SOCIAL INTERACTIONS WITH AUTONOMOUS AGENTS: TEAM PERCEPTION AND TEAM DEVELOPMENT IMPROVE TEAMWORK OUTCOMES

by

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of
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ABSTRACT

SOCIAL INTERACTIONS WITH AUTONOMOUS AGENTS: TEAM PERCEPTION AND TEAM DEVELOPMENT IMPROVE TEAMWORK OUTCOMES

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Among groups of humans, the team structure has been argued to be the most effective way for people to organize to accomplish work (Groom & Nass, 2007). Research suggests that humans and autonomous agents can be more effective when working together as a combined unit than as individual entities (Marble Bruemmer, Few, & Dudenhoeffer, 2004). However, the drive toward capable autonomous teammates has focused on design characteristics while ignoring the importance of social interactions between teammates. Two experiments were performed to study how the perception of teamwork among human-human and human-autonomous agents and the application of team building interventions could enhance teamwork outcomes in the form of affect, behavior, and performance. In the first study, it was revealed that considering your human and autonomous partner a teammate resulted in improved affect and behaviors relative to a considering these agents as tools. However, team structure did not lead to significant performance differences. In the second study, participants completed goal setting and role clarification, two forms of team building, with their teammate prior to task performance. The team building interventions led to significant improvements for all three teamwork outcomes, including performance. Across both studies, participants communicated with human partners differently than they did with autonomous partners. These findings suggest that social interactions between humans and autonomous teammates should be an important design consideration, and that particular attention should be given to team building interventions to improve affect, behavior, and performance. Further research should explore team training, another form of team development, which may be useful for improving communication between humans and autonomous agents.

INTRODUCTION

In interviews, Explosive Ordnance Disposal (EOD) soldiers, highly trained experts who work with bomb disposing robots tasked with destroying improvised explosive devices, have emphasized the importance of close relationships with the members of their team. They give these robots nicknames, take care of their robots, note that they feel affection that grows stronger over time, and experience a great rush of emotions when a teammate is lost (Carpenter, 2016). As evidenced by the tale of EOD soldiers, teamwork is a social interaction, with cognitive, emotional, and behavioral components (Kozlowski & Ilgen, 2006). This way of thinking about teamwork falls in line with definitions from the social psychology literature which emphasizes the study of thoughts, feelings, and behaviors as they are influenced by the actual, imagined or implied presence of others (Allport, 1985). Interestingly, researchers have found that humans interact socially with non-human agents, applying human social rules and expectations to these agents (Groom and Nass, 2007). In fact, the thoughts, feelings, and behaviors of the aforementioned EOD soldiers described above are actually findings from an ethnographic study of the interaction between human soldiers and their bomb disposing robots (Carpenter, 2016). Findings such as those have given rise to a new field of study (e.g. social robotics, human-robot interaction), creating new ways of thinking about how to support effective interaction between humans and autonomous agents.

While great strides are being made in developing increasingly capable autonomous teammates, less is understood about the social interaction between humans and autonomous teammates. As humans and autonomous agents work interdependently to accomplish common goals, we should consider not only the design of the robot but the effect it has on the thinking, feelings, and behavior of the human participant. Teamwork is considered one of the most effective ways for humans to accomplish work (Groom & Nass, 2007). The power of teamwork has, not surprisingly, spurred a growing demand for capable autonomous teammates. In light of our tendency to apply human social rules and expectations to interactions with non-human agents, the research proposed herein will explore the nature of the social interaction between humans and non-human teammates. Particular attention will be devoted to the role that anthropomorphism may play in eliciting social interaction and the evaluation of these interactions from a team process perspective (i.e. affect, behavior, and performance).

The sections below will first describe how humans interact socially with non-human agents, followed by an integration of a paradigm for social interaction with computers and a model for anthropomorphism that may explain why humans interact socially with non-human agents. We will then focus on a specific type of social interaction, teamwork, and discuss whether or not an autonomous system can truly be a teammate. This discussion points toward two specific experiments which will first compare autonomous agents as teammates versus tools and subsequently employ a team building intervention for the purpose of enhancing social interactions between humans and non-human teammates.

Social Interaction with Non-Human Agents

Humans have a long history of social interaction with non-human agents. For example, humans began domesticating wolves approximately 12,000 years ago and cats nearly 4,000 years ago (Serpell, 1996). Today it is recognized that pets provide a number of health benefits to humans, both psychological and physical (Beck & Katcher, 2003). Social support theory proposes that animals provide social companionship which leads to improved health similar to the effects of marriage, good neighbors, or a strong faith community (Beck & Katcher, 2003). These effects may not be surprising in light of the fact that many pet owners consider their animals to be a family member and treat it as a trusted confidant (Katcher, 1981). Much research in human-animal social relationships has focused on the beneficial nature of pets and service animals for elderly or recovering patients (House, Landis, & Umberson, 1988; Raina, Waltner-Toews, Bonnett, Woodward, & Abernathy, 1999), while other researchers have focused on the benefits of pet ownership for young children (Bryant, 1990).

Surprisingly, the tendency to interact socially with non-humans extends beyond living creatures (Nass, Steuer, & Tauber 1994). More recently, with the development of sophisticated computer systems, researchers have begun to study social interactions between humans and computers. When Card, Newell, and Moran first popularized the term "Human-Computer Interaction" they noted that humans and computers engage in a dialogue, suggesting some equivalence to human-human interaction (Card, Newell, & Moran, 1983). Later research into the ways in which humans engage with various forms of media demonstrated that human-computer interaction is fundamentally social, giving rise to the *Computers as Social Actors* (CASA) paradigm (Nass et al., 1994).

A group of CASA studies demonstrated that the social rules of human-human interaction also regulate human-computer interaction (e.g. Nass et al., 1994). For example, humans apply social norms for politeness during interactions with computers (Nass et al., 1994). In the Nass (1994) study, when a computer directly asked participants to evaluate its performance, the participants rated it more positively than when a third party requested the computer evaluation. Another experiment in that study found that humans will apply gender stereotypes to computers, finding the “female” computer to be more knowledgeable about love and relationships, while preferring praise from a “male” computer. A follow up study, applied the “similarity-attraction hypothesis” to HCI, demonstrating that humans prefer computers that have a similar personality to their own (e.g. dominant or submissive; Nass, Moon, Fogg, Reeves, & Dryer, 1995). While even basic desktop computers with minimal human-like characteristics can elicit social responses, researchers have suggested that the growing capabilities of technological systems (e.g. automated systems, autonomous agents) will support even stronger social interactions (MacDorman & Ishiguro, 2006).

The study of human social interaction with technology incorporates increasingly capable systems featuring varying levels of autonomy. Automated systems are non-human machines or software employed to perform work that was once done by humans (e.g. navigate waterways, manage air traffic, manufacturing products; Statheros, Howells, & Maier, 2008; Billings, 1995; Bourne & Fox, 1984). These systems have four classes of functions: information acquisition, information analysis, decision selection, and action implementation (Parasuraman, Sheridan, & Wickens, 2000). In addition to function, automated systems can be characterized by their degree of autonomy. The “level of automation” refers to the degree of authority the autonomous system possesses in order to decide and act (Parasuraman et al., 2000). At the low end of the scale (1-5), humans possess the authority to decide and act. While at the high end of the scale (6-10), decision and action are controlled by the automation. The present study is largely focused on autonomous agents which have been defined as “systems situated within and a part of an environment that sense that environment and acts on it, over time, in pursuit of its own agenda and so as to effect what it senses in the future” (Franklin & Graesser, 1996).

Autonomous agent classes include both software agents and robots, which have been defined as entities empowered to act in facilitation of their own goals (Duffy, 2003, pp. 177-178). The increasing presence of robots and acknowledgment of their capacity to elicit social interaction has precipitated the development of the field of human-robot interaction as an evolutionary offshoot from human-computer interaction. For example, researchers have extended Nass and colleagues (1997) work on robots as social actors in a variety of ways. First, there have been explorations into how a robot’s gender can influence social responses (e.g. Powers & Kiesler, 2006; Niculescu, Hofs, Van Dijk, & Nijholt, 2010). The emotional assessment and expression of robots during social interaction is another area of interest (e.g. Breazeal, 2003). In addition, human robot interaction principles have been assessed in such applied settings as robotic museum tour guides (Burgard et al., 1999), education (Nourbakhsh et al., 1999), and search and rescue

(Murphy & Burke, 2005). More recent research has further extended Nass' work, demonstrating that people treat robots as social actors, and establish social rapport with robots (Freidman, Kahn, & Hagman, 2003).

Whether computer, automation, or autonomous agent, one common thread is that our interaction with this technology remains fundamentally social. Surprisingly few cues are required to elicit strong social responses to technology (Nass & Moon, 2000). Research suggests we are cognitively predisposed to interact socially and this predisposition can be amplified by our need to understand our environment while fostering social connections.

Non-Human Agents as Social Actors

Despite the expanding capabilities of autonomous agents to interactively communicate and fulfill human roles, they are still not human and do not necessarily warrant social interaction. Paradoxically, the CASA paradigm has demonstrated that human-computer interactions are fundamentally social (Nass & Moon, 2000). The interaction with objects as if they were human while at the same time knowing that those objects do not warrant human treatment has been termed *ethopoeia* (Nass & Moon, 2000). The CASA approach suggests that *ethopoeia* occurs as a result of cues that activate human social scripts, which are then applied mindlessly. In particular, computers have several characteristics that may cue social responses, such as (a) words for output; (b) interactivity or responses based on multiple prior inputs; (c) filling roles traditionally filled by humans. These minimal cues have been demonstrated over a considerable body of research to consistently elicit social interactions with computers (Nass & Moon, 2000).

One common explanation for social interaction with non-human agents is anthropomorphism (Barley, 1988; Winograd & Flores, 1987). Anthropomorphism occurs when one ascribes humanlike characteristics, motivations, intentions, and emotions to the imagined or real behavior of nonhuman agents (Epley, Waytz, Cacioppo, 2007). In other words, anthropomorphism can be defined as making inferences about a nonhuman agent, as opposed to simple descriptions of a nonhuman agent's observed behavior. Numerous studies have supported the relative ease at which people anthropomorphize a wide array of agents from simple moving shapes (Heider & Simmel, 1944; Morewedge, Preston, & Wegner, 2007) to God (Barrett & Keil, 1996).

When agents are anthropomorphized it influences how they are treated, how future behavior is predicted, and how observed behaviors are interpreted (Epley et al., 2007). Epley et al. (2007) suggest that incorporation of anthropomorphic principles into design can improve interactions through improved understanding and affect. Much research has been performed along these lines, particularly in the field of human-robot interaction. For example, people demonstrated improved affect and were more cooperative with playful robots as opposed to serious robots (Kiesler & Goetz, 2002). When an interface incorporates anthropomorphic features, participants have felt better understanding between themselves and the agent (Burgoon et al., 2000). Furthermore, users of computer software have found improved learning when aided by anthropomorphic user assistants (Moreale & Watt, 2004). Anthropomorphic features have also been shown to improve affect, people have demonstrated more resilient trust in anthropomorphic agents (de Visser et al., 2016).

