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Cohesion in Human–Autonomy Teams: An Approach for Future Research

by Shan G Lakhmani, Catherine Neubauer, Andrea Krausman, Sean M Fitzhugh, Samantha K Berg, Julia L Wright, Ericka Rovira, Jordan J Blackman, and Kristin E Schaefer

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14. ABSTRACT
Cohesion is an important property of teams that can affect individual teammates and team outcomes. However, cohesion in teams that include autonomous systems as teammates is an underexplored topic. We examine the extant literature on cohesion in human teams, then build on that foundation to advance the understanding of cohesion in human–autonomy teams, both similarities and differences. We describe team cohesion, the various definitions, factors, dimensions, and associated benefits and detriments. We discuss how that element may be affected when the team includes an autonomous teammate with each description. Finally, we identify specific factors of human–autonomy interaction that may be relevant to cohesion, then articulate future research questions critical to advancing science for effective human–autonomy teams.

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1. Introduction

Cohesion, among human teams, has been described as the most important determinant of team success (Carron and Brawley 2000; Dion 2000) as it benefits team productivity by increasing performance and has a positive psychological impact on human team members (Beal et al. 2003; Mathieu et al. 2015; Neubauer et al. 2016). Additionally, the last decade has seen increased interest in teaming humans and robotic or autonomous systems (Schaefer et al. 2019); so, the topic of human–autonomy team cohesion has become ripe for research. This report seeks to answer the following question: Can the current knowledge of human teaming and cohesion extend and generalize to include autonomous teammates? If so, what are the limitations or considerations we must be aware of to ensure cohesion develops within this type of hybrid team?

Human–autonomy teams, or hybrid teams, consist of at least one human and at least one autonomy-enabled system, or intelligent agent, who work interdependently toward shared goals (McNeese et al. 2018). Just as human behaviors and decisions are constrained by human-centred phenomena—such as bounded rationality, heuristics, and cognitive biases—limitations on agents' physical and decision-making capabilities will have implications on their integration within human teams (Rasmussen et al. 1994; Vicente 1999). Constraints on human and agent behaviors and capabilities will thus shape team cohesion as teammates begin to recognize constraints in their work environments and adapt accordingly (Naikar et al. 2005). To understand the emergence, evolution, and characteristics of cohesion in human–autonomy teams, it is critical to understand how the presence of autonomous team members and the environment in which human–autonomy teams operate influence how cohesion is built, maintained, and measured.

To better understand how team cohesion is expressed in human–autonomy teams, it is essential to determine if and how the individual factors and subdimensions of the cohesion construct apply (Griffith 1988; Zaccaro 1991; Griffith and Vaitkus 1999; Dion 2000; Salas et al. 2015b). We begin by examining what is meant by autonomy, what is meant by cohesion, and reviewing team cohesion definitions and dimensions as presented in the human teams' literature. Each dimension, its subdimensions, and any relevant cohesion factors are examined; we discuss how autonomy is expected to influence the development of each specific factor and areas where future human–autonomy research into this factor can go. We then discuss the benefits and detriments of cohesion in human teams—and how autonomy might support benefits and mitigate detriments. Next, we consider autonomy-specific factors and how they might influence the building and maintaining of cohesion. Finally, we conclude with an exploration of the gaps in our current understanding

of cohesion in human–autonomy teams and draw together our synthesis into a series of expectations for the future.

2. What is Autonomy?

Autonomy, defined in the broadest terms, is a technology that performs a function without any human intervention. However, it has been argued that there are different types of autonomy or even levels of automation providing an understanding of human–autonomy interaction (Parasuraman et al. 2000). In effective human–autonomy teams, the autonomy and the human's strengths support each other's weaknesses (see Fitts' [1951] "Men Are Better At, Machines Are Better At" [MABA-MABA] list—now known as "Humans Are Better At, Machines are Better At" [HABA-MABA]). For example, humans are better at creating alternate solutions, handling unexpected events, changing roles or tasks frequently, and aggregating spatial and temporal information (i.e., perceived information) into a meaningful "whole." Machines (e.g., automation) are better at processing and analyzing large amounts of data to determine potential outcomes quickly, repetitive tasks, and monitoring over an extended period. However, with machines having a wider range of capabilities, function allocation is not as clearly delineated as it once was. Today, technology is advanced enough that focusing solely on human needs, a common paradigm in human–automation interaction research, may not be sufficient.

