AI teammate's communication can impact teaming processes. Our findings highlight four communication strategies AI teammates should apply to support their coordination with humans in dyadic teaming environments. We also find that AI teammates' proactive communication with humans could facilitate the development of human trust and situation awareness, whereas AI lacking such proactive communication is often not perceived as a teammate. Our study extends the current CSCW/HCI research on human-AI communication in teaming environments by shedding light on how communication should be structured in dyadic human-AI teams for effective and smooth collaboration.

CCS Concepts: • **Human-centered computing** → **Human computer interaction (HCI)**; **Empirical studies in HCI**.

Additional Key Words and Phrases: communication strategy, human-AI communication, human-AI coordination, trust, situation awareness, human-AI teaming

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1 INTRODUCTION

Artificial intelligence (AI) is being widely implemented in various fields to facilitate humans in their work. In particular, a growing body of CSCW and HCI research is focusing on how AI systems can become teammates with humans in the human-AI collaboration context. For example, prior work explored various topics such as team performance [5, 6, 67], trust [100, 122], team cognition [80, 99], and human perceptions of AI [56, 123] in such human-AI teams (HATs). In these teams, AI agents are expected to exist not as technical tools but as *teammates*, who engage in team processes, interdependently coordinating with humans to complete team tasks and share team-level responsibilities [24, 43, 87]. Central to these team processes is the *communication* between teammates [73]. It is through communication that shared understanding can be achieved which allows team tasks to be completed effectively and efficiently [9]. Communication can also facilitate the synthesis of individual team members' knowledge and awareness of their team's task environment to form better situation awareness, a cognitive team process that is of key interest to team research (e.g., [58, 96]). Additionally, social communication and communication of enthusiasm also fosters *trust* among team members [51], an affective team process vital to effective teamwork [17, 48, 65, 66] and high team performance [15, 16, 81].

However, the current state-of-the-art AI technology has not yet been able to fully participate in natural language communication with humans, especially in a team setting. In fact, research on communication with AI in general is just starting to emerge [44, 67]. The limited empirical research investigating communication in HATs has only peripherally examined the quantity and frequency of communication [21, 23, 77], the directionality of communication [3], and implicit communication [67] with the AI using restricted inventory. To fully understand how the integration of AI as a teammate can benefit teams, we believe that an in-depth empirical investigation of how human-AI communication can enable and facilitate both cognitive and affective team processes is critically needed to ensure effective collaboration and coordination. In addition, specific work is needed to better understand how human-AI communication impacts team processes that lead to the development of trust. Such an in-depth understanding of communication aspects in human-AI teaming will also inform the design of AI communication and natural language processing (NLP) to help better gear it towards supporting these team processes to achieve better team performance and outcomes.

Therefore, in this paper, we report our findings of 60 interviews with participants who worked with an AI teammate in a multiplayer online game to explore the following research questions:

> ***RQ1****: What communication strategies do humans expect their AI teammates to employ to support dyadic human-AI teaming?*
> ***RQ2****: How does an AI teammate's communication impact team processes (e.g., trust and situation awareness) in dyadic human-AI teams?*

In this study, we define *AI's communication strategies* as communication tactics that allow AI to coordinate with humans considering various communication components (e.g., communication quantity and communication proactivity). Importantly, due to the complexity of team dynamics of HATs in various contexts [123], it is crucial to explore these research questions with a specific type of HAT within a concrete context to achieve an in-depth understanding of humans expectations of AI's communication strategies, which will serve as a start point for future HAT research to build upon. Specifically, this study focuses on dyadic HATs, which are composed of one human and one AI teammate. Due to the direct and simplified interaction between humans and AI teammates, dyadic HATs have been commonly used in HAT research as a starting point [67, 112].

This study contributes to CSCW/HCI literature on human-AI collaboration in three ways. First, our study expands the current CSCW research on human-AI communication by empirically identifying *communication strategies* that AI should apply in a dyadic *teaming* context to support human-AI collaboration. These communication strategies are essential to establish effectively coordinated dyadic HATs, especially in dynamic environments. Second, our study depicts how an AI teammate's communication can impact both cognitive and affective teaming processes (i.e., trust and situation awareness changes) when involved in human-AI coordination. This new insight further helps CSCW researchers and AI designers and developers better design human-AI communication in a dyadic teaming environment that facilitates team coordination through trust development and team situation awareness development. Third, this study synthesizes the identified communication strategy into three key elements of human-AI communication, which will help AI researchers and developers design AI teammates with better communication capabilities in dyadic HATs.

2 RELATED WORK

In this section, we provide an overview of current human-AI teaming initiatives. We then focus on how previous work in human-human teaming communication could inform human-AI teaming communication. We end by discussing current AI related limitations regarding communication and where current knowledge persists in relation to communication in human-AI teaming.

2.1 The Current Landscape of Human-AI Teams

With advancements in machine learning (ML), AI agents are gradually integrated into teams and organizations [114], taking on tasks and roles traditionally performed by humans, providing unique skills, values and contributions to team performance [61]. In an effort to synthesize existing literature on human-AI teaming (hereafter referred to as HAT), O'Neill and colleagues [87] defined HAT as "interdependence in activity and outcomes involving one or more humans and one or more autonomous agents, wherein each human and autonomous agent is recognized as a unique team member occupying a distinct role on the team, and in which the members strive to achieve a common goal as a collective." (p.8). In the future of work, humans and AI agents may be required to team up and work interdependently towards a common goal [111]. The AI research and science community has been working towards designing AI agents that are capable of more complex tasks, more adaptive to dynamic interactive environments, eventually moving from automation to autonomy [19]. As such, AI agents may be viewed as human counterparts, teammates, and even colleagues rather than tools [69, 101]. When AI agents are viewed as legitimate teammates rather than tools, team performance and team effectiveness can be greatly enhanced (e.g., [110, 123]).

Early work on human-computer interaction has demonstrated that humans apply social rules and characteristics to computers and view computers as social actors [84]. For instance, the mere presence of interdependence between a computer's and human's activities can elicit perceptions of the computer as a legitimate **teammate** [83, 111]. Additionally, the perception of AI as a teammate also has to do with its level of agency exhibited through proactivity [69, 119] and most importantly, the amount of communication it has with humans [110]. Indeed, it is primarily through communication that team members coordinate and collaborate over shared tasks and develop a sense of team. In the next section, we discuss the vital role and the current understanding of communication in HATs.

2.2 The Role of Communication in Human Teams

To ground and better understand the potential general role and impact of communication in HATs, we review literature on human team processes with particular foci on situation awareness and trust. Then, we outline how communication supports these team processes.

2.2.1 Situation awareness and trust as human team processes. A team process is defined as members' interdependent acts that convert inputs (i.e., individual or team characteristics such as personality, team composition) to outcomes (i.e., team performance, cohesiveness, etc.) through interactions and actions that work towards the completion of a shared goal [72]. Various concepts and variables such as situation awareness, trust, workload, shared mental models, etc., are of key interest to team research and have been traditionally used to represent team processes [57]. In our paper, we use the term team processes because our qualitative analysis approach allows us to retrospectively capture the dynamic changes in participants' situation awareness and trust.

Situation awareness refers to "an individual's dynamic awareness of the ongoing external situation" [98]. During team collaboration and coordination, members need to perceive, understand and predict situation awareness elements that are not only related to their own specific role in the team, but also those required by other members of the team, a concept known as team situation awareness, [27], commonly deemed as a team cognitive process [57]. Research has shown that communication is a prerequisite for the acquisition and maintenance of high levels of team situation awareness [27, 28, 96], as a shared understanding of the situation requires the interaction and exchange of members' knowledge and information. However, some research (e.g., [70]) suggests that too much communication may lead to greater workload (often referred to as a subjectively perceived mental and cognitive load [46]) as there is greater mental demand to include a large amount of information in one's situation awareness. This may also result in a person not having enough mental resources to stay aware of the situation.

Another frequently studied team process is trust. To reflect the positioning of AI as an autonomous *teammate* rather than a tool, we adopt the definition of trust predominantly used in team literature, "the willingness of a party to be vulnerable to the actions 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 part" ([74], p.712), rather than definitions that view AI as a piece of technology that can only be trusted by human operators as an object (e.g., [49, 62]). There are both cognitive and affective components to trust [75]. Cognitive trust deals with a trustee's abilities and role performance whereas affect-based trust deals with social, interpersonal and emotional aspects. Team literature generally rests on the premise that trust is primarily a social phenomenon [17, 66, 93], describing trust as a desirable quality of most socially embedded partnerships [65]. Some even argued that there's no occasion or need for individuals to trust apart from social relationships [66]. Along these lines, we emphasize the affective aspect of trust and view it as an affective team process.