Beyond behavior, prediction, and interpretation, anthropomorphic features have been shown to have a top-down effect on bottom-up attentional processes. One particular area of research focuses on the gaze cueing effect in which attention is shifted in the direction that other people are looking (Frischen, Bayliss, & Tipper, 2007). Researchers have found, for example, that the gaze cueing or “social attention” effect can be triggered by referring to an ambiguous stimulus as eyes rather than a car (Ristic & Kingstone, 2005). Further research has demonstrated that higher order (task-irrelevant) beliefs about the intentionality of an agent can influence sensory processing (Wiese, Wykowska, Zwickel, & Müller, 2012; Wykowska, Wiese, Prosser, & Müller, 2014).

Interestingly, there is a great deal of variation in anthropomorphism, with both the individual and situation influencing the outcome (Epley et al., 2007). In an effort to explain why people anthropomorphize and when they are likely to do so, Epley and colleagues proposed the Three-Factor Model of Anthropomorphism, which is built on the assumption that humans default to an anthropocentric knowledge structure when attempting to understand novel situations (Epley et al., 2007). The three factors are sociality motivation, effectance motivation, and elicited agent knowledge.

The first two factors are motivational, relating to the need for social connection and predictability. Humans possess a *sociality motivation*, or a basic need for social connections with others which can be meth through anthropomorphism (Epley et al., 2007). Humans also maintain a drive to understand and predict the complex world or, put simply to “interact effectively with one’s environment”. This motivation has been termed *effectance motivation* (White, 1959, p 297; Epley et al., 2007).

The final factor in the Three Factor Model, *elicited agent knowledge*, is the cognitive determinant of anthropomorphism (Epley et al., 2007). When faced with novel situations, humans must make inductions about the behavior and thoughts of other agents. These inductions are informed by the most easily accessible information and models for comprehending behavior. Not surprisingly, for humans the most easily accessible model for explaining and predicting behavior is anthropocentric. People refine behavioral knowledge of themselves and humans in general over lifetime and employ that knowledge in nearly every social interaction. The degree to which an agent is anthropomorphized can be predicted by the degree to which it elicits anthropocentric knowledge structures.

Interestingly, CASA paradigms reject anthropomorphism as an explanation, despite the fact that both CASA and the Three Factor Model predict similar outcomes (Nass & Moon, 2000; Epley et al., 2007). Nass and Moon, suggest that any social interaction with technology is mindless, explaining that since it is well understood that technology does not warrant human treatment the response is unconscious application of cued scripts for social behavior. Importantly, the CASA studies defined anthropomorphism as a *sincere* belief that an object possesses human traits or characteristics. This narrow definition of anthropomorphism differs from Epley and colleagues' broader psychological definition: "imbuing real or imagined behavior of nonhuman agents with humanlike characteristics, motivations, intentions, and emotions" (Epley et al., 2007). Furthermore, the broader view recognizes degrees of anthropomorphism along a continuum ranging from *weak*, metaphorical ways of thinking to *strong* convictions about agents. Beliefs about the will or mental state of a deity or the traits of a beloved pet are strongly held anthropomorphic judgements. On the other hand, metaphorical ways of thinking about an object (e.g. cursing at a car that will not start) do not require belief that an object possesses humanlike traits.

Considerable research supports the findings that humans engage socially with non-human agents. In the technology domain, this research began with computers and now also encompasses autonomous agents (e.g. robots, software agents). Increasing capabilities of these agents can enhance social interactions and a common explanation is our tendency to anthropomorphize non-human agents. The Three Factor Model suggests that characteristics of an agent can elicit anthropocentric knowledge structures, thereby resulting in social interactions with the agent evidenced by thoughts, feelings, and behavior. These social interactions may conform to very specific knowledge structure and one area that could especially benefit from enhance social interaction is human-autonomous agent teaming.

Joint Action between Humans and Autonomous Agents

Automated systems perform tasks that were once performed by humans, potentially reducing the danger to humans, improving data, and providing cost and time savings (Marble, Bruemmer, Few, & Dudenhoeffer, 2004). However, these automated systems rarely completely remove humans from the task. Instead, the incorporation of automation changes the nature of the human's role in the task. Rather than directly executing tasks, the human takes on a supervisory role, overseeing the completion of tasks by automated systems (Sheridan, 1992). Some have described this relationship as master-slave, in which the human supervisor commands the automated systems or wields them as tools and retains final decision making authority (Marble et al., 2004). Traditionally, human-automation interaction has been studied under the master-slave control architecture (Muir, 1994; Muir & Moray, 1996; Dzindolet, Pierce, Beck, Dawe, & Anderson, 2001; de Visser, Shaw, Mohamed-Ameen, & Parasuraman, 2010).

Ostensibly, automation supports more efficient operations though a reduction in operator workload (Farrell & Lewandowsky, 2000). In practice, however, the offloading of some tasks onto automation merely places new supervisory demands on the human and creates unforeseen opportunities for errors (Parasuraman & Riley, 1997). These supervisory control systems may amplify cognitive demands on human operators as they struggle to integrate multiple information sources (Cosenzo, Parasuraman, & de Visser, 2010; Cummings & Mitchell, 2008; Woods, Patterson, & Roth, 2002). Many failures in master-slave control structures stem from lapses in communication and loss of situation awareness. Furthermore, this type of strategy requires regular human inputs, meaning performance degrades rapidly when the operator is overloaded or lapses have occurred (Fong et al., 2002).

One method to overcome the human limitations that are associated with automation-as-a-tool control strategies is to utilize autonomous, self-governing systems. Unlike automated systems, which can perform human tasks but still requires a human-in-the-loop, autonomous systems are self-directed, eliminating the need for direct human control. The absence of a human operator has several advantages as autonomous systems do not expend resources for cognitively demanding tasks; can process large amounts of data; and are unaffected by biases, moods or emotions (Groom & Nass, 2007). Many domains have capitalized on the growing capabilities of autonomous systems, making humans increasingly dependent on automated agents such as decision aids, search-and-rescue robots, and unmanned vehicles (Dzindolet et al., 2001; Fincannon et al., 2004; Carpenter, 2016). Examples include air traffic management (Billings, 1997), military decision making (Rovira, McGarry, & Parasuraman, 2007), and driving (Stanton & Young, 1998)

It deserves mention that autonomous systems, despite their many advantages, are not without flaws. In a particular, these systems are limited in their ability to perceive, understand, and act (Marble et al., 2004). In other words, the benefits of fully autonomous systems may be outweighed by their “brittleness” in that they can excel at only those tasks for which they have been programmed (Smith, McCoy, & Layton, 1997). This flaw is not easily overcome as designers cannot program a system to respond expertly in every situation. As a result, humans are required as a part of the system so that unanticipated conditions can be managed (Smith, et al., 1997).

The growing utilization of combined human-automation systems highlight the shift away from a supervisory control paradigms in search of more effective interaction models utilizing autonomous systems. Researchers have recognized the limitations of automation-as-a-tool and stand-alone, fully autonomous systems, suggesting that humans and autonomous agents can be more effective when working together (Marble et al., 2004; Smith et al., 1997) For example, human-automation dyads have been found to be more effective at a target recognition task than a human or automated system working alone (de Visser & Parasuraman, 2011). Combined human-automation systems have also been shown to complete tasks more effectively and more quickly (McKendrick, Shaw, de Visser, Saqer, Kidwell, & Parasuraman, 2013), and are more capable of responding to novel situations (Shaw et al., 2010). However, the best way to structure groups of humans and autonomous systems has not been identified (Groom & Nass, 2007). A number of group social structures can be implemented to achieve a goal including hierarchy, pure divisions of labor, and cliques (Groom & Nass, 2007). However, the team structure appears to have the most potential as a model for joint human and autonomous agent systems.

Among groups of humans, the team structure has been argued to be the most effective way for people to organize to accomplish work (Groom & Nass, 2007). Teams are social organizations characterized by high interdependency between team members and shared common goals (Salas, Cooke, & Rosen, 2008). Team membership is associated with heightened communication, trust, effort, and commitment (Abrams, Wetherell, Cochrane, Hogg, & Turner, 1990). Furthermore, people on teams behave differently than people in other organizational structures. They are more adaptable, productive, and develop more innovative and comprehensive solutions to problems. (e.g., Gladstein, 1984; Hackman, 1987; Sundstrom, DeMeuse, & Futrell, 1990). Despite the advantages offered by a team structure, it is not clear whether autonomous agents can be effective teammates (Groom & Nass, 2007).

Can Autonomous Agents be Teammates?

To date, research on human-autonomous agent teaming has yet to comprehensively evaluate whether or not autonomous agents can truly be perceived as members of a team. For one, researchers often misuse “team” to describe any group of humans and autonomous agents, when, in reality, specific criteria must be met in order to be classified as a team. In addition, teams have a well-defined set of processes and outcomes that are typically overlooked in human-autonomous agent team research. Despite these shortcomings, research suggests that autonomous agents can be teammates. This section will further elaborate on what it means to be on a team, then describe important team outcome and team effectiveness measures before making the assertion that autonomous agents can be teammates.

Researchers tend to label groups of humans and autonomous agents as teams even though they rarely meet the definition. Teams are interdependent social groups with shared identity and goals (Salas, Dickenson, Converse, and Tannenbaum, 1992). With this definition in mind, many of the so-called teams from the literature should be classified under other organizational structures (Groom & Nass, 2007). In one example, a robot “teammate” on the International Space Station acted as a service robot meeting the needs of the humans onboard (Sierhuis et al., 2003). Though this structure was referred to as a team, in reality it was an example of the master-slave relationship (Groom & Nass, 2007).

Though many positive behavioral and subjective outcomes have been observed in human-automation interactions, these outcomes are rarely considered in the context of factors that predict effective teamwork. Studies have demonstrated that human and automated systems working together are more effective than either entity working alone (de Visser & Parasuraman, 2011). Moreover, higher degrees of autonomy have been found to improve communication and subjective ratings of helpfulness, capability, and independence. Greater degrees of autonomy also led to the system being more strongly perceived as a member of the team (Schermerhorn & Schuetz, 2009). Others have explored the effectiveness of adaptable automation, capable of altering its behavior depending on the perceived needs of the human (e.g. Parasuraman, Cosenzo, & de Visser, 2009). Adaptable automation allows for the flexible delegation of tasks to an automated agent. Adaptable automation improved several factors including situation awareness, self-confidence, subjective workload, and trust ratings. These findings align with numerous team effectiveness, output, and process measures but, unlike the team literature, lack the context of a comprehensive framework.

One popular theory of teamwork stems from the *Input-Process-Output* (IPO) model (McGrath, 1964; Gladstein, 1984). In the team domain, *inputs* refer to the individual team members and the available resources. *Processes* are the manner in which team members coordinate knowledge, skill, and effort to accomplish objectives. They are typically measured as emergent states. *Outputs* can be considered team effectiveness, which has three elements: (1) performance judged by a non-team member; (2) meeting team member needs; (3) and willingness to remain a member of the team (Kozlowski & Ilgen, 2006; Hackman, 1987).

Processes refer to activities that team members engage in, combining their resources to resolve (or fail to resolve) task demands. Processes thus mediate the translation of inputs to outcomes. Although team processes are by definition dynamic, they are most typically addressed in static terms—as constructs that emerge over time (i.e., emergent states) as team members interact and the team develops (Kozlowski, 1999; Marks, Mathieu, & Zaccaro, 2001). Team processes, enable effective teamwork, and are typically categorized into three classes: (1) cognitive structures; (2) emergent states; and (3) behavioral patterns (Kozlowski & Ilgen, 2006).