Why this concept is important to human–autonomy team cohesion, is that future teams are likely to use a mixed-initiative interaction strategy, humans and autonomous systems can collaborate on decisions (Allen et al. 1999; Chen and Barnes 2014). This collaborative decision-making requires a shared "understanding" of a situation, which in turn requires a reciprocal exchange of information between human and autonomous system (Bradshaw et al. 2012; Lakhmani et al. 2019). Systems with increased autonomous capabilities allow the autonomy to interact with humans in the same way a human teammate would, and thus contribute to larger team dynamics as a team member (Lyons et al. 2018; Wynne and Lyons 2018; O'Neill et al. 2020).

3. What is Cohesion?

Cohesion is an individual- and group-level construct shaped by the team members' unique characteristics and interactions. As an individual level construct, cohesion can be viewed as an attitudinal measure, referring to how a person feels toward their group and how the group makes that person feel (Dion 2000; Salas et al. 2015a). As a group level construct, cohesion is an emergent state—a dynamic

property of a team that varies depending on the team's surrounding factors, including team contexts, inputs, outputs, and processes (Marks et al. 2001; Salas et al. 2015b).

Like other team states, cohesion is a property of the team itself, which is distinct from but affected by a team's inputs, outputs, and processes (Marks et al. 2001; Ilgen et al. 2005). Given the unique inputs and processes that come with autonomy, its addition can transform the dynamics of a team (You and Robert 2018; Sebo et al. 2020).

As such, understanding cohesion in the context of human–autonomy teams will require an understanding of how these elements of the autonomous systems impose constraints on factors of cohesion; understanding behavior in the context of constraints follows the Cognitive Work Analysis framework for work systems (Rasmussen et al. 1994, Vicente 1999). However, the analysis of cohesion in human–autonomy teams is a relatively rare topic in the literature (Schaefer et al. 2019; Abrams and Rosenthal-von der Pütten 2020). In order to explore how cohesion can manifest in human–autonomy teams, first we must define what cohesion is.

Definitions

Early definitions of cohesion emphasized the forces underlying group membership. Some of the earliest conceptions of cohesion stem from the work of Kurt Lewin (1935), an early Gestalt psychologist who defined cohesion as the forces keeping members together, including both the forces of attraction and the forces of repulsion (as described in Dion 2000, who cites Marrow 1977). This idea of influencing forces is in line with the definition from Moreno and Jennings (1937, 371), stating that cohesion consists of "the forces holding the individuals within the groupings in which they are." Definitions of cohesion over the next 15 years then saw a convergence on the "field of forces," compelling group members to remain in the group and resist leaving it (Festinger et al. 1950; Gross and Martin 1952; Seashore 1954; Mudrack 1989; Dion 2000; Grossman 2014).

When examining sports and military teams, researchers have emphasized the forces acting on individuals to stay in the group, including attraction to the group (Libo 1953; as cited in Dion 2000), the desire of members to remain in the group (Cartwright 1968, as cited in Zaccaro et al. 1995), and commitment to the group (Piper et al. 1983; Mudrack 1989). This emphasis on the individual is mirrored in Carron (1982) and Brawley et al.'s (1988) definition for cohesion in sports teams, "a dynamic process that is reflected in the tendency for a group to stick together and remain united in the pursuit of its goals and objectives" (Carron 1982, 124). This cohesion definition has been consistently used and cited for decades, both in

and out of the sports literature (Ahronson and Cameron 2007; Grossman 2014). These different definitions connote different perspectives on cohesion as a construct and how it is operationalized and measured (see Table 1 for a list of definitions). Mudrack (1989) argues that these definitions do not match the model and subsequent operationalization of cohesion that the researchers used. A deeper examination of this mismatch led some researchers to examine this relationship and contend that cohesion may not be a solely unidimensional construct (Dion 2000). While there does not seem to be a consensus about the number of dimensions within cohesion, recent work by Salas et al. (2015a) found that only 16% of studies reviewed described cohesion as a unidimensional construct. Thus, viewing cohesion as a multidimensional construct seems even more relevant as we consider cohesion in human–autonomy teams.