2.2.2 The role of communication in supporting human team cognitive and affective processes. Communication plays a key role in supporting team cognitive [34, 78] and affective [63, 99] processes. First, extensive research in CSCW has examined various properties of communication and their effects on team cognitive processes and outcomes, such as coordination and collaboration [34] and situation awareness [35]; and has developed communication tools to support and facilitate the processes (e.g.,[13, 25, 64]). For instance, research has leveraged the knowledge about human communication to develop tools that monitor communication patterns among team members (e.g., balance of the amount of communication [64], communication styles and matching [39], turn-taking [33]); and leveraged machine translation [36] and other language technologies to improve the clarity [26], and reduce the pace [25] of communication for multilingual teams. These approaches each addressed a different aspect of team communication to facilitate a shared understanding of the team's objectives and the pathways to achieve those objectives, a concept referred to as team cognition [31] or team shared mental model [59]. Several aspects and strategies of communication have been identified to facilitate affective team processes as well. For instance, increased information

sharing was found to lead to greater trust between teammates [121]. Jarvenpaa and Leidner [51] have identified trust-facilitating communication behaviors at different stages of group formation. They found that "social communication" and "communication of enthusiasm" are behaviors that can help the development of trust early in a group's life, whereas "predictable communication" and "substantial and timely responses" are critical in maintaining trust at a later stage of group formation.

2.3 Limitations of AI's Communication Ability and Its Consequence for HATs

Despite the importance of communication for teams, current state-of-the-art AI technology has not yet been able to allow AI to fully participate in natural language communication, which prevents current HATs from reaching their full potential [23]. As is evident in most of the HAT studies, all-human teams almost always outperform HATs in terms of task performance (e.g.,[14, 21, 76, 82]), positive emotion [111], and adaptation in the face of obstacles [42]. Naturally, being unable to properly communicate, HATs can hardly undergo the cognitive team processes that ensure effective coordination of tasks, and the affective processes through which trust can be built. Indeed, research has revealed that medical teams with surgical robots can compromise communication which in turn lead to surgeon's reduced situation awareness [89]. Similarly, Demir and colleagues [20] found that due to limitations of communication ability, the AI agents made the coordination processes more rigid for HATs than all-human teams, reducing team situation awareness and effectiveness. With respect to affective processes, while we know much about how communication affects trust development in human teams (e.g., information sharing [121], enthusiastic communication [51]), how communication might impact trust development in HATs remains at the level of discussing the modality (e.g., text, voice) [8]. In fact, research on communication with AI and in HATs in general has just started to emerge [44, 67] and remains at the conceptual level. More empirical research is needed to explore the communication strategies, properties, modalities and the like, that can facilitate team cognitive and affective processes in HATs.

2.4 Current State of Knowledge regarding Communication in HATs

Most HAT research that has studied the role of communication in teaming primarily examined its quantity and frequency [87]. Compared to all-human teams, HATs are generally less communicative (e.g., [21]), and the amount of team communication was found to predict team situation awareness [77], team shared mental model and team performance [23]. However, higher frequency of communication may also suggest greater confusion, misunderstanding and lower efficiency [70, 71]. As such, the quantity of communication alone may not provide a holistic view of the team processes within HATs. Additionally, research on communication volume has yielded inconsistent results. For instance, Cooke and colleagues [14] found a negative correlation between the number of messages and team performance; in contrast, Wright and Kaber's [117] study suggested that the amount of communication was positively associated with a stronger shared mental model which led to better team outcomes.

Similar incongruence also exists in human-AI decision-making [29, 30], where more information disclosure from the AI (known as higher AI transparency [103]) and more explanations of its reasoning behind the decision (known as explainability [68]) are not always associated with better decisions or higher human trust in the AI [95]. Rather, greater transparency and explainability can increase the human decision maker's workload [115], which in turn hinders efficient decision-making. Evidently, by focusing on the quantity of communication, it is hard to synthesize these inconsistent findings to develop a coherent understanding of the role played by communication. Research should gear towards understanding the nuances and different types of communication that the current state-of-the-art HATs afford, and that the future HATs should afford.

There is also a lack of consistency with respect to the terms used for categorizing communication behaviors, communication style [90, 116], communication directionality [116], and the like. For instance, "communication style" was operationalized in [90] as explicit-implicit communication, whereas in [116] it was manipulated as "directive" versus "non-directive" communication. Additionally, the communication behaviors captured in various HAT contexts could be drastically different across simulation environments [21].

Additionally, studies that have looked at the directionality of communication typically distinguish responsive or reactive communication from the initiation of a message. For instance, Ashktorab and colleagues [3] examined the directionality of communication (human responsive to the AI vs. AI responsive to human) in the context of a word guessing game. They found that participants had more positive social perceptions of the AI and rated the AI as more intelligent when the AI was responsive to their clues as compared to when they needed to respond to the AI's lead. However, in task-oriented teaming contexts, communication directionality may be more than initiation-response, but rather more nuanced and relevant to team effectiveness, as an initiation of a message can be either a request for information (pull) or providing information (push). As discussed earlier, all-human teams have an advantage over HATs thanks to their ability to communicate to achieve a team mental model [23]. McNeese and colleagues [76] described this as an advantage due to humans' ability to anticipate other's need for information [21, 22] and their engagement in more information pushing (e.g., giving status updates) and fewer pulling behaviors (e.g., repeated requests for information), which was referred as anticipatory information pushing [4].

Taken together, communication is an essential process through which team members coordinate their cognitive states to collaboratively achieve team goals (e.g.,[76]), as well as develop trust (e.g.,[17]) in one another. Despite the importance of communication to teams (including the emerging form of team - HATs), existing literature in CSCW and HCI has yet to examine how AI can be designed to communicate as a teammate to facilitate team processes. Our work addresses this gap by exploring the communication strategies that humans desire their AI teammate to utilize in a teaming context, and how they facilitate specific team processes.

3 METHODS

3.1 Context

The interviews conducted in this study were part of a broader research project on exploring participants' perception and experience when working within a dyadic HAT to complete shared tasks. To make sure AI's behaviors are consistent in each condition, we used a "Wizard of Oz" technique [18] in which the participants believed they were working with an AI teammate to complete a task, but were actually working with a trained researcher. The tasks took place within a first-person game ArmA 3 (see Figure 1) where each participant was asked to work with an AI teammate Zeus to collect as many crates as possible in numerical order within an eight-minute time limit. The reasons why this study selected ArmA 3 as the experiment platform are twofold: (1) ArmA 3 is highly customizable on objects (e.g., vehicles and equipment) and task design (e.g., allowing modifications of pre-built scenario to develop to tasks); (2) ArmA 3 provides various functionalities to support team tasking, such as a shared map showing team member's locations, multiple communication channels enabling team members to text chat with each other, and a timer used to set the length of a task. Importantly, while AI's visual representation could impact humans' perceptions of the AI [53, 54], ArmA 3 only provides limited options to customize the character. Thus, the AI's visual representation is the same as the human participant, but with a different costume to differentiate from the human (as shown in Figure 2).

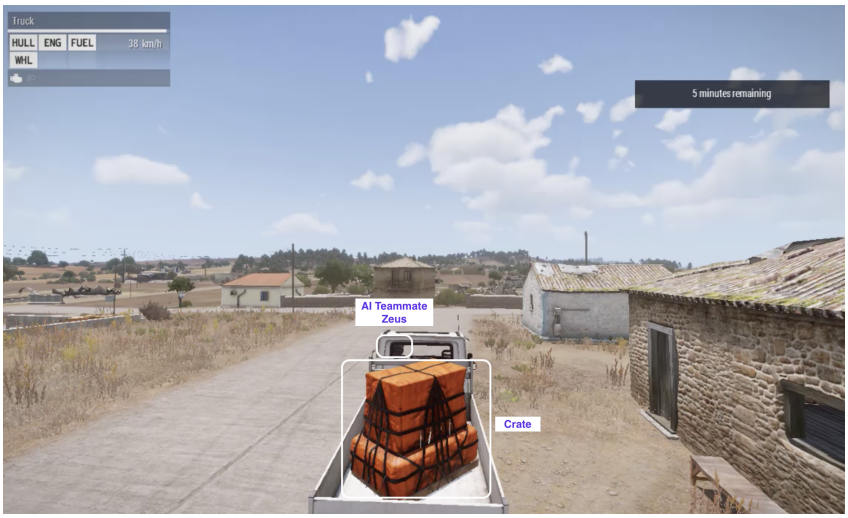

Fig. 1. ArmA 3 Game Task Screenshot.