A comprehensive approach to evaluating human-autonomous agent teaming will consider not only team effectiveness (i.e. performance, validity, and needs met), but also processes in terms of knowledge structures, emergent states, and behavior patterns (Kozlowski & Ilgen, 2006). Team cognitive processes and structures encompass team climate, mental models, and team learning. Some frequently measured emergent states include team cohesion, team efficacy and potency; affect, mood, and emotion; and team conflict. Team behavior incorporates actions such as coordination, cooperation, and communication; and regulation and adaptation (Kozlowski & Ilgen, 2006).

Some claim that the one obstacle to effective human-autonomous agent teaming stems from an inability of that autonomous agent to perform essential teammate behaviors (Groom & Nass, 2007). Several characteristics were identified, including: shared common goals, shared mental models, sacrifice for the good of the group, positive view of interdependence, fulfilled roles, and mutual trust. In consideration of these characteristics, Groom and Nass (2007) suggested that robots could not meet the essential qualities of a teammate. In particular, robots lack self-interest and cannot form shared mental models with teammates. Due to the shortcoming of robots to meet the specific behaviors discussed by these authors, they suggested that alternative models for human-robot interaction be explored (Groom & Nass, 2007). However, it may be possible that humans can work effectively with autonomous systems using other interaction frameworks, and others have suggested that human-robot interactions should be modeled after human behaviors (Krämer, von der Pütten, & Eimler, 2012). It is unlikely for humans to interact with non-human agents in ways that differ from those that are used in everyday interactions with humans. This also aligns with the Three Factor Model which emphasizes that humans default to human models for social interaction (Epley et al., 2007).

The criticisms raised by Groom & Nass (2007) were raised at a time when the shortcomings of autonomous systems to behave as teammates could not be fully overcome. Autonomous systems are now capable of sharing goals with a team and even disregarding human directions if they are perceived by the non-human agent as being counter to higher order goals (Schermerhorn & Scheutz, 2009). Others have explored augmented reality as a method to improve the sharing of mental models with autonomous systems (Green, Billinghurst, Chen & Chase, 2008). These efforts suggest that the teamwork capabilities of autonomous systems will continue to expand. In fact, research seems to indicate that humans quite readily form teams with both humans and autonomous agents.

Research has identified two elements that cause people to organize as teams: interdependence and identity (Nass, Fogg, & Moon, 1996). Interdependence exists when individual outcomes are dependent on the outcome of the group and it seems to induce individuals to behave more like a team, perceiving greater similarity within the group and displaying higher levels of conformity (Mackie, 1986). Identity manipulations have also successfully elicited team behaviors. Individuals with common team names, badges, and labels were more easily influenced by written messages between group members (Wilder, 1990). In fact, a shared social identity as basic as "green team" vs "orange team" have influenced perceptions of dependence and positive affect (Turner, 1982). Highlighting similarities such as shared goals has also been effective at enhancing a sense of team (Groom et al., 2007).

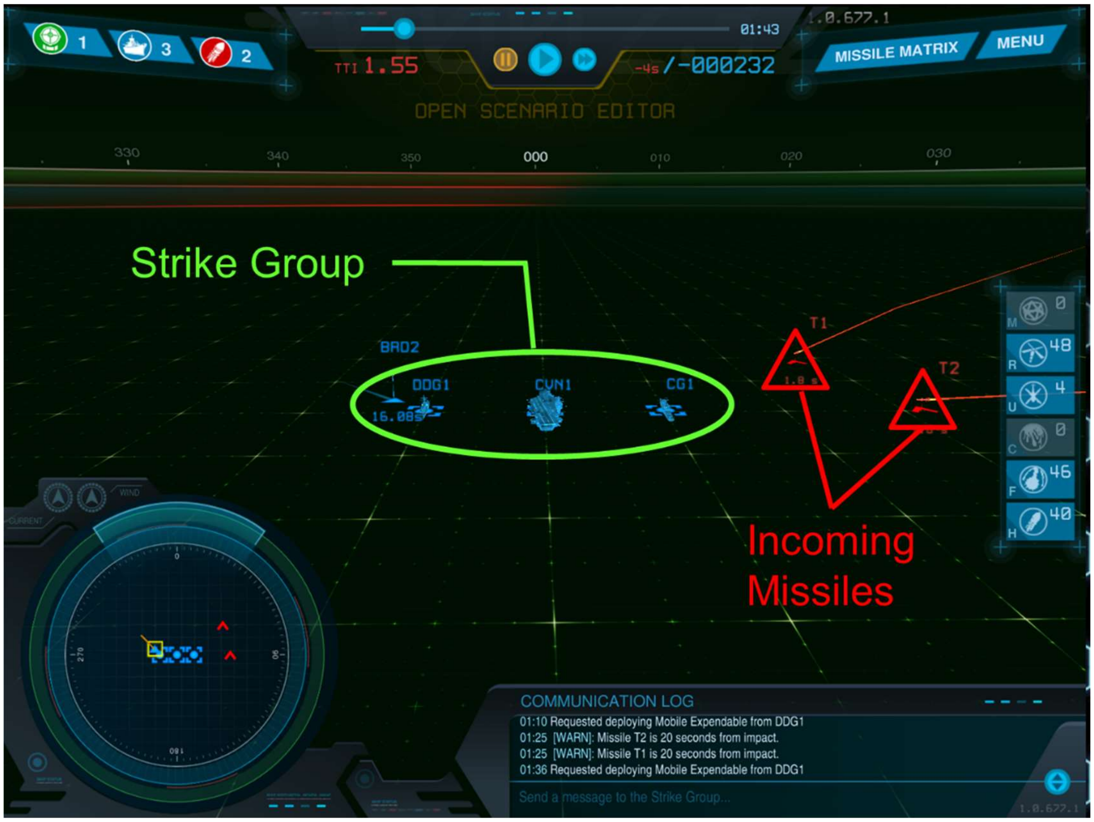
Interestingly, research has demonstrated that humans will affiliate with computers as teammates if the minimal criteria for human team formation are met. An example comes from a study in which participants engaged in a *Desert Survival* task, in which they ranked the value of objects (e.g. knife, water, vodka) in a survival situation while interacting with a computer system that also ranked the value of the objects. In that study, researchers manipulated interdependence by making the final evaluation dependent on the human alone or the performance of both the computer and the human. Participants in the interdependence condition exhibited improved affect and were more likely to conform to the ratings of the automated system (Nass et al., 1996). The outcome of this study was predicted by the CASA paradigm and it also conforms to the predictions of the Three Factor Model (Nass & Moon, 2000; Epley et al., 2007). The presence of interdependence and identity on a simple desktop computer were sufficient to elicit knowledge structures related to team social interactions.

Given that a minimal level of social cues paired with a basic computer could elicit a social response, it is not surprising that others suggest that autonomous and robotic agents would elicit even stronger social behaviors. Autonomous and robotic agents can possess an expanded range of humanlike characteristics and behaviors which should increase the strength of social cues (MacDorman & Ishiguro, 2006). In fact, humans appear to adopt robots as teammates quite naturally, just as they do with their fellow humans. In a field study, a team of search and rescue professionals engaged socially with an assistive robot despite its lack of social intelligence (Fincannon, Barnes, Murphy, & Riddle, 2004). However, until recently, researchers had not explored social interactions with autonomous agents in a teamwork setting while utilizing a comprehensive set of teamwork outcomes (i.e. affect, behavior, and performance).

Pilot Study

The topic of social interactions in human-autonomous agent teams was addressed in a recent study which expanded on the work of Nass and others (1996; Walliser, Mead, & Shaw, 2016). In this study, 32 participants completed a missile defense task in the presence of either a human or autonomous agent. The human agent was played by a confederate and the autonomous agent was simulated using the Wizard-of-Oz technique. This is a commonly used form of deception in which the participant is led to believe that an agent is controlled by a computer when, in reality, its actions are controlled by a human operator (Kelley, 1984). In addition, participants were informed that the partner agent was either a teammate or a non-teammate. When the agent was their teammate, they were informed that their performance was interdependent with the partner agent. When in the non-teammate condition, they were informed that their performance was independent of the partner agent. The agent type (human/autonomous) and partner type (teammate/non-teammate) were the independent variables in a 2 x 2 between subjects design.

The experimental platform used in the study was *Strike Group Defender*, a serious game designed to train United States Navy personnel in ship defense techniques (see Figure 1). The game provides instruction and practice for players with the goal of enhancing their ability to employ defensive countermeasures against a variety of missiles. Each type of enemy missile has a corresponding countermeasure. A number of variables are considered when countering enemy missiles. Successful defense requires the player to identify the missile type, heading, and time-to-impact, then deploy the appropriate countermeasure in a suitable location during a specific window of time. Performance depends on the outcome of each threat missile, the efficient use of countermeasures, and the amount of time each missile was tracking a friendly ship. The interface includes a three-dimensional and two dimensional view of a battlespace centered on the player's ship or group of ships (i.e. a Strike Group).



```
01:10 Requested deploying Mobile Expendable from DDG1
01:25  [WARN]: Missile T2 is 20 seconds from impact.
01:25  [WARN]: Missile T1 is 20 seconds from impact.
01:36 Requested deploying Mobile Expendable from DDG1
Send a message to the Strike Group...
```

Figure 1 Strike Group Defender Virtual Environment

The game allows for multiple players to participate in a single scenario, which creates an environment that requires teamwork. The participants were tasked to defend the strike group from incoming missiles while working with a partner that they believed to be either human or autonomous. Though effective teamwork was not essential to complete the task, better performance would occur when participants employed teamwork behaviors such as coordination, communication, monitoring, and backup.

Results of this study revealed that when a team structure increased affect and performance relative to a non-team structure. At the same time, there was no significant difference in affect and performance between the human and autonomous agent conditions. These results can be interpreted as an indication that humans will interact with autonomous teammates similar to the manner in which they interact with human teammates. Human-autonomous agent interaction may be improved when it is framed as teamwork, with an emphasis on interdependence.

Social Interaction between Humans and Autonomous Agents

This research focuses on human and autonomous agent teamwork from a social interaction perspective. Past research has shown that even rather simple non-human agents will induce social responses from humans (Nass & Moon, 2000). When working together, humans and autonomous agents have the potential to compensate for individual weaknesses resulting in more effective performance. Though it is common to consider any group of humans and automation as teams, researchers have rarely taken into account the social nature of teamwork or considered the need to evaluate human-autonomous agent teams from a social interaction perspective. The pilot study described above addressed these shortcomings with an expansion of the CASA paradigm to teamwork with an autonomous agent. Importantly, the study confirmed the validity of the CASA paradigm and the utility of an evaluation grounded in teamwork outcomes for human-autonomous agent teams.

However, the study failed to address some questions that may be essential for the effective application of these findings to human-autonomous agent teams. First, the pilot study did not consider the predominant automation-as-tool interaction paradigm. The teammate and tool paradigms should be evaluated in order to assess their viability. In addition, another feature of human teams is that they often require targeted interventions to ensure effective social interactions. It is not yet known if team building interventions can also be applied to human-autonomous agent teams. Finally, the pilot study was an extension of the CASA paradigm which emphasizes mindless responses and rejects anthropomorphism. More recent models suggest that anthropomorphism may play a large role in how humans interact with non-humans. However, the pilot study did not incorporate the concept of anthropomorphism as it may relate to social interactions with autonomous teammates. These shortcomings suggest a set of experiments which will consider anthropomorphism as a mediating variable to explain social interactions with autonomous teammates. One experiment will compare the social outcomes when autonomous agents are presented as teammates versus tools. A second study will evaluate the utility of team building interventions for the purpose of enhancing social interactions between humans and non-human teammates.