Table 1 List of cohesion definitions

Definition	Citation
The resultant of the forces that keep members together—the positive forces of reciprocal attraction and the negative forces of reciprocal repulsion	(Lewin 1935 as cited in Marrow 1977, 169)
The forces holding the individuals within the groupings in which they are	(Moreno and Jennings 1937)
The total field of forces that act on members to remain in the group	(Festinger et al. 1950)
The resultant of all the forces acting on members to remain in the group	(Festinger 1950)
The resistance of the group to disruptive forces	(Gross and Martin 1952)
Attraction of members to the group in terms of the strength of forces on the individual member to remain in the group and resist leaving the group	(Seashore 1954)
That group property that is inferred from the number and strength of mutual positive attitudes among the members of a group	(Lott and Lott 1965)
A dynamic process that is reflected in the tendency for a group to stick together and remain united in the pursuit of its goals and objectives	(Carron 1982)
A dynamic process that is reflected in the tendency for a group to stick together and remain united in the pursuit of its instrumental objectives and/or for the satisfaction of member affective needs	(Carron and Brawley 2000)

4. What Makes Up Cohesion: Cohesion Factors

Building on the multidimensional nature of cohesion, we provide an organizational framework for cohesion and discuss its components (Table 2). This framework not only includes commonly discussed factors of cohesion, but also discusses factors thought to be relevant to human–autonomy team cohesion, including team resilience and structural cohesion (Berg et al. 2021). The organizational framework developed in this report is a result of an exploration of the literature, culminating in three major dimensions: functions of cohesion, direction of cohesion, and team

resilience. Each dimension contains subdimensions and relevant factors, and, after discussing each, we will discuss how they are applicable to human–autonomy teams.

Table 2 Dimensions and factors of cohesion relevant to human–autonomy teams

Dimensions of cohesion	Subdimensions of cohesion	Factors of cohesion
Functions of cohesion	Task cohesion	. . .
	Interpersonal cohesion	Social cohesion Interpersonal attraction Morale
	Structural cohesion	Exclusivity Group pride Belongingness Norms
Directions of cohesion	Primary	Vertical cohesion Horizontal cohesion Complementarity
	Secondary	Organizational cohesion Societal cohesion
Team resilience	. . .	. . .

4.1 Functions of Cohesion (Three Subdimensions)

This grouping integrates task cohesion and interpersonal cohesion with self-categorization theory. Self-categorization theory revived research into cohesion in the 1990s by challenging the view of cohesion as primarily stemming from interpersonal attraction (Dion 2000). Instead, this approach suggests that cohesion can result from individual-level attraction to group members and identification with the larger group (Dion 2000). Using the self-categorization theory perspective, we grouped these cohesion factors into three subdimensions: *task cohesion*, *interpersonal cohesion*, and *structural cohesion*. The first details commitment to the shared task, the second details the interpersonal aspects within the group, and the third details identification with the in-group.

4.1.1 Task Cohesion

Task cohesion is action-oriented or proactive and is a group's shared commitment, understanding, or attraction to the group task or goal or the group's capacity for teamwork (Siebold and Kelley 1988; Beal et al. 2003). This subdimension of cohesion requires a combined understanding of joint mission parameters and goals. As such, it is perhaps the most straightforwardly applicable cohesion subdimension to teaming with intelligent agents (Beal et al. 2003).

Existing work on mixed-initiative systems and autonomy is moving toward a future where autonomous systems can act collaboratively with a group of human teammates to pursue a shared goal, but independently enough to appropriately exercise initiative (Yen et al. 2006; Sukthankar et al. 2012). Autonomy capable of this behavior must also understand the team's goals and alter its behavior to meet these goals (Sycara and Sukthankar 2006). Therefore, the autonomy that has a clear model of the team's goals and pursues those goals will be acting in a way that human collaborators may view as "committed" to these goals and contributing to the team's collective achievement (Zaccaro et al. 1995). One potential pitfall, however, is a possible lack of transparency. If human teammates do not understand the reasoning behind an autonomy's actions, they may misconstrue its behaviors, which could lead to errors, loss of shared awareness, and presumably lower cohesion (Chen and Barnes 2014). It follows that establishing bidirectional communication and carefully designing displays that incorporate transparency can provide insights into the autonomy's current state, situation awareness, and actions; it can also minimize opportunities or misunderstandings and solidify the shared commitment to the team and team tasks (Severt and Estrada 2015; Matthews et al. 2021). An important future research area then, is to identify how and what information is needed to communicate this shared commitment, how this information should be presented (e.g., display or modality), and when it should be presented.