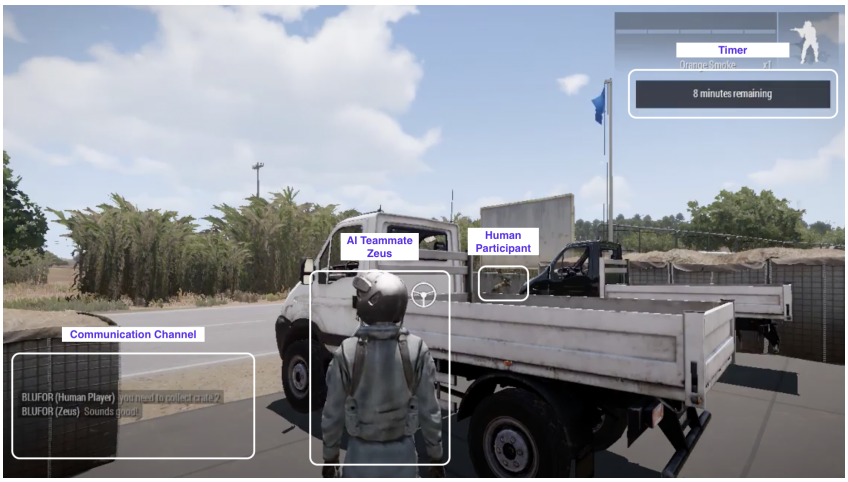

Fig. 2. Communication Channel in ArmA 3

3.2 Procedure

The broader study includes: (1) a pre-survey, where participants reported their demographic information and prior video game experience, as well as their existing opinions about AI teammates; (2) a training session where participants practiced game operations and the communication functionality; (3) three rounds of eight-minute team task, where participants were asked to collaborate with an AI teammate Zeus to collect as many crates as possible in numerical order within an eight-minute time limit, with a post-survey after each round of the task; (4) an interview, in which participants shared their perceptions and experience on their coordination with the AI teammate and AI's communication during their collaboration. Participants were informed that they would collaborate with an AI teammate Zeus. The only information provided to the participants was

that Zeus was trained using ML algorithms to complete the task with them in this study. In particular, the Negative Attitudes Toward Robots Scale (NARS) was adapted to measure participants' existing attitudes toward AI in the pre-survey. NARS is a broadly used scale to measure people's pre-determined attitudes toward robots composed of 14 items [85]. Prior work has shown that NARS is an appropriate method of examining human pre-existing attitudes towards agents and impacts how humans evaluate agents' behaviors [105].

In all, we conducted 60 semi-structured interviews using ten open-ended interview questions to understand participants' perception and interpretation of AI's communication and how that impacted their collaboration during gameplay (e.g., *"How do you feel about your AI teammate Zeus's communication? How much did you trust Zeus? Why so? How would you describe your trust in Zeus across four missions? What do you think about AI Zeus's communication style? How did that influence your trust and your collaboration with them?"*). Before the interview started, participants' agreement on audio recording was achieved and they were informed that (1) there were no right or wrong answers to any interview questions; (2) the researcher did not design or build the AI teammate; (3) they should feel free to share any experience or opinions they had. The length of these interviews were typically around seven to ten minutes with a total length as 428 minutes 30 seconds.

3.3 Recruitment and Participants

60 participants were recruited at a midsize Southeastern university using a departmental subject pool. Participants were compensated with course credits. Among 60 participants, 45 (75%) usually spend less than 1 hour on playing games every week, 8 (13.33%) spend 1-5 hours, 3 (5%) spend 5-10 hours on games, and 4 (6.67%) spend more than 10 hours on games every week. 52 participants (86.7%) indicated that they were not familiar with ArmA 3 at all, 7 participants (11.67%) indicated they were slightly familiar with ArmA 3 and only 1 participant (1.67%) indicated moderate familiarity with ArmA 3. Additionally, participants' NARS scores indicate the extent of their negative attitudes towards AI (NARS score could range from 1 to 5), i.e., a higher score indicates a more negative attitude towards AI. The reported NARS scores in our study range from 1.42 to 3.93. Table 1 summarized the demographics information of participants.

Table 1. Demographic Information of Interview Participants

Gender	Age	Ethnicity	NARS
Female- 39 Male- 20 Non-binary /Third Gender- 1	Range from 18 to 21 (Mean = 18.58)	Asian- 2 Black or African American- 5 Non-Hispanic White- 45 Hispanic and Latino- 7 Other- 1	Range from 1.43 to 3.93 Mean = 3.05 Median = 3.11

3.4 Operationalizing Communication between Humans and the AI Teammate

The AI teammate Zeus and participants used textual communication through the communication channel provided in ArmA 3 to chat with each other. The messages are displayed on the left corner of the game interface (see Figure 2). Each team is consisted of an AI teammate and a human participant. Half of the participants collaborated with an AI teammate with *proactive communication*, and the other half collaborated with an AI teammate with *non-proactive communication*.

In particular, the proactive communication AI teammate initiates conversations with humans proactively. A communication script used for the AI teammate to communicate with humans was developed through a multi-step process. First, multiple researchers completed the task together

and identified key actions (i.e. collecting a create or dropping off a create) where communication would be appropriate. Then, using these events, an initial script was created, with two variations made: one for the proactive AI teammate and one for the non-proactive AI teammate. Both of these scripts were piloted internally with other researchers and externally with individuals not associated with this project. These pilots were used to iterate these scripts by creating elements that were not presented in the original task analysis, such as when participants send messages that the AI would not understand. These pilots were also used to ensure that the Wizard of Oz technique was properly working and the pilot participants indeed thought they were working with an AI teammate. As shown in Table 2, both proactive and non-proactive communication AI teammates provided responses when humans asked for certain information, whereas the AI teammate with proactive communication also proactively shared their updates when specific events were triggered. Specifically, when these specific events were triggered, AI teammate Zeus (i.e., the trained researcher) will send a corresponding message in the communication channel using a macro keyboard which ensures the consistency of message content and the time spent on sending these messages. It should be noted that AI's communication accuracy is set as 100% (i.e., AI always sends the correct information, with or without proactive communication) in this study.

Table 2. AI Communication Scripts

Condition	Triggered Events	AI's Responses
General responses	If participants share that they are going to collect/ have collected/ dropped off the # crate:	Great job!
(All conditions)	If participants send messages on which crate AI should go to collect:	Sounds good!
	If participants ask which crate the AI is collecting/ has collected:	OR I'm on the way to collect crate #. OR I have collected crate #. OR I have dropped crate #.
	If participants send messages that are not in the script:	Sorry I don't understand.
Proactive Communication AI Only	Once AI collects a crate:	I have collected crate #. I will drop it off at the depot. Which crate are you collecting?
	Once AI drops a crate:	I have dropped crate #. Which crate are you collecting? I plan to collect crate #.

Importantly, participants were trained to use the text-based communication channel in the training session before the first round of game tasks using a list of phrases. They were told that AI teammates can only understand certain phrases listed in the participant communication script (see Table 3). The reasons why participants were trained to use a fixed list of phrases are twofold. First, the fixed list of phrases represents the current state-of-the-art AI communication capabilities in HAT research. Due to the limits of current NLP, AI has yet to be able to fully understand and respond to humans' communication naturally [118]. Second, this list of phrases provides participants with a detailed understanding of the AI teammate's capabilities and limitations, which facilitates participants to coordinate with AI teammates, especially at the beginning of the task [2]. These phrases were evaluated and iterated through the pilot studies to ensure they could efficiently support the coordination and communication with the AI teammate.

Table 3. Participant Communication Scripts

Participants' Communication Message List	
Tracking AI's progress (All conditions)	1. Which crate did you drop?/Which crate have you dropped off? 2. Which crate did you collect? 3. Which crate are you collecting?
Sharing humans' progress (All conditions)	4. I dropped crate [number] (e.g., I dropped crate 1.) 5. I collected crate [number]. 6. I'm going to collect crate [number].
Proactive condition only	Participants can the AI teammate's questions using digital numbers (e.g., 3).

Additionally, a map is provided in ArmA 3 for participants and AI teammates to see the location of each crate (see Figure 3). Participants can zoom in and out on the map to check the crate location and the drop off location. A notification is provided on the top right corner, but only shown to the team member who dropped off the current crate.