EXPERIMENT 1: METHOD

The purpose of experiment 1 was to provide a comparison between the automation-as-a-tool and automation-as-a teammate interaction paradigms. This experiment built on the findings of the pilot study which demonstrated that teamwork with an autonomous agent could be evaluated from a social interaction perspective. The pilot study also demonstrated that a team relationship can enhance outcomes over a non-relationship, but failed to incorporate the tool paradigm. Furthermore this study explored the importance of anthropomorphism with regard to its effect on social interactions with non-human agents. Previous research did not consider anthropomorphism as a factor, but recent models suggest it may play a significant role in guiding these interactions.

Participants

Sixty participants (33 females, 27 males) participated in Experiment 1. The mean age of participants was 20.1 (*SD* = 2.6) years. Participants received class credit for completing the study.

Design

The design of Experiment 1 was a 2 × 2 between subjects design with agent type (human/autonomous) and organizational structure (tool/teammate) as the independent variables.

Apparatus

Strike Group Defender

The participants in this study completed a scenario created in the Strike Group Defender platform (see description in Pilot Study).

Subjective Questionnaires

All surveys were be administered with the Qualtrics online survey software. A total of 11 subjective questionnaires were be administered during the experiment. Two questionnaires (*Propensity to Trust Machines/Humans* & *The Ten Item Personality Inventory*) were administered at the start of the experiment as assessments of individual differences. They required approximately 5 minutes to complete. The remaining questionnaires were administered at the end of the experiment. These nine questionnaires contained a total of 73 items and require approximately 15 minutes to complete.

Propensity to Trust Machines. Prior to interacting with strike group defender, participants will complete the Propensity to Trust Machines inventory (Merritt & Ilgen, 2008). This 6 question Likert scale inventory assesses an individual's general attitude toward interactions with machines. It has been shown to predict subsequent interactions and post-interaction trust ratings. When the participants are in the human partner condition, the word machine will be substituted with "person".

Ten Item Personality Inventory. The TIPI assesses the Big Five personality traits (Openness, Conscientiousness, Extraversion, Agreeableness, and Neuroticism) with just two items per trait on a 7 point Likert-type scale ranging from 1 (strongly disagree) to 7 (strongly agree) (Gosling, Rentfrow, and Swann, 2003). This scale has been found to be appropriate for research in which very short measures are needed, when personality is not the primary topic of interest, and diminished psychometric properties are acceptable.

Checklist for Trust. The Checklist for Trust is a questionnaire designed to assess trust in automation after a period of interaction (Jian, Bisantz, & Drury, 2000). It is a Likert scale inventory with 12 questions ranging from one to seven.

Godspeed Questionnaire. The Godspeed questionnaire is an assessment of five critical aspects of human-robot interaction (Bartneck, Kulic, & Croft, 2008). The factors measured are anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety. Each measure is a composite of five items that are assessed on Likert scales ranging from one to five.

Team Affect Questionnaire. The Team Affect Questionnaire provides an assessment of critical teamwork affective outcomes (Nass et al., 1996). The measures include team perception, perceived similarity, perceived interdependence, and perceived information quality. The 16 items are measured on a Likert scale ranging from one to five.

Collaborative Climate & Team Goals. This set of questions was adapted from human team inventories (Huang, Wei, Watson, & Tan, 2003). The Collaborative Climate inventory is comprised of four questions which assess the perceived collaboration between team members. While the Team Goals inventory, consists of six questions, that assess perceptions of the degree to which goals are clearly defined, shared, and effective.

Role Clarity. The Role Clarity questionnaire assesses the participant's understanding of his or her particular role and also the participant's perception of his or her teammate's understanding. This eight question inventory was adapted from a questionnaire developed for human only teams (Hassan, 2013).

Team Confidence. The Team Confidence survey gauges participant's belief in the team's abilities. This ten item survey was adapted from a questionnaire previously designed for human teams (Bushe & Coetzer, 1995).

Team Cohesion. The Team Cohesion inventory measures to degree to which the participant perceived a connection with his or her partner. This five item questionnaire was adapted from surveys previously used to assess human teams (Seashore, 1954; Huang et al., 2003).

Satisfaction. The satisfaction survey assessed the degree to which the interaction met the participant's expectations for team and individual member performance. This seven item inventory was adapted from a survey previously used in a human team setting (Bushe & Coetzer, 1995).

Procedure

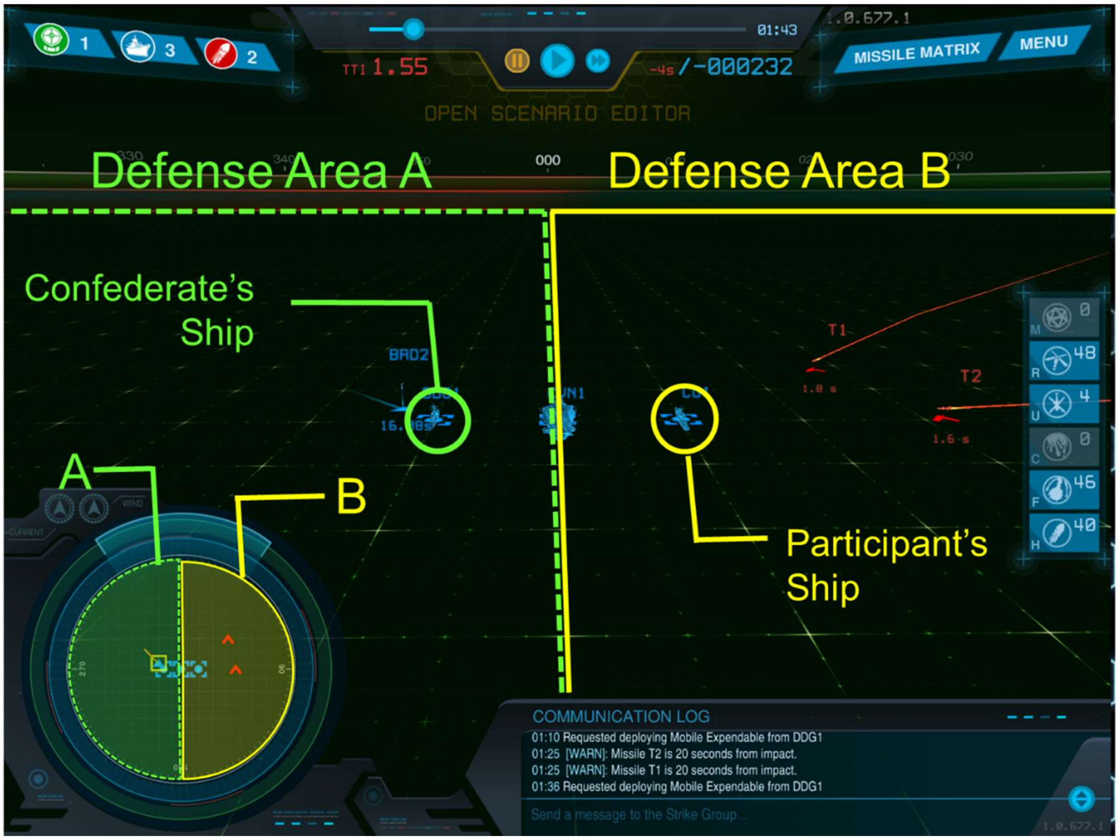
Experiment 1 began when participants entered the research laboratory, at which time they were directed to sit at one of two computer stations. In the autonomous agent condition, the second computer station would be running but there would be no human sitting at the station. In the human condition, a confederate would be sitting at the second station. Upon getting seated, participants signed an informed consent document and completed some biographical questions. Participants were then asked to provide responses for the *Propensity to Trust Machines* inventory (Merritt & Ilgen, 2008) and *Ten Item Personality Inventory* (Gosling et al., 2003). Following the questionnaires, participants read self-paced instructions for Strike Group Defender and then moved on to Strike Group Defender training.

Participants completed the same three training scenarios that were presented during Experiment 1, requiring about 20 minutes of gameplay. Participants were required to reach minimum performance scores for each training scenario. They were allowed to repeat each scenario once, because each of the three training scenarios introduced new skills, threats, and countermeasure concepts. Due to time constraints and the potential for continued poor performance, repeated failures during training resulted in cessation of the experiment.

Upon completion of the training scenarios, participants were informed of the interaction structure for the experimental trial. Participants were assigned to one of two interaction structures: teamwork or partner-as-a-tool. Those in the teamwork condition were informed that the experimental trial would be a multiplayer game in which the confederate was a teammate. Further guidance emphasized that participants should work to achieve the best team performance possible. Participants in the partner-as-a-tool condition, were instructed to consider the confederate as a tool that could be directed or bypassed during gameplay. Further guidance emphasized that participants should focus on achieving the best individual performance possible, while effectively using the other player to support their performance.

In the human condition, the instructor would further explain that the study was focused on distributed multiplayer gaming and that one of the participants would need to move to a different room. The experimenter would select the confederate and briefly escort him to a separate lab space where he would continue acting as the teammate. Then the experimenter would return to the participant's lab and continuing with the experiment. The change in location for the experimental trial was performed to reduce the risk of social facilitation effects. The role of confederate was always played by the same male graduate student.

Participants in all conditions were also informed of two gameplay strategies: Area Defense and Threat Defense. Under the Area Defense strategy, the participant was responsible for defending against any missile that originated from 0-180 degrees and the confederate had responsibility for missiles originating from 180-360 degrees (see Figure 2). Under the Threat Defense strategy, the participant was responsible for defending against one of two missile types, regardless of its point of origin. The confederate was responsible for the other missile type. The participants were instructed to begin the scenario with the Area Defense strategy. However, the confederate's ship possessed a limited number of countermeasures, which prevented the confederate from successfully carrying out an Area Defense strategy. When the limitations became apparent, the participant could either assume a greater workload and compensate for the confederate's limitations or adapt player roles by switching to the Threat Defense strategy.



```
COMMUNICATION LOG
01:10 Requested deploying Mobile Expendable from DDG1
01:25  [WARN]: Missile T2 is 20 seconds from impact.
01:25  [WARN]: Missile T1 is 20 seconds from impact.
01:36 Requested deploying Mobile Expendable from DDG1
Send a message to the Strike Group...
```

Figure 2 Area Defense Strategy Division of Responsibility

The experimental trial began with the participant completing the *Desert Survival Task*. This problem solving task is revolves around a scenario in which a person has been stranded in the desert with a limited list of items available for survival. The participant was directed to rank the items in order of importance. The first 5 minutes of the experimental trial was set aside so the participant could share his or her rankings with the confederate. The confederate, in return, would share a similar ranked list of items for an *Ocean Survival Task*. This task familiarized the participant with the chat feature but the differing lists avoided any form of collaboration that might have been considered team building. Communications from the confederate were scripted to ensure content was similar regardless of agent type. See Appendix A for the script.

Following the experimental trial, participants will complete three post-task inventories: the Godspeed Questionnaire, Checklist for Trust, and Team Affect Questionnaire (Bartneck, Kulic, & Croft, 2008; Jian, Bisantz, & Drury, 1998; Nass, Fogg, & Moon, 1996). Finally, the participants were debriefed and released from the study.