4.1.2 Interpersonal Cohesion (Three Factors: Social Cohesion, Interpersonal Attraction, and Morale)

Researchers have described other cohesion components outside the functional or directional dimensions, whose elements can be grouped under *interpersonal cohesion* (Dion 2000; Grossman 2014). This subdimension refers to factors of cohesion that relate to the social constructs and personal dynamics that occur between members of a group, including *social cohesion*, *interpersonal attraction*, and *morale*.

4.1.2.1 Social Cohesion

Social cohesion, also referred to as interpersonal cohesion, is considered a significant function of cohesion, second only to task cohesion (Dion 2000; Griffith 1999) and is considered an integral aspect of well-functioning groups (Ahronson and Cameron. 2007). This type of cohesion is represented by the group members' attraction to or liking the group, level of identification with the group, and desire to remain in the group (Evans and Jarvis 1980; Craig and Kelly 1999; Siebold 1999; Friedkin 2004). Social cohesion tends to arise from social processes such as sharing personal stories and celebrating major life events, which enable team members to

develop rapport and favorable attitudes toward one another, further strengthening mutual attraction and team bonding (Grossman 2014; Severt and Estrada 2015).

The addition of autonomy can potentially influence group members' attraction to the group. Autonomy can facilitate teamwork in human teams by supporting human behaviors that lead to teamwork (Sukthankar et al. 2012). Consequently, if autonomy supports knowledge or behaviors that lead to cohesion (e.g., prosocial behavior [Al-Yaaribi and Kavussanu 2017], role clarity [Zaccaro 1991], or team building [Walliser et al. 2019]), then we argue that autonomy can support cohesion between human teammates. Future researchers can determine whether supporting these behaviors and knowledge can facilitate team cohesion, the extent to which it can do so if that is the case, and if doing so can accelerate the development of social cohesion in newly formed teams.

When autonomous systems possess some form of interactive capability, they may be able to influence the team's social dynamic more directly (Carlson et al. 2015; Panganiban et al. 2019). Given the various contexts where autonomous systems may appear, ranging from social robots in eldercare to high-risk environments, this interactive capability needs to be robust (Phillips et al. 2011). The difficulty of replicating rich social interactions found in human–human teams poses a challenge for developing social cohesion in human–autonomy teams (Irmer et al. 2000; Walliser et al. 2019). However, future researchers and engineers may overcome this hurdle by endowing autonomous teammates with more human-like qualities (e.g., personality, attitudes) or social abilities and behaviors (Bernier and Scassellati 2010; Broadbent 2017), and assessing how these qualities, abilities, and behaviors impact acceptance and social cohesion.

4.1.2.2 Interpersonal Attraction

Interpersonal attraction is a shared liking for, or attachment to, the group members, reflecting the individual-level behavior outlined in the previously described self-categorization theory (Beal et al. 2003). Liking individual group members, however, is not the same as liking the group (Abrams et al. 2020). Interpersonal attraction has been described as central to the cohesiveness of small groups, enough so that some unidimensional conceptualizations of cohesion have equated the two (Lott and Lott 1965; Dion 2000). While this approach has fallen out of fashion, especially with the advent of self-categorization theory in the 1990s, interpersonal attraction does have a meaningful correlation with performance (Dion 2000; Beal et al. 2003).

Further, research suggests a relationship between attraction and team identity (Grossman 2014; Bell and Brown 2015). Team identity describes the degree to

which a person "identifies" or belongs to a social group or category, and this perception is often based on how similar (e.g., in-group vs. out-group) team members are to one another (Tajfel 1974; Grossman 2014). Shared identity among team members may promote social connections and a level of comfort compared to other team members with whom they do not identify (Severt et al. 2015). That said, the heterogeneous nature of human–autonomy teams may limit the degree of interpersonal attraction and hinder the initial emergence of cohesion due to the inherent differences between humans and autonomous team members. However, Bell and Brown (2015) suggest that the drivers of interpersonal attraction depend on repeated interactions over time. Thus, it is likely that the more humans and autonomous team members interact with each other, the faster the "barrier" of heterogeneity is broken down, and a sense of team identity and cohesion emerges. This topic warrants attention in future research to determine how prolonged interactions within human–autonomy teams shape interpersonal attraction. Future researchers could examine how potential interventions, such as training for human–autonomy team interactions, could impact the development of a users' interpersonal attraction to, and subsequent cohesion with, an autonomous teammate.