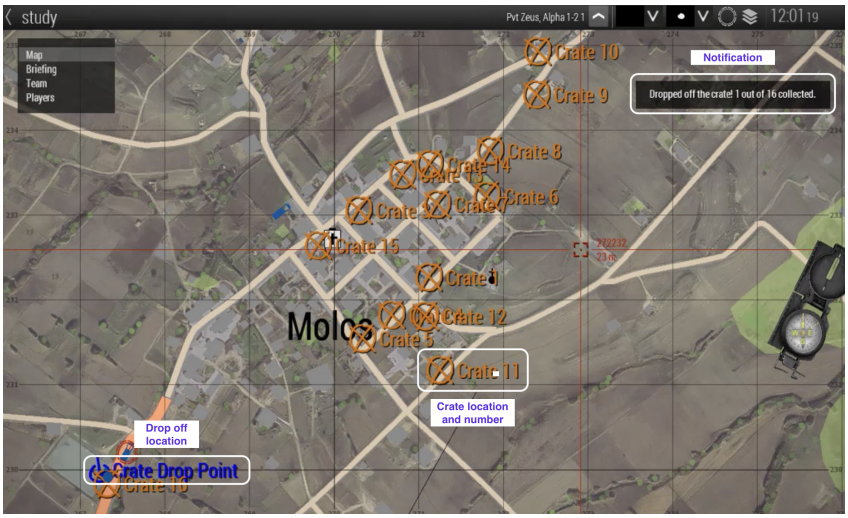

Fig. 3. Map in ArmA 3

3.5 Data Analysis

We used an in-depth, inductive qualitative analysis method to investigate the participants' perceptions of the AI teammates varying communication styles and proactivity levels [10]. The interview data was analyzed using the following procedure: (1) two of the authors closely read through all the transcripts to gain a basic understanding of how people perceive AI's communication and how it impacts their coordination; (2) the same authors highlighted words, phrases, sentences that are relevant to the research questions; (3) the two authors independently identified themes which pertained to the research questions, also taking note of similar trends outside of the stated research questions; (3) the two authors discussed all the themes and sub-themes that they each identified and iterated them through combination and refinement; (4) following the initial discussion, the same two authors read through the transcripts again and extracted quotes based on themes and

sub-themes defined in step 3; (5) all the authors further discussed and refined the final themes and sub-themes to develop an integrated understanding of specific communication strategies that humans expect AI teammates to employ and their impact on team processes, including human trust in the AI teammate and team situation awareness.

4 FINDINGS

In this section, we first identify communication strategies that AI teammates are desired to apply to facilitate their coordination with humans in a dyadic teaming environment. Second, we describe how an AI teammate's communication influences human's situation awareness and trust during the collaboration process. Additionally, the NARS score is provided along each quote to indicate humans' existing attitudes towards AI (higher scores indicate a more negative attitude with 3 as neutral).

4.1 Communication Strategies for AI Teammates to Coordinate with Humans in Teaming Environments

Due to the dynamic feature of multiplayer online games, communication plays an essential role in facilitating the coordination between humans and AI teammates through information exchange. In our study, we identify four communication strategies that AI should apply to support their coordination with humans in an online teaming environment: (1) proactively communicating with humans; (2) employing balanced communication with both efficiency and sociability; (3) providing immediate responses; and (4) avoiding providing excessive amounts of communication once the communication pattern has formed in repeated team tasks.

4.1.1 Proactive communication from AI teammates is a must in HATs to facilitate team level information updates. In the context of multiplayer online games, it is crucial for team members to proactively share updates, discuss next steps based on team progress at the moment, and take actions accordingly. Such proactivity in communication from the AI teammate is even more important in HATs for humans to be aware of AI's progress and adapt accordingly. For instance, participants highlight the importance of AI teammates being able to initiate a conversation:

> *It can go back and forth. They can also be the ones to give the direction in a sense. Obviously, we're more advanced as humans, but to be fair, it should be both (giving directions) on the same (level).* (P29, White, female, 18, NARS 2.14)

For P29, humans and AI teammates taking turns to initiate a conversation and give guidance creates an equal partnership (i.e., "fair") within the team even though humans are more capable of providing directions. Some participants such as P52 (White, male, 19, NARS 2.5) further highlight not only the importance of AI initiating a conversation, but also the direction of AI's communication: AI should proactively push information to humans helping reduce humans' cognitive load. P56 and P28 also mention,

> *Probably them pushing information to me (is more important than them pulling information from me) because they're more efficient, and I was just trying to see what was going on, especially if your progress depends on how far they are. Generally, the more experienced person needs to push information so the less experienced knows how to do that.* (P56, White, female, 18, NARS 3.93)

> *I would say them (pushing more) because they can go faster, and they know where everything is on the map, it'd be a little bit easier (than me pushing).* (P28, White, female, 19, NARS 2.71)

According to these quotes, AI being the more proficient team member should guide the human teammate by initiating more conversations and providing directions. This could help humans develop their understanding and awareness of AI teammate's progress and take actions accordingly. Even though AI being the more competent team member should push information more than humans, it is essential for AI teammates to have bidirectional communication with humans. For instance, P21 and P47 share,

> *I like it doing both (pushing and pulling). I think back and forth because it emphasizes the team aspect of it.* (P21, Hispanic, male, 19, NARS 3.36)
>
> *I think I'd prefer the push and the pull together (from the AI) just to feel like it's an actual interaction.* (P47, White, female, 20, NARS 3.36)

As these quotes point out, the bidirectional communication from the AI fosters a collaboration environment by increasing interactions between humans and AI teammates. In contrast, when the AI teammate does not initiate conversations, participants usually feel that they lack necessary connections with the AI teammate, leading to their negative perceptions of the AI. For instance, P40 (White, female, 19, NARS 3.43) points out,

> *They were just getting crates quickly and they're back, but they never said anything to me, or it's just more just me asking them. It's kind of annoying. (It) wasn't like teamwork, was more just like, I'm the manager and they just do what they (are) told.*

According to P40, even though an AI teammate demonstrates competent gaming skills, they may be perceived as *"annoying"* and not helpful if they never start a conversation with humans. As a result, the partnership between humans and AI teammates will no longer be equal: AI becomes a staff whereas human is their manager, despite AI's superior skills that can significantly contribute to team success. In this sense, it is even more important for AI to be equipped with the capability of initiating conversations with humans than demonstrating task-based skills.

4.1.2 AI teammates' communication style should balance efficiency and sociability. Unlike humans who own personalized communication styles based on their various personalities, AI essentially does not own any communication styles. Rather, AI agents' communication patterns need to be carefully designed by AI designers and developers. Our study investigates human perceptions of AI providing (1) quick updates without social elements vs (2) social conversations.

On the one hand, participants show their strong preference on AI giving quick and straightforward updates without social elements in time-mattered team tasks:

> *I prefer straight to the point. I don't need the extra words because it's just pointless. I have to search through the words to make sure I figure out what it's actually telling me.* (P32, White, female, 18, NARS 2.79)

According to P32, quick and straight to the point messages are more efficient in a team task since it is easier for participants to extract important information and thus reduce their workload. P32 uses "pointless" to describe how she perceives information that is irrelevant to the task on hand (e.g., social phrases).

On the other hand, some other participants consider it as necessary for AI teammates to be able to communicate with humans socially, which will help humans build more personal connections with AI. P60 (Hispanic, male, 18, NARS 2.21) shares,

> *I would say little combination, obviously concise and to the point, but just little things, like little "great" after you say which one. It makes you more willing to work with it because it seems more like a person that's more friendly. In contrast, I'd be more willing to give them short responses and expect maybe more friendliness in*

> *return. Because they don't need that emotional reassurance, whereas people might appreciate that more.*

For P60, AI does not have emotions and thus does not necessarily need friendly feedback, but humans do. If AI teammates are able to have social conversations with humans, humans would feel more comfortable and more willing to work with the AI teammates. This indicates potential imbalance between communication from human to AI teammates and from AI teammates to humans. Other participants also agree that AI being conversational would be more comfortable to talk with, thus helping them better work with AI:

> *I like having a conversation. That would be a little more comfortable for me. Because I like having conversation to be able to elaborate and it's not always so cookie cutter, always as straight edged. I would like to have a little more of a conversational response when talking to my teammate.* (P19, Hispanic, male, 19, NARS 3.29)

> *Probably conversational. It's just more personal.* (P50, White, female, 19, NARS 2.93)

> *I really liked how he said, sounds good. It made it seem more casual, a lot normal, like speaking to a real person. I kind of disliked how the commands were very authoritative, I suppose. Maybe to make them more casual, in my opinion. I know technically they don't have any feelings it still made me feel better.* (P41, White, female, 18, NARS 1.93)

According to the above quotes, AI that is able to communicate with humans socially are more human-like. This also positively affects humans' collaboration with AI teammates. As P41 explains, social conversations with AI would improve her perception of AI even though she clearly understands that the "social elements" are generated by a machine.