Dependent Measures

Measures in this study focused on two areas: teamwork and anthropomorphism. Teamwork was assessed by processes and outcomes in the same manner that human teams are evaluated (Kozlowski & Ilgen, 2006). Two processes were assessed during this study: Affect and Behavior. Cognitive processes were not considered in this study. Outcomes were assessed in terms of team effectiveness: 1) performance judged by a non-team member; (2) meeting team member needs; (3) willingness to remain a member of the team (Kozlowski & Ilgen, 2006; Hackman, 1987).

Teamwork

Affect Processes. Measures of affect were assessed subjectively. All subjective questionnaires previously described in the apparatus section provided dependent measures. The exceptions are the *Propensity to Trust Machines* scale (Merritt & Ilgen, 2008) and *Ten Item Personality Inventory* (Gosling et al., 2003) which are designed to assess individual differences that may predict teamwork outcomes.

Behavioral Processes. Behavioral processes were assessed objectively. Specific behaviors being captured included adaptation behaviors, resource allocation, and communication behaviors.

Team Effectiveness. Team effectiveness was measured through several performance metrics and two subjective measures. Performance metrics were recorded through the in-game scoring system. The first scoring category was "Results", which scores missile event outcomes. The Results measure accounted for approximately 72% of the overall score. Participants were also be scored on "Efficiency", each countermeasure expended reduces the efficiency score. The Efficiency measure accounted for approximately 28% of the overall score. The final performance category was "Tracking", which is an indication of risk. The Tracking measure accounted for less than 1% of the overall score. Players can reduce missile tracking time (risk) by timing and placing countermeasures accurately. Subjectively, participants will provide feedback on their satisfaction with the team and satisfaction with performance, which are indications of team effectiveness.

Anthropomorphism

The degree to which participants anthropomorphize their partners was assessed by the Godspeed Questionnaire (Bartneck et al., 2008).

Hypotheses

In general, a teammate structure and human agents were predicted to lead to better social interaction outcomes than the tool structure and autonomous agents. Specific hypotheses are listed in the table below:

Table 1. Hypotheses for Experiment 1.

Hypothesis	**Dependent Measure**	**Prediction**
Organizational Structure (Teammate vs Tool) - The teammate condition will result in…		
H1	Affect	more favorable affect than the tool condition.
H2	Behavior	more frequent teamwork behaviors than the tool condition.
H3	Effectiveness	greater effectiveness than the tool condition.
H4	Anthropomorphism	a higher degree of anthropomorphizing than the tool condition.
Agent Type (Human vs Autonomous) - The human condition will result in…		
H5	Affect	more favorable affect than the autonomous condition.
H6	Behavior	more frequent teamwork behaviors than the autonomous condition.
H7	Effectiveness	greater effectiveness than the autonomous condition.
H8	Anthropomorphism	a higher degree of anthropomorphizing than the autonomous condition.

EXPERIMENT 1: RESULTS

Affect Measures

A 2 x 2 between-subjects ANOVA was conducted to determine the effect of Agent Type (Human, Autonomous) and Structure (Team, Tool) on subjective measures of affect. In six out of ten measures, there was a significant main effect for Structure such that affect was higher when the interaction was structured as teamwork rather than tool (see Table 2). There was no main effect for Agent Type among any of the affect measures and no interactions between the independent variables.

Table 2. F-values for measures of affect.

	Structure	Agent Type	Interaction
Team Goals	12.19**	2.25	0.76
Perceived similarity	6.62*	0.08	1.13
Cohesion	5.62*	0.08	0.66
Trust	5.01*	2.17	0.78
Interdependence	4.75*	0.85	0.30
Confidence	4.52*	0.92	2.99
Collaborative climate	2.50	0.56	0.92
Team perception	1.45	0.95	0.00
Information quality	0.98	0.17	0.30
Role clarity	0.74	0.97	3.81

Behavioral Measures

Adaptation

The primary behavioral measure was strategy adaptation. Over one third of participants (22 of 60) adapted defense roles during the game and switched to the Threat Defense strategy, in which each player took responsibility for defending against a specific missile type rather than a specific area. A total of 7 participants in the tool condition and 15 participants in the team condition adapted strategy.

Binomial logistic regression analysis was employed to predict the probability that a participant would switch defensive strategies. The predictor variable was Structure. A test of the full model versus a model with intercept only was statistically significant, $\chi^2(1, N= 60) = 4.67$, $p< .031$. The model was able to correctly to classify 68% of those who switched strategies and 61% of those who did not, for an overall success rate of 63%. The odds ratio for Structure indicates that, a participant in the team condition is 3.29 times more likely to adapt strategies than a participant in the tool condition.

Communication

All chat messages sent during gameplay were recorded. The messages were filtered to remove pre-task discussions, greetings, and incomprehensible chats. The remaining, teamwork relevant, chats and classified into four groups: Coordination (role clarification, adapting strategy, and goal setting), Performance (encouragement, recognition of good performance, and apologies for mistakes), Informational (task related statements and questions), and Acknowledgements (understanding, receipt, and agreement). A 2 x 2 between-subjects ANOVA was conducted to determine the effect of

Agent Type (Human, Autonomous) and Structure (Team, Tool) on communication in the form of chat messages. The analysis produced a significant main effect with a large effects size for Structure (*F*(1, 58) = 9.6, *p* = .003, $\eta^2 = .15$), such that chat message counts were higher in the teammate condition as compared to the tool condition

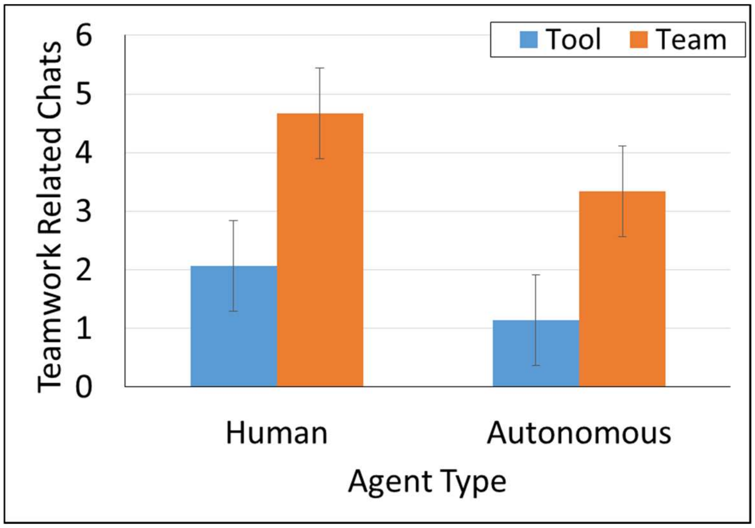


Figure 3. Frequency of teamwork related chats.

Three of the four chat subcategories produced main effects for Structure (Table 3). Team structure was associated with greater number of coordination, performance, and acknowledgement chat messages. Furthermore, there was also a main effect for agent type among three of four chat subcategories. Participants in the human condition sent a significantly higher number of Performance, Informational, and Acknowledgement chats than a non-team structure. Two chat subcategories produced significant interactions such that a team structure significantly increased informational chats and acknowledgements in the human condition. The same effect was not present in the autonomous agent condition.

Table 3. F-values for chat message categories.

	Structure	Agent Type	Interaction
Coordination	4.75*	0.48	0.82
Performance	8.89**	8.89**	0.99
Informational	2.64	6.52*	6.52*
Acknowledgement	19.03**	26.58**	7.71*

*Significant at the .05 level.
**Significant at the .01 level.

Coordination chats, which included discussion of roles and decisions to adapt strategy, made up the bulk of all communications. These types of communications were more frequent in the team condition but equally common between human and autonomous agent conditions. The other three chat categories were less frequent overall, and were virtually absent from the autonomous agent condition. Examples of performance related chat messages included encouragement (e.g. “Let’s do this!”) and apologies (e.g. “My bad.”, “Sorry, I was confused”). Informational chat messages were also absent from the autonomous agent condition and included status updates (e.g. “I have 50 bull and 42 michner) and questions (e.g. “What does your armory look like?”). Acknowledgement chat messages were simply responses to messages from the confederate (e.g. “yeah”, “ok”, “I got it”).

Team Effectiveness Measures

Satisfaction

A 2 x 2 between-subjects ANOVA was conducted to determine the effect of Agent Type (Human, Autonomous) and Structure (Team, Tool) on subjective ratings of satisfaction with membership and performance. With respect to both membership and performance satisfaction ratings, the analysis did not produce main effects for either independent variable. The interaction between Agent Type and Structure was also not significant.

Scoring

Game performance was indicated by an overall performance score, which is comprised of three sub-scores. The Results Score, is calculated by the outcome of each missile attack (softkill, hardkill, hit). Efficiency Score is determined by the number of countermeasures remaining in a player's inventory. Tracking Score depends on the amount of time each missile targeted a friendly ship.

A 2 x 2 between-subjects ANOVA was conducted to determine the effect of Agent Type (Human, Autonomous) and Structure (Team, Tool) on Overall Score and the three sub-scores. There was not a significant main effect or interaction for three of the four performance measures. There was a significant main effect with a large effects size for Structure on the Tracking Score, $F(1, 58) = 5.4$, $p = .029$, $\eta^2 = .08$). However, as mentioned earlier, Tracking Score only accounted for less than 1% of a player's Overall Score.

Anthropomorphism

A 2 x 2 between-subjects ANOVA was conducted to determine the effect of Agent Type (Human, Autonomous) and Structure (Team, Tool) on anthropomorphism. There was a significant main effect with a large effects size for Agent Type such that a human agent received higher anthropomorphism scores than an autonomous agent, $F(1, 58) = 34.2$, $p < .001$, $\eta^2 = .38$). There was no main effect for Structure and there was no interaction between the independent variables.

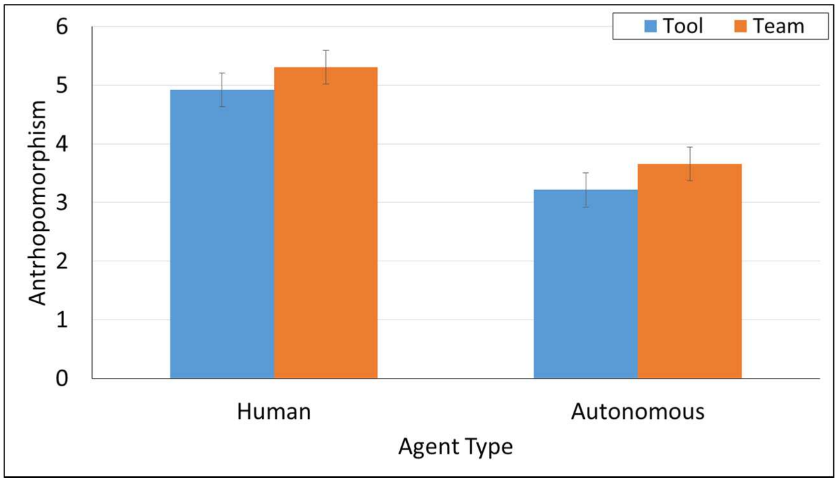


Figure 4. Anthropomorphism ratings.

EXPERIMENT 1: DISCUSSION

The purpose of Experiment 1 was to compare social interactions between human and autonomous teammates in terms of affect, behavior, and performance outcomes when interacting as a team or tool. It was hypothesized that a team structure would improve outcomes relative to a tool structure. Furthermore, it was predicted that interaction with humans would produce better affect and performance outcomes than autonomous agents.