4.1.2.3 Morale

Morale stems from Bollen and Hoyle's (1990) work with perceived cohesion and refers to the global affective response, positive and negative, associated with being in a group (Bollen and Hoyle 1990). It is also defined as an individual's high degree of loyalty to fellow group members and their willingness to endure frustration for the group (Salas et al. 2015a). This factor has a temporal component that makes it an important determining factor when teams deal with conflicts or setbacks (Dion 2000; Grossman 2014). Team members with a strong sense of team identity tend to experience higher levels of morale and are also more likely to be loyal to one another and endure the frustrations that come with 1) teamwork, 2) operating in extreme environments, and 3) working with autonomous team members who reason, communicate, and behave differently than human team members (DeCostanza et al. 2018).

Establishing morale in human–autonomy teams poses initial challenges. Nevertheless, like social cohesion, morale should increase over time as human and autonomous team members acclimatize to each other, learning each other's capabilities, each other's knowledge, and how to interact with one another. Providing human teammates with information about autonomy to foster familiarity and establish appropriate expectations of the autonomy may expedite this process. Further, designing autonomous systems that possess more intelligence and social capabilities (You and Robert 2018) that enable them to participate with their human

team members more fully on both a task (e.g., collaboration, cooperation) and social-emotional level (e.g., providing encouragement, expressing care for team members) has been shown to facilitate cooperation (Kiesler and Goetz 2002) and ease coordination demands (Novikova et al. 2015). These features may also positively influence team identity and subsequently, team member morale. Consequently, future researchers can examine how interacting with autonomy on different levels of the intelligence and social capabilities spectrum can affect a human–autonomy team's morale.

4.1.3 Structural Cohesion (Four Factors: Exclusivity, Group Pride, Belongingness, and Norms)

Structural cohesion details identification with the in-group and comprises four subfactors: *exclusivity*, *group pride*, *belongingness*, and *norms*. Whereas the preceding section highlighted how interpersonal cohesion is a function of the interpersonal relationships among teammates, structural cohesion captures elements of the relationship between teammates and the group itself (or the notion of a group).

4.1.3.1 Exclusivity

According to self-categorization theory, exclusivity reflects the extent to which individuals adhere, via attitudes and behaviors, to group norms that characterize the in-group and distinguish themselves from out-groups (Hogg 1992). Self-categorization theory specifically distinguishes between individual- and group-level behavior, where cohesion emerges from both an individualized attraction to group members and a generalized attraction to the group due to their embodiment of the group's defining features (Dion 2000). Consequently, exclusivity represents individuals' identification with a particular group in contrast to other groups. The salience of group boundaries plays an important role for exclusivity. When primed with an intergroup comparison orientation, subjects showed greater in-group identification, in-group pride, and rejection of out-groups than those with no such priming (Mummendey et al. 2001). Increased salience of subgroups rather than the superordinate group tends to make subgroup members more defensive of their own group at the expense of other groups (Crisp et al. 2006). When members of different groups begin to perceive themselves as belonging to a larger, superordinate group, however, they increasingly recognize previous out-group members as part of this larger, more inclusive group (Gaertner and Dovidio 2009). The salience of human–human subgroups within human–autonomy teams may thus have important implications on exclusivity.

Even though autonomous team members may have different manners of reasoning, communicating, and behaving (see DeCostanza et al. 2018), human team members may not feel that they embody the group's defining features, which may limit or slow the development of exclusivity. However, given time to interact with autonomy and build familiarity with its capabilities and limitations will help facilitate a greater sense of group norms and a degree of exclusivity (Bell and Brown 2015). Future research should delve deeper into how designing autonomy to be more intelligent and human-like will influence the cohesion of a group, specifically how these factors lead to perceptions of following group norms, attributions of in-group versus out-group characteristics, and subsequently group exclusivity (Matthews et al. 2021).

4.1.3.2 Group Pride

Group pride is an affect-based component of cohesion and reflects the extent to which group members exhibit liking for their group's status or ideology (Beal et al. 2003) and the shared importance of being a group member (Mullen and Copper 1994). Group members with elevated group pride will work harder for the pleasure of belonging to a high status, successful group, yet group pride is not a predictor in the cohesion-performance relationship (Mullen and Copper 1994). It is not easy to envision autonomy's authentic group pride in line with human–autonomy teaming. Rather, autonomy may be able to cultivate group pride in others through intentional design choices. To the extent that autonomy can embody and represent essential values, needs, and goals within the group, autonomy will have the capacity to shape group pride (Hung and Gatica-Perez 2010). If identified in advance, these may be programmed within the autonomy to help foster group pride. Future research should investigate the effects of the mere presence of autonomous team members and the presence of intentionally designed, pride-enhancing autonomy on group pride.