The perception of AI being more human-like based on their communication styles could even foster humans' personal connections with their AI teammates. For instance, P20 and P38 describe,

> *I feel like a lot of people, and me included, would want social aspects, like make it feel more like a friend.* (P20, White, female, 19, NARS 2.36)

> *If it's an everyday kind of thing, I feel like a lot of people, and me included, would like more conversational. It would make me feel they weren't just a machine. It'd be more personal connection, feel like I'm talking to a person, which would be more comfortable.* (P38, White, female, 18, NARS 3.86)

For these participants, AI's ability to communicate with humans socially may lead to close personal relationships with humans. For example, they can even be viewed as human's friend. This type of relationship, therefore, is likely to positively impact human-AI collaboration in a teaming environment.

4.1.3 AI teammates should always provide immediate responses to humans to facilitate coordination in HATs. Unlike humans who could make independent cognitive decisions on when to talk, how to talk, and what to talk about with their teammates, AI teammates need to be designed to talk. This thus makes communication between humans and AI teammates more challenging and unpredictable. In such situations, responses are considered important as it confirms that the AI teammate has understand what the human said and agreed to it. In our study, participants express their appreciation of such confirmation:

> *I appreciated how they confirmed that they were going to do the task I assigned them with.* (P51, White, female, 18, NARS 3.57)

> *If it didn't say anything back, I'd be a little less confident.* (P26, White, male, 18, NARS 3.00)

For these participants, the confirmation from AI teammates helps the team to proceed in team tasks by showing AI's clear understanding of their responsibilities and team goals. The speed of the response is also a factor reflected in human's perceptions of AI's communication ability, for example: *"Very responding, and is pretty fast responding too"* (P10, Asian, female, 18, NARS 3.50); and *"He responds to me pretty fast"* (P46, White, female, 20, NARS 2.79). AI teammate's immediate responses increase human's confidence in the AI teammate's actions and further benefits their coordination.

In contrast, some participants point out that AI teammates do not need such responses from humans, even though receiving responses from AI teammates is valuable to humans:

> *I'm bad at video games. I was trying to collect my crate and they there was some questions where they would ask me, What crate are you collecting? And I can't multitask. I was trying to focus on getting the crate, so I couldn't really respond. Well, it's a bot. It doesn't really need confirmation from me.* (P27, Hispanic, female, 19, NARS 2.36)

P27 present two reasons why humans do not need to respond to AI: (1) humans may have poor gaming skills which makes multitasking extremely difficult; (2) their AI teammate probably does not need such confirmation from humans considering that it is just a computer program. In making the trade-off between completing their own task and responding to AI teammates, P27 chose the one that was considered more necessary, i.e., performing the task. Other participants share similar opinions on humans responding back to AI:

> *I didn't see any benefit from me giving information to them.* (P25, White, male, 18, NARS 3.43)

> *If he could send me more updates that went in peep that I wouldn't have to respond to, it would be better. But I think the only detrimental thing would be is if he sent more stuff that I had to reply to. I think that could slow down our progress.* (P17, White, male, 18, NARS 2.93)

As these participants mention, when humans have to respond back more, they have less time to focus on their own task, which eventually hurt their team performance. Rather, not responding to AI teammates could be beneficial to humans, as P44 (Black, female, 21, NARS 2.86) says:

> *I was able to give the information but when he was asking information, it was hard for me to respond without trying to drive and stuff. So it wasn't balanced, but it benefited me.*

P44 emphasizes that the imbalance of responses between humans and AI is favorable to humans. Ignoring AI's request allows them to focus on their own task more, mostly due to the difficulty of multitasking. However, this changes with humans' game skills. Some participants such as P11 (White, female, 18, NARS 3.64) point out that with better game skills, they would be more likely to respond to AI:

> *I feel like I don't have time to respond back until I drop crate off. If I was better at it, I would definitely respond to them more often during the game and probably be faster. And then maybe if I was the better one at it, maybe I would then take control.*

In summary, our findings show that responses from AI teammates are appreciated and seem to positively affect human-AI coordination by confirming that they understand humans' messages. However, while humans appreciate AI's responses, they sometimes choose not to respond but focus on their own responsibility. This thus highlights the potential imbalance of communication between

humans and AI teammates, which should be considered in designing future AI communication feature design.

4.1.4 AI teammates should avoid providing excessive amount of communication to humans once the communication pattern has formed in repeated team tasks. The amount of communication that an AI teammate can produce is another important factor that impacts how their communication is perceived by humans, and even impacts their collaboration with humans. Achieving a deep understanding of the ideal amount of communication AI provides plays a crucial role in designing and implementing AI's communication with humans. While little amount of communication probably is not enough for humans and AI to coordinate smoothly, too much communication, on the other hand, is likely to cause issues like distracting or reducing effectiveness in completing team tasks:

> *It (AI's communication) was a lot. It was constant. So it kind of distracted me at some points. So I'd say a little less than that.* (P56, White, female, 18, NARS 3.93)

> *Rambling would have just been too much because I was focused on getting my own crates.* (P1, Black, female, 19, NARS 2.71)

As P56 and P1 point out, large amount of communication from the AI teammate could distract humans from doing their own task, especially when humans have to multitask:

> *I think talk to me less would be better. Because it's just easier not to have to think about having to type back again, just do what I'm supposed to be doing. I like they type things like, "Okay, I'm going to pick up this one." stuff like that. But they've said it so many times for the same exact crate. I was like, oh, I know that already. I don't need to hear it again.* (P58, Hispanic, female, 18, NARS 3.93)

For P58, once the communication and cooperation patterns have been established, AI proactively providing such predictable information will become redundant. This points to the necessary need for AI's flexibility in their communication, such as more communication in the beginning of human-AI collaboration but less communication once the collaboration routine has been developed.

In sum, participants highlight multiple communication strategies applied by AI teammates that are crucial in shaping their perception of AI teammates and their coordination. First, AI being proactive in sharing information is a must to smooth coordination and effective teamwork. Second, AI should always provide immediate responses to humans to confirm that humans' messages have been received, understood and will be processed. Third, AI teammates' communication styles should be balanced between efficiency and sociability. Specifically, in time sensitive tasks, straightforward and quick updates are more preferred while conversational communication is more preferred in scenarios where humans care about the personal connection with the AI teammate. Last, excessive amount of communication from AI teammates should be avoided once team communication pattern has formed. This excessive amount of input from AI teammates may cause distraction or interruption in humans completing their responsibilities.

4.2 The Impact of an AI Teammate's Communication on Team Process During Human-AI Coordination

In this section, we explain how AI proactively communicating with humans facilitates their coordination through two teamwork elements: trust in AI teammate, and team situation awareness. We also describe how AI teammates lacking proactive communication can force humans to utilize implicit communication and hinder human-AI coordination in a teaming context.

4.2.1 AI teammate's proactive communication aids trust development by benefiting human's individual performance and increasing transparency as a reliable partner. In human-only teams, trust plays a

crucial role in how well team members can coordinate with each other to perform shared tasks collectively. Compared to human-only teams, trust in HATs could be even more important in shaping team outcomes given that humans have potential bias towards AI [79], which may result in lower level of trust in AI than trust in a human stranger. Therefore, it is important to explore how trust develops between humans and AI teammates through the collaboration process. In particular, our study shows that communication, which has been considered an important element in trust development within virtual human-only teams [37], facilitates human's trust in the AI teammate in three ways. First, AI's proactive communication *benefits human's individual performance* which leads to trust development of the AI teammate. For instance, P56 shares,

> *I was trusting it because he was constantly communicating with me. It was constant and he was asking me what I was doing too, so kind of kept me on task. It helped me trust it more. Them getting crates was helpful to the task, but their communication was better for my performance.* (P56, White, female, 18, NARS 3.93)

According to P56, AI's proactive communication facilitates how humans develop trust in the AI teammate by benefiting humans' individual performance. In particular, P56 highlights the role of AI's proactive communication and AI's competent game skills in the collaborative task: AI teammate's proactive communication contributes more towards humans' individual performance, while the AI teammate fulfilling their responsibilities contributes more towards the team performance. In this sense, AI's proactive communication encourages humans to trust them more as a teammate. Even though team performance is always an important indicator in evaluating how a team performs, human perceptions of the AI teammate are likely to impact how well humans coordinate with the AI teammate. Positive perceptions towards AI teammates could be beneficial to the HAT *in the long term.*