The findings of this study demonstrate that the framing of interactions with autonomous agents as teamwork may serve to improve outcomes. In particular, a team structure (regardless of agent type) led to improved subjective ratings of perceived similarity, interdependence, shared goals, confidence, cohesion, and trust. However, four measures of affect (team perception, information quality, role clarity, and collaborative climate) were not improved by a team structure. It should be noted that the missile defense scenario did not provide an opportunity for participants to share much task relevant information, discuss role assignments, or collaborate. Lack of relevant experience may explain why these subjective ratings did not vary between conditions.

Similar to measures of affect, team structure led to beneficial teamwork behaviors in the form of adaptation and communication. Participants in the team condition were 3.3 times more likely to adapt roles during gameplay to a more effective strategy than those in the tool condition. From a communication standpoint, significantly more task relevant chat messages were sent by participants in the team condition than by participants in the tool condition. Task relevant chat messages also seemed to be sent with equal frequency to both human and autonomous agents. However, several categories of chat messages (performance, informational, and acknowledgements) were only observed in the human condition. There was a fundamental difference in the way participants communicated with humans and autonomous agents. The absence of chat in several teamwork relevant categories of communication could affect team performance due to problems with shared cognition and situational awareness. These communication deficiencies may be related to the anthropomorphic qualities of the autonomous agent. There was a significant difference in anthropomorphic ratings between humans and autonomous agents. Participants may have struggled to understand how to communicate with the non-human, autonomous agent.

Despite encouraging findings with regard to affect and behavioral measures, performance outcomes were not significantly improved by a team structure. These performance outcomes included subjective measures of the participants' satisfaction with being a member of the team and the team's overall performance. It also included a scoring measure with three sub-score categories. Team structure was found to improve tracking score. However, tracking score only contributed less than 1% to the final score of the game so it did not have much influence on overall score.

These findings demonstrate that emphasizing a teamwork structure could potentially improve affective and behavioral outcomes between humans and autonomous teammates. Predicted performance outcomes, however, were not clearly observed. This could potentially suggest that a team structure between human and autonomy is necessary but insufficient to produce desirable teamwork performance outcomes. In other words, participants seemed to embrace the team structure with both humans and autonomous agents. They demonstrated improved affect and more frequent teamwork behaviors. However, these outcomes did not translate into performance. Teams of humans often struggle to perform effectively and researchers employ a number of interventions designed to improve team outcomes. One subset of these interventions, Team Building, became the focus of Experiment 2 described in the following chapter.

EXPERIMENT 2: METHOD

With the tremendous interest in human-autonomous agent teams, a great deal of effort has been devoted to identifying the characteristics of effective autonomous teammates (Klein, Woods, Bradshaw, Hoffman, & Feltovich, 2004; Hancock et al., 2013). The primary challenges for autonomous teammate design include maintaining a team orientation, supporting mutual predictability, enabling directability (i.e. the capacity to assess and modify a teammate's actions), and sharing mental models (Klein et al., 2004). Though not explicitly stated, these challenges are directly tied to team processes: team cognition (predictability and shared mental models), affect (team orientation), and behavior (directability). In other words, the principal challenge for developing human-autonomous agent teams is to improve the social interaction between man and machine.

The pilot study and experiment 1 served to explain how a team structure may encourage beneficial social interactions between humans and autonomous agents. However, those studies rely solely on structure to produce positive outcomes. Team research has demonstrated that structure alone cannot ensure effective teams and positive outcomes (Klein et al., 2009). Human teams often require team development interventions specifically designed to enhance teamwork.

Team development interventions are employed to directly influence team interactions and effectiveness (Klein et al., 2009). These interventions can be categorized as team building and team training (Klein et al., 2009). However, there are critical aspects that differentiate team training and team building (Tannenbaum, Beard, & Salas, 1992).

Team training is skill focused, applying a set of tools and methods to meet learning objectives based on knowledge, skill, and ability outcomes (Salas et al., 2008). Team building, on the other hand, focuses on improving social relations between teammates (Klein et al., 2009). It also differs from team training in that it is less systematic and not focused on skill based competencies. Ultimately, team building encourages team members to evaluate and enhance interpersonal relationships (Schein, 1969, 1999).

The focus of team building interventions on social interactions suggests they may be useful when applied to human-autonomous agent teaming. Challenges in creating effective human-autonomous agent teams include cognitive, affective, and behavioral components. There has not yet been an attempt to directly address these processes to enhance the social interaction of humans and autonomous agents. Role clarification and goal setting have been found to improve human teamwork processes, particularly affect and behavior (Klein et al., 2009). The same interventions may be applicable to human-autonomous agent teaming, but may rest on the degree to which we apply human models for social interaction.

Participants

Sixty participants (29 females, 31 males) participated in Experiment 2. The mean age of participants was 20.6 (*SD* = 4.4) years. Participants received class credit for completing the study.

Design

The proposed design of Experiment 2 is a 2 × 2 between subjects design with agent type (human/autonomous) and team building type (informal/formal) as the independent variables. The Agent Type variable was defined by whether or not the participant's teammate was a human or autonomous agent. The Team Building Type variable was defined by the way the participant and confederate interacted prior to beginning the missile defense scenario. In the informal team building condition, participants completed a non-task related cooperative game with the confederate. In the team building condition, participants engaged in a formal role clarification and goal setting exercise.

Apparatus

Strike Group Defender

The platform described in the Pilot Study was used in Experiment 2. The same missile defense scenario that was used in Experiment 1 was used for Experiment 2.

Subjective Questionnaires

The same questionnaires that were used in Experiment 1 were also used in Experiment 2.

Procedure

When a participant entered the research laboratory they were directed to sit at a specific computer station. In the autonomous agent condition, the neighboring computer station would be running but there would be no human sitting at the station. In the human condition, a confederate would be sitting at the second station. Upon getting seated, participants signed an informed consent document and completed some biographical questions. Participants were then asked to provide responses for the *Propensity to Trust Machines* inventory (Merritt & Ilgen, 2008) and *Ten Item Personality Inventory* (Gosling et al., 2003). Following the questionnaires, participants read self-paced instructions for Strike Group Defender and then moved on to Strike Group Defender training.

Participants completed the same three training scenarios that were presented during Experiment 1, requiring about 20 minutes of gameplay. Upon completion of the training scenarios, the experimenter would announce that the next portion of the experiment was to study teamwork and that the participant and agent (human or autonomous) would be playing as teammates. In the human condition, the instructor would further explain that the study was focused on distributed teamwork and that one of the participants would need to move to a different room. The experimenter would select the confederate and escort him to a separate lab space where he would continue acting as the teammate before returning to the participant's lab and continuing with the experiment. The confederate was always the same male graduate student.

Following this step, participants were completed either a formal or informal team building intervention. Participants in the formal team building condition completed an online team building task comprised of goal setting and role clarification interventions. For the goal setting intervention, participants set Results, Efficiency, and Tracking performance goals. Participants were not able to set goals that exceeded the range of highest and lowest possible scores for each category. In order to help with establishing goals, participants were provided with information about the typical range of scores. During the role clarification exercise participants were informed of two successful defense strategies: Threat Defense and Area Defense. With these strategies in mind, participants were asked to assign a division of responsibility between themselves and their teammate. For both goal setting and role clarification, participants were directed to write down their responses because the information would be required when they established team goals and roles with their partner. Once the individual portion of the team building intervention was complete, the SGD multiplayer game was started. The first five minutes of the game were set aside so that participants could complete the team building exercise with their teammate. Participants used the chat feature of SGD to establish mutually agreed upon goals and roles with their teammate. The experimenter, playing as the teammate, provided a scripted set of goals and role assignment suggestions then allowed the participant to select the final choices (see Appendix A). The team building intervention required about 15 minutes of time, 10 minutes for individual work and 5 minutes for collaborative work.

In the informal team building condition the participants played a freeware version of Tetris™ called Quadra. The game was modified so that the participant and confederate were required to play cooperatively. The participant was only able to move shapes laterally and the confederate was only capable of rotating shapes. As in the formal team building condition, the SGD scenario with a 5 minute period of no missile attacks was used. During the 5 minute window, participants played Quadra with their teammate. The experimenter stopped the game after 4 min 45 seconds of gameplay and redirected the participant’s attention toward SGD. After the collaboration intervention, participants completed the 13 minute SGD teamwork scenario.

Following the experimental scenario, participants completed the post-task inventories described in Experiment 1. Finally, the participants were debriefed and released from the study.

Hypotheses

Table 4. Hypotheses for Experiment 2

Hypothesis	Dependent Measure	Prediction
Team Building Type (Formal vs Informal) - The Formal Team Building condition will result in…		
H1	Affect	more favorable affect than the non-team related condition.
H2	Behavior	more frequent teamwork behaviors than the non-team related condition.
H3	Effectiveness	greater effectiveness than the non-team related condition.
H4	Anthropomorphism	a higher degree of anthropomorphizing than the non-team condition.
Agent Type (Human vs Autonomous) - The human condition will result in…		
H5	Affect	more favorable affect than the autonomous condition.
H6	Behavior	more frequent teamwork behaviors than the autonomous condition.
H7	Effectiveness	greater effectiveness than the autonomous condition.
H8	Anthropomorphism	a higher degree of anthropomorphizing than the autonomous condition.

EXPERIMENT 2: RESULTS

Affect Measures

A 2 × 2 between-subjects ANOVA was conducted to determine the effect of Agent Type (Human, Autonomous) and Team Building Type (Informal, Formal) on subjective measures of affect. In nine out of ten measures, there was a significant main effect for Team Building Type such that affect was higher for participants in the formal team building condition relative to the informal condition (see Table 4). There was no main effect for Agent Type among any of the affect measures and no interactions between the independent variables.

Table 4. F-values for measures of affect.

	Team Bldg Type	Agent Type	Interaction
Team Goals	7.63**	0.08	3.30
Perceived similarity	7.51**	0.68	6.46*
Cohesion	7.58**	0.25	2.01
Trust	4.56*	0.27	2.59
Interdependence	10.67**	0.03	0.05
Confidence	10.89**	0.38	0.72
Collaborative climate	2.59	0.64	1.20
Team perception	11.40**	1.76	2.18
Information quality	6.43*	0.06	2.23
Role clarity	5.25*	1.65	2.81

*Significant at the .05 level.
**Significant at the .01 level

Behavioral Measures

Adaptation

The primary behavioral measure was strategy adaptation. Nearly two-thirds of participants (39 of 60) adapted defense roles during the game and switched to the Threat Defense strategy, in which each player took responsibility for defending against a specific missile type rather than a specific area. A total of 13 participants in the informal condition and 26 participants in the formal condition adapted strategy.

Binomial logistic regression analysis was employed to predict the probability that a participant would switch defensive strategies. The predictor variable was Team Building Type. A test of the full model versus a model with intercept only was statistically significant, $\chi^2(1, N= 60) = 13.08, p< .001$. The model was able to correctly classify 81% of those who switched strategies and 67% of those who did not, for an overall success rate of 72%. The odds ratio for Team Building indicates that, a participant in the formal team building condition was 8.5 times more likely to adapt strategies than a participant in the informal condition.