4.1.3.3 Belongingness

Belongingness, the degree to which members of a group are attracted to each other, is grounded in group members' cognitive appraisals of the degree to which they belong in a group and how they feel about that cognitive appraisal (Bollen and Hoyle. 1990; Grossman 2014; Salas et al. 2015a). This cognitive attraction to the group reflects the interaction between group membership and self-identity (Dion 2000). This aspect of cohesion has been considered fundamental to the existence of a group, such that a sense of belonging to a group is a prerequisite to any other group characteristic (Bollen and Hoyle 1990). Research into belongingness has shown that it correlates with social outcomes and social self-esteem (Dion 2000). While this factor is highly correlated with morale, it is, in fact, distinct; one example that illustrates this distinction is that of a natural disaster hitting a city, which may

increase one's feelings of belongingness to that city while simultaneously reducing morale (Bollen and Hoyle 1990).

Belongingness may be constrained in human–autonomy teaming contexts as autonomous agents may lack the self-identity necessary to generate such feelings. However, autonomous agents can take other steps to enhance belongingness in teams. Those belonging to the same social group often subsequently engage in mutual mimicry and synchronization, enhancing group membership and feelings of connectedness (Bütepage and Kragic 2017). Synchronizing and mirroring teammates' actions may help an autonomous teammate enhance the sense of belongingness within the group. Additionally, demonstrating apparent involvement in team tasks will help the autonomy enhance its image as collaborative, committed, and vital to team success (Hoffman 2019).

Another way that autonomous teammates can supplement team belongingness is through team-building activities. For example, Carlson and colleagues (2015) found that, regardless of team success, working together with robots on a team-building task made the humans perceive them as more human-like and more intelligent. In the context of human–autonomy teams, completing more objectives can improve overall team belongingness between humans and autonomous agents. Further, as demonstrated by You and Robert (2018), forging a team's emotional attachment to robotic systems has positive impacts on both the viability of the team and overall performance and fosters a strong sense of team identity between robots and their human teammates. Team identity develops as an emotional connection forms and members no longer see themselves solely as individuals, but as belonging to a team or group (Ashforth et al. 2008). Further research in this area is warranted to better understand how to facilitate social and emotional connections that promote a shared identity, with the end goal being greater team belongingness and stronger collaborative partnerships in human–autonomy teams.

4.1.3.4 Norms

Early work in the field of sociology described the power of group norms in folk societies to constrain its members' behavior (Dion 2000). Thus, norms become the standards for evaluating what behaviors are and are not acceptable within a group (Forsyth 1999). Norms complement task cohesion by focusing on team members' group tasks (Carron 1993). Adherence to team norms is strongly and positively associated with high cohesion (Gammage et al. 2001). Because norms can enhance (or degrade) performance, they serve as moderators in the relationship between cohesion and group performance (Carron 1993; Langfred 1998).

While several elements of structural cohesion have limited application to autonomy, norms may play an essential role in shaping such behavior. To the extent that autonomous systems model their behavior after humans, norms may constrain the behaviors they deem acceptable. Mirroring behaviors in chatbots and other interactive agents represent an example of how such systems may identify and guide their behaviors according to perceived group norms. Mirroring also allows the system to adapt to group norms over time. Group members may change their opinions of acceptable behavior in response to team member capabilities and group performance. For example, a high-performing group may begin to tolerate informal behaviors, such as joking, as long as the group maintains a particular performance standard. Although autonomous systems are not necessarily programmed to adhere to a specific set of norms, they may not adapt to changing norms and thus are less likely to deviate from pre-specified behavior. Consequently, autonomous team members acting consistently with pre-specified norms may actually help solidify and reinforce those norms within the group. This topic deserves additional, future research to investigate how autonomous team members can be used to anchor group norms, as well as how group norms may evolve in teams with autonomous systems capable of mirroring behaviors.

4.2 Directions of Cohesion (Two Dimensions)

Cohesion may vary within different team structures. For example, consider the differences in the structure of military teams, organizational culture, and societal culture and how structure shapes cohesion within those groups. This structural-based cohesion difference is further exacerbated by how people view themselves as members of different groups. Most frequently, the literature describes this phenomenon as the *direction* of cohesion, which we outline in the subdimensions of primary and secondary cohesion.