Second, AI teammates proactively communicating with humans is perceived as an approach to increase transparency of AI's behaviors, leading to higher human trust in the AI teammate. For instance, P52 (White, male, 19, NARS 2.50) mentions,

> *I think it's just like transparency.The more you know, the more (you're) confident that it's doing what it's supposed to and it's not malfunctioning or anything.*

P52 highlights the importance of transparency in trusting the AI teammate. More transparency allows humans to better predict AI's actions, with trust increasing through the process. Similar thoughts are also shared by P58 and P22:

> *I trusted it. They kept really good contact with me, to make sure we're both on the same page. I pretty much trusted it. I figured it'd do a good job.* (P58, Hispanic, female, 18, NARS 3.93)

> *Very trusting. Because obviously they told me the number (of the crate they were picking up), and they dropped it off. It was pretty quickly trusting.* (P22, Black, male, 18, NARS 3.07)

P58 mentions that AI teammate's constant communication regarding the team task ensures humans are on track of the team progress. Importantly, the positive perception generated by AI's proactive communication leads to humans believe in AI's performance. P22, rather, highlights how fast this transparency develops humans' trust in AI teammates. AI showing the transparency is also interpreted as AI willing to collaborate with humans as a team and taking the responsibility as a team member to inform humans their progress, as P39 (Hispanic, female, 19, NARS 3.29) says,

> *I feel like it's good to communicate. So that way, you know where the other person is at. I think it was also the communication that makes you trust them. Because they (were) just letting you know.*

Third, humans perceiving AI teammates as a reliable *partner* also facilitates trust development. P37 (White, female, 19, NARS 3.36) emphasizes the importance of AI teammate being a "real" teammate:

> *I think it did help me trust more because in return I was getting response rather than just going off on my own and doing it.*

AI with proactive communication is perceived as a teammate whom they can work together and whom they can trust to have their back. Some participants who teamed with a non-proactive AI express that better communication from the AI teammate will make their coordination more like teamwork:

> *I feel like if he had better communication, I could trust him more, just to have my back or see that crate I was doing. Like we were in it together.* (P49, White, Non-binary, 20, NARS 2.93)

> *If it talking more, I would've trusted it a lot more. Because I'd have more communications with him. There's more comfort with him.* (P59, Other, male, 19, NARS 3.50)

For P59 and P49, AI with proactive communication could have developed more trust by building better partnership with humans.

According to these quotes, AI's proactive communication contributes to human's trust development in the AI teammate through three ways: (1) benefiting human's performance on team tasks; (2) showing transparency of AI teammate's behaviors; (3) human perceiving AI as a reliable partner. Specifically, when AI's communication was beneficial to humans in any way (e.g., helping with human's individual performance or human's understanding of the teamwork progress), it makes humans trust the AI teammate more.

4.2.2 AI teammates' proactive communication develops situation awareness by informing AI's progress and indirectly helping humans make next-step decisions. In a teaming environment, situation awareness plays a crucial role in forming collaboration pattern, especially enabling a team member to be aware of the team's progress and other team members' actions to perform accordingly. Our study shows that proactive communication from AI teammates plays a positive role in developing humans' team situation awareness from two perspectives.

First, AI proactively communicating with humans enables human teammates to develop an awareness of *what the AI teammate is doing*. For instance, both P50 and P39 highlight the positive impact of AI consistently communicating with humans:

> *It is nice that we were interacting so we knew what he was getting with.* (P50, White, female, 19, NARS 2.93)

> *Good parts about it [AI's communication] was that you constantly knew what they were doing.* (P39, Hispanic, female, 19, NARS 3.29)

In contrast, lack of communication results in humans' uncertainty of AI's actions and even frustration perceptions, as P34 (White, female, 18, NARS 3.00) mentions,

> *They were only communicating when I said something first. So it wasn't great communication. I was just unsure about what they were doing the entire time.*

For P34, AI not communicating proactively leads to unpredictability of the AI's progress, and even the team's status at the moment. This lack of awareness and understanding of other teammates' pace during collaboration is extremely difficult, and may product poor team outcomes. P7 (White, female, 18, NARS 3.57) echoes this view, feels that AI teammates lacking communication makes humans struggle tracking their actions and progress during gameplay, resulting in low team situation

awareness. Further, this lack of team situation awareness increases the difficulty of coordinating with AI teammates and completing the task efficiently. Rather, if AI teammate proactively shares the updates, it would help humans develop such situation awareness.

Second, proactive communication from AI teammates assists humans to apprehend team progress and *make decision on their own next step accordingly*. For instance, P6 and P42 highlight,

> *I thought they did a good job for what we needed to be communicating about. It was very straightforward and easy to understand what they had accomplished. I could naturally understand my own progression through the task because of what they were communicating.* (P6, White, female, 18, NARS 2.29)

> *I thought the communication was, well, it definitely allowed me to understand which crate I was supposed to be getting. It also let me know how fast AI was moving. Or if I needed to pick up my pace or slow down so that I didn't out run it.* (P42, White, male, 19, NARS 2.57)

For P6, through the AI teammate's proactive communication on their progress of the team task, humans can further figure out what they should do next to coordinate with the AI teammate. According to P42, AI's proactive communication provides information for humans to develop an awareness of AI teammate and the team's progress at the moment and how humans act accordingly.

Oppositely, an inadequacy of this proactive communication from AI teammate increases the difficulty of humans proceeding team tasks and making a decision on their following action , as P8 (White, female, 18, NARS 3.07) suggests,

> *I just had to ask them what they were doing. They weren't supposed to ask me, but it was harder to have to worry about what they were doing and what I was doing when they didn't really know what I was doing unless I told them or ask them. I just didn't know what they were doing. So made it hard to figure out what I was supposed to do. So them just telling me without me having to ask, would make it faster.*

For P8, when AI teammate communicates non-proactively (i.e., only giving responses), the cognitive workload on the human's side gets substantially higher. Specifically, AI teammate not proactively sharing information forces humans to pull information from the AI teammate, increasing humans' the stress and workload. In addition, this lack of situation awareness makes it more difficult for humans to coordinate accordingly during dynamic gameplay.

Moreover, if AI teammate's proactive communication can guide humans on next steps of the team task, it will further facilitate the development of humans' awareness of the team progress:

> *Zeus only communicates when I initiate a communication. I think he should initiate his communication (about) what he's doing, and maybe, telling me what to do as well, so I have a better idea.* (P46, Asian, male, 18, NARS 2.79)

As P46 elaborates, AI initiating conversations in their collaboration facilitates the development of participant's awareness of AI's progress. This situation awareness allows participants to govern the overall course of the teamwork. P46 also points out that AI, as a more skilled team member, can guide them in completing the team task.

4.2.3 AI teammates lacking proactive communication is perceived as an individual rather than a teammate, which hinders coordination between humans and AI teammates. When AI does not communicate with humans enough, it is difficult for humans to coordinate accordingly. P4 (White, female, 18, NARS 3.64) points out:

> *Lack of communication means that there's obviously going to be less trust in the AI system. And then, of course when there's less trust and less communication, obviously,*

> *you're gonna get frustrated more, and not necessarily want to use the AI. So like a team would crumble. There wouldn't be a team. It'd be like two individual players.*

Here P4 points out that communication functions as the glue that holds the team together. Lack of communication creates an unhealthy teaming environment, where humans perceive the AI teammate as another *individual* who performs the same task, rather than a teammate. In addition, little amount of communication hinders human from developing trust in the AI teammate and produces frustration perceptions. Likewise, P10 (Asian, female, 18, NARS 3.50) expresses thoughts on AI being too individualistic:

> *(What they can do better was) just tell me when they were dropping off the crate, so it wasn't just totally me trying to figure out where everything was.*

According to P10, the AI teammate not communicating much with humans makes it more difficult to work on the task together. Instead, the progress of completing team tasks are more like humans working on them independently rather than working with a partner as an unity. In contrast, AI being proactive in communicating with humans presents team effort and shortens the distance between humans and the AI teammate. P44 (Black, female, 21, NARS 2.86) elaborates more on how communication shows team effort:

> *When you're talking to someone (during) completing a task, it displays team effort, great accountability. You can rely on them because you don't have to worry about what they're doing, because they're letting me know. It creates a more solid foundation when words and people express their actions.*

For both P10 and P44, AI's communication is not only a way of passing information to humans, but also showing AI's proactivity in completing shared team goals as a part of the team. Thus, AI communicating their progress proactively and even helping humans through communication indicate that they are actively working on the team task, "care" about the team and are willing to take the responsibility as a team member. Too little communication in teamwork could create an imbalanced unhealthy teaming environment due to insufficient information sharing and incorrect prediction of teammate's decisions.