Communication

All chat messages sent during gameplay were recorded. The messages were filtered to remove pre-task discussions, greetings, and incomprehensible chats. The remaining, teamwork relevant, chats and classified into four groups: Coordination (role clarification, adapting strategy, and goal setting), Performance (encouragement, recognition of good performance, and apologies for mistakes), Informational (task related statements and questions), and Acknowledgements (understanding, receipt, and agreement). A 2 x 2 between-subjects ANOVA was conducted to determine the effect of Agent Type (Human, Autonomous) and Team Building Type (Informal, Formal) on communication in the form of chat message count. The analysis produced a significant main effect with a large effect size for Team Building Type such that participants in the formal team building condition sent more chat messages than those in the informal condition ($F(1, 58) = 103.3$, $p < .001$, $\eta^2 = .65$).

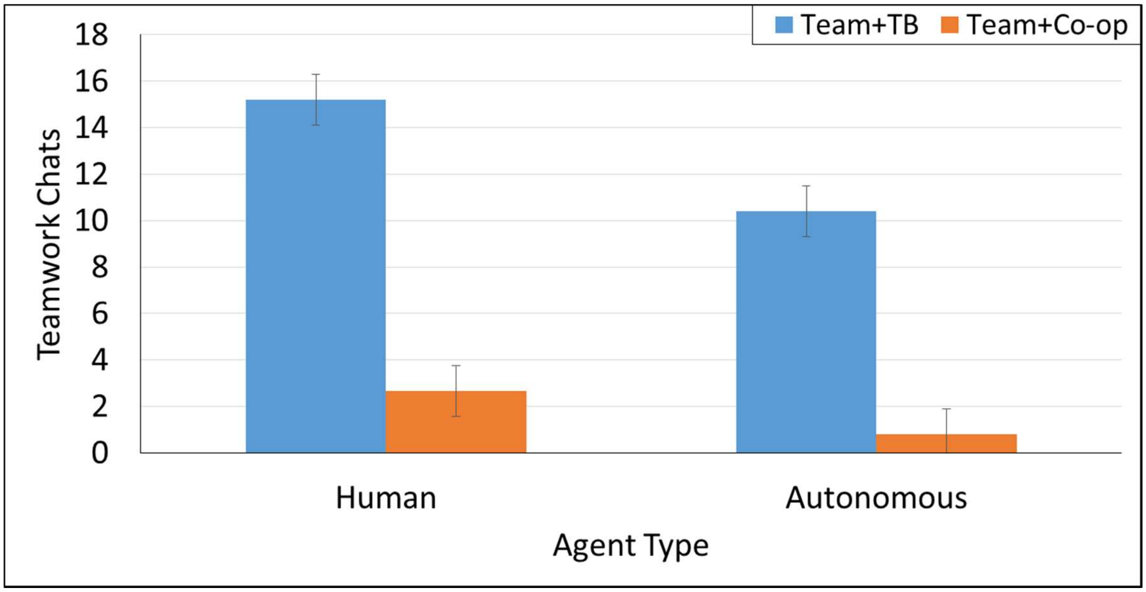


Figure 5. Teamwork related chat message counts

All four chat subcategories produced main effects for Team Building Type such that participants in the formal team building condition sent more chat messages than those in the informal condition (Table 5). Furthermore, there was also a main effect for agent type among three of four chat subcategories. Participants in the human condition sent a significantly higher number of Performance, Informational, and Acknowledgement chats than those in the autonomous agent condition. Two chat subcategories produced significant interactions such that a team structure significantly increased informational chats and acknowledgements in the human condition. The same effect was not present in the autonomous agent condition.

Table 5. F-values for chat message categories.

	Collaboration	Agent Type	Interaction
Coordination	197.22**	1.78	0.00
Performance	14.78**	14.78**	1.92
Informational	9.56**	13.76**	6.12*
Acknowledgement	6.10*	18.34**	13.13**

*Significant at the .05 level.
**Significant at the .01 level

Coordination chats, which included discussion of roles and decisions to adapt strategy, made up the bulk of all communications. These types of communications were more frequent in the team building condition but equally common between human and autonomous agent conditions. The other three chat categories were less frequent overall, and were virtually absent from the autonomous agent condition. Autonomous agents received zero performance related chats, two informational chats, and eleven acknowledgement chats.

Team Effectiveness Measures

Satisfaction

A 2 × 2 between-subjects ANOVA was conducted to determine the effect of Agent Type (Human, Autonomous) and Team Building Type (informal, formal) on subjective ratings of satisfaction with membership and performance. There was a main effect for Team Building Type for both dependent variables, $F(1, 58) = 4.36$, $p = .041$, $\eta^2 = .65$ and $F(1, 58) = 5.31$, $p = .025$, $\eta^2 = .65$ respectively. Participants in the formal team building condition experienced greater satisfaction with membership and performance than those in the informal condition. There was no main effect for Agent Type and no significant interaction for either membership of performance satisfaction.

Scoring

Game performance was indicated by an overall performance score, which is comprised of three sub-scores. The Results Score, was calculated by the outcome of each missile attack (i.e. softkill, hardkill, hit). Efficiency Score was determined by the number of countermeasures remaining in a player's inventory. Tracking Score depended on the amount of time each missile targeted a friendly ship.

A 2 x 2 between-subjects ANOVA was conducted to determine the effect of Agent Type (Human, Autonomous) and Team Building Type (Informal, Formal) on Overall Score and the three sub-scores. There was a main effect for Team Building Type on all four scoring categories such that participants in the formal team building condition scored higher than those in the informal condition (Table 6). Furthermore, there was a main effect for Agent Type on two of the four categories: overall score and results score. Participants in the autonomous agent condition outscored those in the human condition.

Table 6. F-values for scoring categories.

	Collaboration	Agent Type	Interaction
Overall Score	7.85**	7.86**	1.40
Results Score	6.89*	8.29*	1.37
Efficiency Score	13.17**	0.43	0.78
Tracking Score	12.40**	2.35	0.31

*Significant at the .05 level.
**Significant at the .01 level

Anthropomorphism

A 2 x 2 between-subjects ANOVA was conducted to determine the effect of Agent Type (Human, Autonomous) and Team Building Type (Informal, Formal) on anthropomorphism. There was a significant main effect with a large effect size for Agent Type such that a human agent received higher anthropomorphism scores than an autonomous agent, $F(1, 58) = 27.4$, $p < .001$, $\eta^2 = .33$. There was no main effect for Team Building Type, though the value was approaching significance, $F(1, 58) = 3.79$, $p < .057$, $\eta^2 = .06$. There was no interaction between the independent variables.

EXPERIMENT 2: DISCUSSION

Experiment 2 sought to address social interactions between human and autonomous teammates by applying a commonly used set of teamwork interventions known as Team Building. We predicted that a formal team building intervention that employed commonly used team building tasks would improve outcomes relative to the informal team building that may occur during cooperative gameplay. Furthermore, we predicted that interaction with human teammates would produce better affect, behavioral, and performance outcomes relative to an autonomous agent teammate.

The findings of Experiment 2 demonstrate that interventions that are intentionally designed to improve social interactions between teammates can support enhanced teamwork outcomes between humans and autonomous teammates. In particular, a formal team building intervention comprised of role clarification and goal setting exercises led to improved affect, behavior and performance outcomes relative to an informal intervention based on cooperative gameplay.

With regard to affect, formal team building was found to improve 9 of 10 affect measures. Furthermore, the lack of a main effect for agent type suggests that the formal team building intervention is equally beneficial for both human and autonomous teammates. Behaviorally, participants that engaged in formal team building were 8.5 times more likely to adapt roles and switch to a more effective defense strategy. In addition, formal team building led to more frequent chat communications between participants. This effect was observed in overall chat messages, as well as task coordination, performance related, and acknowledgement chats. However, it is important to highlight that content and frequency of chat communication differed significantly between human and autonomous agent conditions. The results mirrored Experiment 1, in which participants were far more likely to send performance, informational, and acknowledgement chat messages to a human than to an autonomous agent.

The formal team building intervention was also found to improve team effectiveness outcomes. From a subjective standpoint, participants reported significantly more satisfaction with both team membership and team performance. Objectively, the formal team building intervention led to higher performance scores than the informal condition. The effect was observed across all three sub-scores: Results, Efficiency, and Tracking. Interestingly, participants that worked with an autonomous teammate were also found to perform better than participants that worked with a human teammate.

These findings demonstrate that formal team building interventions, which are designed to enhance social interactions can improve teamwork outcomes relative to teams that do not receive such interventions. Predicted affect, behavioral, and performance outcomes were observed for nearly every measure. Furthermore, the effect of formal team building seemed to reduce differences between human and autonomous agent teammates that had been observed in Experiment 1. Differences in communication, however, were still observed. This study supports the need for consideration of social interactions between humans and autonomous agents. Beyond simply labeling an interaction as teamwork, it may be necessary to employ formal team building interventions, which are designed to improve social interactions.

GENERAL RESULTS

In a follow up analysis, the data from Experiment 1 and Experiment 2 were merged. This allowed a comparison between four conditions: Tool, Team, Formal Team Building, and Informal Team Building.

Affect Measures

A 2 × 4 between-subjects ANOVA was conducted to determine the effect of Agent Type (Human, Autonomous) and Team Treatment Type (Tool, Team, Informal, Formal) on subjective measures of affect. In ten out of ten measures, there was a significant main effect for Team Building Type.

Table 7. F-Values for Measures of Affect

	Team Treatment	Agent Type	Interaction
Team Goals	7.65**	1.40	1.69
Perceived similarity	6.35**	0.63	2.72*
Cohesion	5.87**	0.03	1.32
Trust	3.58*	1.97	1.28
Interdependence	6.26**	0.32	1.43
Confidence	6.97**	0.13	1.32
Collaborative climate	3.52*	0.73	1.13
Team perception	8.05**	0.04	1.55
Information quality	6.84**	0.96	1.74
Role clarity	2.94*	2.57	2.22

*Significant at the .05 level.
**Significant at the .01 level

Post hoc analyses were conducted given the statistically significant omnibus ANOVA. Specifically, Tukey HSD tests were conducted on all possible pairwise contrasts. All ten affect scores in the Formal Team Building condition were found to be significantly greater ($p < .05$) than scores for the Tool condition. Similar results were found when comparing the Formal Team Building and Informal Team Building conditions, nine out of ten affect scores (all but collaborative climate) were found to be significantly greater ($p < .05$) in the Formal Team Building condition. The comparison between Formal Team Building and Team conditions did not yield similar results. Only three of ten measures were found to be significantly different at the $p < .05$ level.

Behavioral Measures

Communication

A 2 x 4 between-subjects ANOVA was conducted to determine the effect of Agent Type (Human, Autonomous) and Team Treatment Type (Tool, Team, Informal, Formal) on communication in the form of chat message count. The analysis produced a significant main effect with a large effect size for Team Treatment Type ($F(3, 112) = 62.8$, $p < .001$, $\eta^2 = .63$). Post hoc analyses were conducted given the statistically significant omnibus ANOVA. Specifically, Tukey HSD tests were conducted on all possible pairwise contrasts. Formal Team Building was found to produce significantly ($p < .05$) more chat messages than all other conditions. The Team condition was also found to produce significantly ($p < .05$) greater chat message counts than the Tool and Informal Team Building conditions.

Three out of four chat subcategories produced main effects for Treatment Type such that participants in the formal team building condition sent more chat messages than those in the informal condition (Table 5). Post hoc analyses were conducted given the statistically significant omnibus ANOVA. Specifically, Tukey HSD tests were conducted on all possible pairwise contrasts. Formal Team Building was found to produce significantly ($p < .05$) more Coordination, Informational, and Acknowledgement chat messages than all other conditions. The Team condition was also found to produce significantly ($p < .05$) greater chat message counts than the Tool and Informal Team Building conditions.