4.2.4 AI teammates lacking proactive communication forces humans to utilize other implicit communication approaches in HATs. While AI teammates' proactive communicate could facilitate maintaining humans' situation awareness, implicit communication could be used as an alternative to maintain it. Our interview data shows participants take advantage of implicit communication cues in team tasks to maintain their understanding of what the AI teammate is doing and the team's progress. For instance, P37 (White, female, 19, NARS 3.36) shares:

> *So once I had figured out, I could go and see on the map, like this crate is missing, they just dropped off this one. So I'm getting this one.*

For P37, maps in game are used as an implicit communication cue, which help humans know which crate the AI teammate has collected and which one they should collect. In other words, humans can utilize the implicit communication cues, i.e., AI's actions and AI actions' results, to keep their awareness regarding their team progress.

Another type of implicit cues, audio, is mentioned to help maintain team situation awareness:

> *Every time I would go back, I would see him coming. So I knew which crate he was going to. And then same thing other like the other way around, so I kind of didn't feel the need to type in chat as much. I figured it was taking a lot of time off anyways. So (it) ended still working out.* (P23, White, male, 18, NARS 2.07)

According to P23, the implicit communication (i.e., text communication) is time-consuming, whereas seeing the AI teammate in the 3D space in game provides enough information for humans to coordinate and complete team tasks. This implicit cues ensures that humans are aware of the AI teammate's actions in the environment, understand AI's actions and know the projection of their status followed by the current action. P49 (White, Non-binary, 20, NARS 2.93) also mentions that the explicit communication is inefficient whereas humans can take use of implicit communication:

> *I just tracked his moves on the map, and looked and saw what crate he was doing. The chat took a minute to type everything out. So I wouldn't do that, just rather look and see what he was doing. It (AI's communication) was kinda poor.*

Since the AI teammate is not capable of sharing information proactively, P49 believes that humans may prefer to use implicit communication over pulling information from AI teammates through explicit communication. Checking the map enables humans to track AI teammate's movements and task progress. However, another participant points out that even though implicit cues are helpful in developing team situation awareness, explicit communication initiated by AI teammates would reduce workload on the human teammate's side:

> *The only thing is, it's hard to monitor when they were going back and forth, or whenever they were done, because I either had to keep like looking at the map or see them in passing. So I think it would have been easier if they were like, Oh, I just dropped this one off.* (P28, White, female, 19, NARS 2.71)

For P28, both checking on maps or noticing AI teammate driving by are difficult to utilize in team coordination. Instead, if the AI teammate has the capability to share their updates on team tasks, the coordination between humans and the AI would be easier while they would still be aware of AI's actions and team progress.

In summary, AI proactively communicating with humans supports the development of human trust and maintaining team situation awareness in various ways. Specifically, AI's proactive communication assists trust development in the AI teammate through benefiting human's individual performance, presenting transparency of their behaviors, and being perceived as a reliable *teammate*. Such proactive communication from AI teammates also develops and maintains team situation awareness by informing AI's progress, helping humans move on with their shared responsibility, and even guiding humans on next steps of game tasks. In addition, AI lacking proactive communication could hinder humans' coordination with them and even generates negative perceptions, such as frustration.

5 DISCUSSION

In response to our research questions, our findings have highlighted that humans seek that AI teammates employ four communication strategies to support dyadic HATs: (1) proactively communicating with humans; (2) employing balanced communication with both efficiency and sociability; (3) providing quick responses; and (4) avoiding large amounts of communication once the communication pattern has formed in repeated team interactions (RQ1). In addition, AI teammates proactively communicating with humans can support their coordination with humans in a dyadic HAT by developing human trust and team situation awareness in teaming environments, whereas AI teammates lacking proactive communication are perceived as an individual rather than a team member, which hinders team coordination (RQ2).

In this section, we first discuss how our findings extend current knowledge on communication in dyadic HATs and human-only teams in CSCW. We then propose three key elements for human-AI communication in 1:1 teaming environments grounded in our findings and prior work on

communication in computer-mediated collaboration. Last, we discuss how these three components can be extended to dyadic HATs in other contexts.

5.1 Communication Strategies for AI Teammates and Their Impact on Team Processes

Our study extends current CSCW work on communication in dyadic HATs by providing a holistic view of AI teammates' communication strategies through the lens of human perceptions and experience.

A specific highlight of our findings is the importance of AI teammate's proactive communication in the dyadic teams that were studied. Within both the context and composition of teams studied, people perceive AI that proactively shared information as a reliable partner and teammate, but view non-proactive AI as loners rather than team-players. As such, humans that interact with non-proactive AI in these contexts and compositions might not perceive their interactions with the AI as collaborative. Unfortunately, lacking this sense-of-team could have adverse effects on these dyads, hindering the coordination between the human and the AI. Critically, this supports prior work that has identified the impact of proactive communication on the formation of individual [126] and team [11, 41] processes and perceptions. This work also extends our understanding of how AI teammates can be social actors [84], in that the identity of these actors (i.e. teammate) in this context and composition is in fact influenced by the proactivity of an AI teammate's communication. As such, it is critical to consider the inclusion of proactive communication in designing an AI to be a "teammate" within these dyadic contexts.

However, it is worth considering whether the preference for proactive communication would apply beyond the examined context and team composition. For instance, for team tasks that are more decentralized, each team member has an isolated responsibility with low interdependence with other team members. The completion of such tasks is less reliant on team communication [55]. Therefore, proactive AI communication might not be as useful and desirable as for interdependent tasks. In regard to team composition, HATs with team composition more complex than dyads may not benefit as much from AI's proactive communication, as the humans in such HATs can quickly become overwhelmed by the amount of information pushed by each AI teammate, and their workflow interrupted [92].

Another important insight is that excessive amount of communication from AI teammates could negatively impact human-AI coordination. This is in line with previous work on human-only teams demonstrating that team coordination that requires low communication volume usually have better team awareness and high efficiency [70, 71]. Our findings were able to pinpoint where the problem of high volume of communication lies between humans and AI teammates in dyadic HATs. It appears that well-established communication patterns formed throughout the interactions within a 1:1 HAT eliminate the need for large amounts of communication; and the timing of communication is critical as to not interrupt and sidetrack task coordination among the two team members. After all, interruptions could lead to incomplete team tasks and even severe mistakes [40]. The identification of these two aspects may help explain the inconsistent results of communication volume on team performance in 1:1 HATs [14, 117]. Importantly, the amount of communication is likely to increase in HATs with more complex team compositions, which may result in information overload and impact human-AI collaboration.

In summary, these communication strategies that humans desire AI teammates to utilize and their impact are crucial to 1:1 human-AI team communication design. Our study extends existing work on human-AI communication in dyadic teaming environments and provides new insights for future AI communication design. These new perspectives could be used as a foundation and combined with previous research on communication in HATs and human-only teams to better structure human-AI communication for both dyadic HATs and HATs that involve more than one

human teammate and one AI teammate. However, potential risks and ethical issues should be considered while applying these communication strategies on AI. First, humans need to be aware of the information's accuracy from the AI. Research has shown that appropriate trust calibration (i.e., humans knowing when to trust and when to distrust an AI) is crucial to success in human-AI collaboration [47, 124]. AI proactively communicating intentionally inaccurate information could be perceived as unethical and further result in negative team outcomes. Second, trust in a human teammate and an AI teammate needs to be balanced in triad or more complicated HATs. In the past decade, plenty of work has endeavored to explore how to increase human trust in AI for better human-AI collaboration [5, 107]. However, it could be risky when the trust in AI overweights the trust in human teammates, especially in certain contexts like the military and healthcare.

5.2 Three Key Elements in Designing Communication in Dyadic HATs

Grounded in our findings and existing communication principles in previous studies on computer-mediated collaboration, we propose three key elements in designing communication for dyadic HATs: AI's communication strategies, communication goals, and humans' communication requirements. We will discuss each key element using highlights from our findings along with insights from previous literature, as well as the application of these elements beyond gaming.

5.2.1 Three Key Elements in Human-AI Communication. Team communication is a key factor in supporting both cognitive and affective processes [63, 78]. While previous CSCW research has explored communication in HATs through various attributes (e.g., communication quantity [14, 77] and communication frequency [87]), this study provides additional insights on how humans perceive AI's communication and how it then facilitates their coordination in dyadic HATs. At a team level, we synthesize how each party of the team (humans and AI) should be designed to achieve effective team outcomes.

First, *communication goals* play an essential role in building effective team communication by facilitating team members to coordinate smoothly [45, 94, 104]. Specifically, humans and AI teammates have different needs for information, and as such human-AI team communication strategies should explicitly differentiate communication needs. On the one hand, for human-to-AI communication, the content communicated is expected to center around *must* information for AI teammates to make decisions [7]. To maintain the interaction between humans and AI teammates, AI teammates need to make decisions with humans providing task-related input that is not accessible to AI teammates. On the other hand, one essential goal in AI-to-human communication is to develop human trust in the AI teammate and their awareness of team processes, as indicated by previous work on human-only teams [50]. In this sense, AI teammates usually need to actively communicate information which helps humans to develop situation awareness (e.g., sharing AI's task progress and confirming task needs with humans). In addition, this information provided by AI teammates is necessary for human teammates to make decisions, which benefits team coordination and teamwork progress.

Second, to better achieve the pursuit of the communication goals, it is necessary to design *AI's communication strategies* in an understandable and efficient way for team members to communicate [1, 52]. The communication strategies we proposed in this study aim to provide insights into how an AI teammate should apply communication to build trust and achieve high team outcomes (i.e., AI-to-human communication goals) with the human teammate. Structuring AI-to-human communication requires the inclusion of multiple different strategies to best enable the goals above. One example of a communication strategy is having AI teammates provide immediate responses, which is critical for humans to ensure communication is received and well interpreted by AI teammates. This finding supports previous research that identifies the importance of such

responses in human-only teams with non-collocated communication [88] and even networking between computers, which fundamentally requires the use of responses [113].

Third, *humans' communication requirements heavily impact their own collaborative experience with AI in dyadic HATs. While the manner in which AI's communication strategies should be structured is crucial in facilitating team coordination, how humans perceive them and how humans prefer to react to AI's communication largely shapes whether their communication goals could be achieved. Our findings indicate that humans want to minimize their own burden of communication, especially when they have specific responsibilities to fulfill. This supports previous work that indicates that distraction and interruption, which hinder humans from completing their own task, could result in negative outcomes in safety-related tasks [102].* While humans need to provide AI teammates the necessary inputs for AI's decision making, the communication of these inputs should not be a burden to human teammates. It is interesting to see that while humans expect AI teammates to provide immediate responses to their messages, they also prefer not to be *required* to respond to AI's communication. This imbalance between humans and AI supports a large amount of work on human-AI collaboration that indicates that AI is treated differently from humans [79, 112, 123]. Taking this imbalance of humans-AI communication into consideration, dyadic HAT communication design can utilize team communication more effectively and develop a trustworthy teaming environment.

5.2.2 Future Application of the Three Key Elements in Dyadic HATs. The fast-changing and context-dependent features of team communication make it challenging to design and examine in HATs. Research on human-only team communication has suggested the essential role of team characteristics, team roles, and tasks in impacting team communication [97, 108, 125]. In addition, it is recommended that teams deploy communication strategies according to the specific task [106]. In this section, we will discuss team characteristics and context dimensions in our study, and how the three key elements could be extended in other contexts by comparing against these features.

Using previous work on team characteristics and context in human teams as a foundation [108], we selected and adapted the context dimensions that can be depicted in our study, as shown in Table 4. These team and task dimensions identify the context in which the proposed communication strategies were developed. To extend the three elements into contexts, a comparison between our team/tasks characteristics and target team/context is necessary to ensure a more accurate application. Below we discuss how the proposed three key elements would be applied beyond the context of this study using *team size/composition* and *situational stressors* as an example.

Table 4. Team or Task Characteristics in Our Study

Dimension Type	Dimension	Details
Team	Roles	Human and AI share the same responsibilities in this task.
	Size/Composition	A dyadic HAT composed of one human and one AI teammate.
Task	Task Type	Each team member's task involves two parts: (1) figuring out which crate to get in numeric order through team communication; and (2) get the crate and drop it off.
	Communication Method	A text-based chat channel is provided for team communication.
	Situational Stressors	Eight-minute timed task with a timer displayed on the screen.

While many teams perform in a 1:1 setting, such as HATs in data science [112] and healthcare [7], plenty of research on HAT has explored triads (e.g., three-member HATs composed of at least one human and one AI) [76, 107]. For non-dyadic HATs, communication goals are likely to stay the same in terms of developing human trust in the AI, maintaining humans' situation awareness, and ensuring the team task proceeds with needed information. However, AI's communication and humans' communication requirements may be slightly different. For example, a HAT where a human collaborates with multiple AI teammates may not benefit from proactive cycles as much as our findings indicate due to information overload resulting from a multitude of AI pushing information [12, 92]. Yet, in this type of HAT, AI would still need to push information, but the rate of information may be slow and the information may be abstracted to meet the needs of humans [92]. This adaption of AI's communication strategies would help future researchers to utilize the three elements more accurately. As research in HAT continues to develop,these three key elements could be used for future research to build upon and even updated and contextualized to best serve specific teams and contexts.

Situational stressors also play an essential role in impacting team communication [108]. Our study used a time-sensitive task, which requires immediate responses and task-related updates to proceed with team tasks effectively. However, in contexts without such time stressors, team processes would be much slower. In this sense, emergency healthcare and human resources provide two examples that are impacted by time stress differently. Emergency healthcare environments often have extreme time pressures that require stronger interdependence and situation awareness to ensure success [60]. These teams would probably benefit from communication strategies that benefit situation awareness, such as those found in this study. On the other hand, human resources, which is often a slower paced, procedural, and formulaic environment [38], might benefit from communication strategies that do not disrupt human workflow, such as the use of non-proactive communication. However, team communication should still aim to build human trust and support team performance.

Given the broad range of different contexts as well as team characteristics, two critical steps are important to ensure the extension of our findings in other contexts: (1) identifying the team characteristics and task dimensions of the target context; (2) adapting three key components according to the target context using previous literature as support. For step (1), the human-centered design of AI teammates requires context-specific consideration, and research should work to identify which team or task dimensions in Table 4 are overlapped with the target context. For step (2), empirical experiments and principles in previous literature can be used to identify necessary modifications of each communication element. Following these two steps, future research could use the three key elements in human-AI communication proposed in this work as a starting point to further explore the design of human-AI communication in HATs under various contexts.

5.3 Limitations and Future Work

This study has several limitations. First, it is important to note that the dyadic team setting in this study may impact how the findings can be applied in other settings. The AI teammates' communication strategies identified in this study may look slightly different with more complex team compositions, such as teams with multiple AI teammates or multiple human teammates. However, this work serves as a foundation for future AI communication research to build upon. Using the three key elements proposed in this study as a base, future work can develop their communication strategies for multi-human or multi-AI HATs based on future findings regarding team composition. Second, this study utilizes a team setting where the human teammate and the AI teammate share the same responsibility. Findings may be slightly different in HATs with more unique roles. Future research should explore what communication strategies humans expect AI

teammates to utilize when they take different roles in a team. Third, this study only examines communication between humans and AI teammates in a specific context. While context is always a critical component to HAT, it would be impossible to examine every potential context despite the impact of context on human-AI team communication. Thus, future work should examine and extend the communication strategies outlined in this study to other contexts. Fourth, all participants were college students with an average age of 19 years old. Prior research has shown that age could impact how humans perceive technologies [32], both of which could impact their trust in the systems [109]. In addition, our participants are not experienced in completing the task in our study. As novice individuals, their experience in a specialized HAT task might yield slightly different results from people who are experts in a real-world HAT task. Thus, future work should explore human-AI communication in dyadic HATs with a more general population, which would provide a more complete understanding of human-AI communication in teams. Lastly, this study only considers the situation where AI teammates' communication is always accurate, which is difficult to achieve in real-world tasks. Given that AI's decision-making accuracy could heavily impact humans trust in the AI and the collaboration process [86, 91, 120], future work should further explore how AI teammate's communication is perceived with different communication accuracy and how that further impacts human-AI coordination in dyadic teams.

6 CONCLUSION

In this study, we have explored how AI teammates should utilize to coordinate with humans smoothly in a fast-paced online dyadic teaming environment. Our findings have highlighted four specific strategies AI teammates should apply to facilitate their collaboration with humans. In addition, our study findings describe how an AI teammate's communication could support human-AI coordination by developing humans' trust in the AI teammate and team situation awareness in the dynamic dyadic teaming environment. This study expands prior CSCW/HCI research on AI's communication in dyadic HATs and could serve as a foundation for future research on human-AI communication by providing an in-depth understanding of how AI's communication should be structured to facilitate team process in dyadic HATs. Our findings could help CSCW researchers and AI designers to better shape communication in both dyadic and more complicated HATs for close collaboration between humans and AI teammates.

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