Table 8. F-values for chat message categories.

	Treatment Type	Agent Type	Interaction
Coordination	90.32**	0.20	0.96
Performance	1.20	23.49**	1.20
Informational	5.09**	12.06**	3.06*
Acknowledgement	9.53**	15.64**	2.38

*Significant at the .05 level.
**Significant at the .01 level

There was also a main effect for agent type among three of four chat subcategories. Participants in the human condition sent a significantly higher number of Performance, Informational, and Acknowledgement chats than those in the autonomous agent condition. One chat subcategories produced significant interactions such that a team structure significantly increased informational chats in the human condition. The same effect was not present in the autonomous agent condition.

Team Effectiveness Measures

Satisfaction

A 2 × 4 between-subjects ANOVA was conducted to determine the effect of Agent Type (Human, Autonomous) and Treatment Type (Tool, Team, Formal Team Building, Informal Team Building) on subjective ratings of satisfaction with membership and performance. There was a main effect for Treatment Type for both dependent variables, $F(3, 112) = 2.69$, $p = .050$, $\eta^2 = .68$ and $F(3, 112) = 3.13$, $p = .028$, $\eta^2 = .08$ respectively. Post hoc analyses were conducted given the statistically significant omnibus ANOVA. Specifically, Tukey HSD tests were conducted on all possible pairwise contrasts. Formal Team Building was found to produce significantly ($p < .05$) higher ratings of membership satisfaction than the tool condition. The formal team building condition was also found to produce significantly ($p < .05$) greater performance satisfaction than the tool, team, and informal team building conditions.

Scoring

A 2 x 4 between-subjects ANOVA was conducted to determine the effect of Agent Type (Human, Autonomous) and Team Treatment Type (Tool, Team, Informal, Formal) on Overall Score and the three sub-scores. There was a main effect for Team Treatment Type on all four scoring categories (Table 6). Post hoc analyses were conducted given the statistically significant omnibus ANOVA. Specifically, Tukey HSD tests were conducted on all possible pairwise contrasts. Formal Team Building was found to produce significantly ($p < .05$) higher scores across all categories relative to the tool condition.

Table 9. F-values for scoring categories.

	Collaboration	Agent Type	Interaction
Overall Score	3.21*	4.13*	1.48
Results Score	3.02*	4.70*	1.74
Efficiency Score	6.02**	0.46	0.93
Tracking Score	7.16**	1.04	1.46

*Significant at the .05 level.
**Significant at the .01 level

GENERAL DISCUSSION

When viewed comprehensively, these two experiments provide compelling evidence for the importance of social interactions between humans and autonomous agents. Effective teamwork relies heavily on social interactions but this aspect is often ignored with respect to autonomous teammates in favor of expanding the capabilities of the autonomous agent. Experiment 1 demonstrated that an emphasis on team structure can improve teamwork outcomes relative to the more common automation-as-a-tool paradigm. However, the perception of teamwork alone only supported mixed improvement of affect and did not lead to significantly better performance. Experiment 2 further supported the importance of social interaction between humans and autonomous agents, demonstrating that a formal team building intervention can support affect, behavior, and performance improvements.

With respect to measures of affect, a team structure alone improved six out of ten subjective measures. However, a formal team building intervention in conjunction with team structure led to significant affect improvement on nine out of ten measures. These findings indicate that team structure may contribute to affect toward a teammate, but significant improvements in affect may require additional, formal intervention.

Evidence that the team structure changed the way participants thought about the interaction with their teammate were also observed in behavioral measures. Participants in Experiment 1 were 3.3 times more likely to adapt roles during the task by switching to a more effective defense strategy. Furthermore, the formal team building intervention was even more effective at encouraging effective teamwork behaviors, as the likelihood of adapting strategy increase by 8.5 times over the informal condition. Similar results were observed in chat messaging. Team structure increased chat message frequency over the tool structure and formal team building increased chat message frequency over the informal condition.

Team effectiveness measures were not significantly improved by the introduction of a team structure, as seen in Experiment 1. These results were consistent across both subjective measures of satisfaction and three of four objective performance scores. However, formal team building in conjunction with a team structure, as seen in Experiment 2, did lead to significant performance score improvements and satisfaction ratings. These results indicate that team structure alone may not be sufficient to increase all teamwork outcomes, but that the addition of formal interventions focused on social interaction may be sufficient to significantly increase outcomes.

In some measures, particularly chat messaging, human teammates were treated differently than autonomous teammates. Participants sent more chat messages to humans and those messages were richer in content. Participants rarely or never sent chat messages to autonomous agents that were classified as performance related, informational, or acknowledgements. This is an important area of focus for future research because communication behaviors can directly influence team cognition, affect, and effectiveness.

This study also explored the degree to which participants anthropomorphized their teammate. Contrary to predictions, team structure and formal team building did not lead to a significant difference in the degree of anthropomorphizing. Autonomous agents were also given significantly lower anthropomorphism scores that humans. These findings support the *Computers are Social Actors* (CASA) paradigm which describes how computers are treated as social actors despite users knowing they are not human (Nass & Moon, 2000). The CASA paradigm explicitly rejected anthropomorphism as an explanation and those findings are supported here.

Limitations

One important limitation of these experiments is that they were performed with ad hoc teams. These findings may differ when applied to intact teams. The primary challenge in extending this research to intact teams is that the human-autonomous agent teams necessary for such a study do not yet exist. Even the computer based experiments in the present work were dependent on simulating an autonomous agent that was, in fact controlled by a human confederate. Despite this limitation, current research indicates that team development interventions are more effective and more commonly employed with respect to intact teams (Salas et al., 2008, Klein et al., 2009). Furthermore, less sophisticated robots have been shown to influence human affect and behavior even when they are viewed as a tool (Carpenter, 2016). The implications are that intact teams, especially those that engage in team development interventions, may exhibit even stronger feelings of affect, more frequent teamwork behaviors, and better performance than the ad hoc teams employed in these experiments.

Future Directions

These findings open the door to a range of interventions that may improve human interaction with autonomous agents. Those intending to design systems for effective human-autonomous agent teamwork should consider social interaction (e.g. team structure, team building) in conjunction with more traditional design factors (e.g. transparency, adaptability). Failure to consider the fundamentally social nature of human-autonomous agent interaction could leave humans unprepared to effectively team with autonomous agents.

A number of questions remain with regard to human-autonomous agent teaming. Though the team structure and formal team building interventions employed in these experiments did not significantly improve anthropomorphism it is possible that anthropomorphism may improve social interactions, leading to enhance affect, behavior, and performance. Studies should also focus on other team development interventions, particularly team training, which can improve teamwork skills such as communication. Other studies should explore the effects of team size and composition as well as how team structure may influence acceptance of recommendations from autonomous decision aides.

APPENDIX A

Desert Survival Task Script

- Greetings, I am your teammate. We can communicate using the chat feature on your interface.
- Let's begin by discussing your cognitive reasoning exercise.
- First please describe your scenario.
- My scenario was also a survival problem but took place on a life raft in the Atlantic Ocean.
- Now let's review your top responses. Tell me the item you considered most important and explain why.
- The most important item for Lost at Sea was the shaving mirror, which can be used to signal for help.
- Now please discuss your #2 item.
- The next item for Lost at Sea was 10 L of gasoline which floats and can make a large signal fire.
- Now please discuss your #3 item.
- The next item for Lost at Sea was 25 L of water which can sustain the survivors for several days.
- Now please discuss your #4 item.
- The next item for Lost at Sea was a case of army rations which provide much needed calories for longer survival.
- Now please discuss your #5 item.
- The next item for Lost at Sea was 20 square feet of sheeting which collects rain and provides shelter.
- Now please discuss your #6 item.
- The next item for Lost at Sea was 2 boxes of chocolate which are a reserve food supply.
- Now please discuss your #7 item.
- The next item for Lost at Sea was an ocean fishing kit since it is not a guaranteed food source.
- Now please discuss your #8 item.
- The next item for Lost at Sea was 15 ft. of rope which can lash together people or supplies.
- Now please discuss your #9 item.
- The next item for Lost at Sea was a floating seat cushion which can be used as a life preserver.
- Now please discuss your #10 item.
- The next item for Lost at Sea was a can of shark repellent which would be useful during a shark attack.
- Now please discuss your #11 item.
- The next item for Lost at Sea was 1 L of 160 proof rum which could be a disinfectant but is also dangerous to drink.
- Now please discuss your #12 item.
- The next item for Lost at Sea was a small radio which would probably not be in range of any radio stations.
- This concludes the cognitive reasoning exercise. The missile attacks will begin shortly.

Team Building Script

- Greetings, I am your teammate. We can communicate using the chat feature on your interface.
- Let's begin the team building exercises with a discussion of team goals…
- What was your proposed results score goal?
- Based on previous player data, I chose 200,000 points as an appropriately "challenging" goal.
- Our proposed goals were the same. This value is accepted as our final results score goal.
- Our proposed goals differ, we must negotiate a shared goal. Please use the comm log to propose a new results score goal.
- Your updated results score goal is accepted as our shared goal.
- What was your proposed efficiency score goal?
- Based on previous player data, I chose 30,000 points as an appropriately "challenging" goal.
- Our proposed goals were the same. This value is accepted as our final results score goal.
- Our proposed goals differ, we must negotiate a shared goal. Please use the comm log to propose a new efficiency score goal.
- Your updated efficiency score goal is accepted as our shared goal.
- What was your proposed tracking score goal?
- Based on previous player data, I chose 250 points as an appropriately "challenging" goal.
- Our proposed goals were the same. This value is accepted as our final results score goal.
- Our proposed goals differ, we must negotiate a shared goal. Please use the comm log to propose a new tracking score goal.
- Your updated tracking score goal is accepted as our shared goal.
- Now that a set of shared goals have been established, our roles should be clarified.
- First we will discuss area defense roles.
- What was your proposed split of responsibility?
- Our proposed division of responsibilities were the same. The division is accepted.
- I proposed to divide responsibilities equally 50 / 50.
- Our proposals differ, we must negotiate and agree upon a division of responsibility.
- Please use the comm log to poropse a new Area Defense division of responsibility.
- You will be responsible for the right side of the map (from 0 degrees to 180 degrees).
- Now let's discuss Threat Defense roles.
- How did you propose to divide threat responsibilities?
- This division is accepted.
- My ship has a limited supply of IR Decoys which means I would not be able to effectively defend against MOTH missiles.
- Perhaps the assignments should be reversed.
- We also need a strategy monitor.
- The strategy monitor decides when to switch from Area Defense to Threat Defense.
- You should take this role. We will begin with Area Defense.
- If you wish to switch during gameplay you will type "Threat Defense" or "Area Defense" in the comm log.
- This concludes the goal setting and role clarification exercise. The missile attacks will begin shortly.

Game Play Script

- My Michner IR Decoys and Hardkills are depleted. I cannot defeat MOTH missiles.
- Strategy accepted, I will now defend against all HUNGRY missiles.
- Strategy accepted, I will now defend the area from 180 to 360 degrees.
- Understood, I will continue to defend against all HUNGRY missiles.
- Understood, I will continue to defend the area from 180 to 360 degrees.
- Affirmative
- Negative
- I do not understand
- Understood

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