4.2.1 Primary Cohesion (Three Factors: Vertical Cohesion, Horizontal Cohesion, and Complementarity)

The primary dimension of cohesion emphasizes hierarchy in team cohesion (Griffith 1988) and explicitly contrasts the relationship between peers with superior-subordinate relations (Siebold and Kelly 1988; Dion 2000). Examinations of cohesion within the military often examine these relationships (Siebold and Kelly 1988; Grossman 2014). Within this dimension, there are three factors: vertical cohesion, horizontal cohesion, and complementarity.

4.2.1.1 Vertical Cohesion

Vertical cohesion refers to the bonding at different hierarchy levels, such as those between subordinates and leaders. Leaders of military platoons with strong vertical cohesion display quality leadership, competence, technical ability, and sincere caring for their Soldiers (Stewart 1999; McBreen 2002). Furthermore, there is a relationship between Soldiers' positive perception of leaders (i.e., caring and competent) and increased cohesion (Ingraham and Manning 1981; Griffith 1985; Marlowe et al. 1985; Siebold et al. 1988; Manning 1991; Alderks 1992; Kirkland and Kelly 1993). Trusted leadership also provide an additional component to combat task-related, or external stressors, which can destroy a unit's cohesiveness (Stewart 1999).

Placing autonomy in a group's hierarchy can be complicated, given that, depending on the autonomy, team members may not even consider it a part of the hierarchy (Phillips et al. 2011). When autonomy *is* considered part of the hierarchy, it often tends to be subordinate to human teammates, occasionally an equal to its human teammates, and rarely if ever superior (Sycara et al. 2006; Kilgore and Voshell 2014; Lyons and Havig 2014). When humans supervise a subordinate autonomy, they do not have to worry about the autonomy's perception of their competence, though a human supervisor's behavior toward autonomous subordinates may influence human subordinates' view of the supervisor—potentially influencing team cohesion (Dion 2000).

Studies found that humans working with "robot supervisors" ceded task responsibilities to them, were critical of them, and blamed these robotic supervisors for failure; furthermore, humans expressed more responsibility for successful task completion when working with a subordinate robot (Hinds et al. 2004; Lei and Rau 2021). Future researchers can examine vertical cohesion between autonomous supervisors and human subordinates—as well as human supervisors and autonomous subordinates—to confirm if this pattern holds. Furthermore, future researchers can examine the interaction between autonomy modelling high performance (Zaccaro et al. 1995; Bradshaw et al. 2003), autonomy's place in the hierarchy, and vertical cohesion.

4.2.1.2 Horizontal Cohesion

Most cohesion research focuses on horizontal or peer-to-peer relationships within an immediate group at the same hierarchical level (Siebold and Kelly 1988; Dion 2000). This bond does not immediately coalesce; it builds over the life cycle of a team. Under Tuckman and Jensen's (1977) model of group development, teams start developing cohesion at the "norming" stage, when group members have finished competing for positions and established group norms and expectations.

Kozlowski and associates' (1999) process model of team development also suggests that team members require some time to build that bond between peers before the team can successfully build cohesion. Given that the introduction of automation can affect the development of norms in teams (Bowers et al. 1996), future researchers ought to compare cohesion development in human teams and human–autonomy teams.

Although the development of the social aspects of a human team is somewhat well-known, peer-to-peer relationships between humans and autonomy are still relatively rare. Human operators tend to have a supervisory-control relationship with their autonomous systems; as technology progresses such that autonomy can fulfill the role of a human teammate, a human–autonomy peer relationship can exist, though this approach is rarer than the alternative (Chen and Barnes 2014; Ososky et al. 2013). Autonomy can successfully fulfill the role of a peer by acting like a typical teammate: perform its task well, convey results to teammates, monitor teammates' activities, and intervene given the requisite team dynamics (Sycara and Sukthankar 2006). Moreover, people can form personal bonds with autonomy from a social standpoint, attributing attitudes toward them that they cannot possess (e.g., care and concern; Sung et al. 2007; Williams et al. 2015). These bonds may help facilitate cohesion. However, to maintain these bonds, either autonomy needs to maintain the illusion of human capability or humans need to adjust their expectations of autonomy to a level it could reasonably fulfill. Likely, a combination of both strategies would be needed for autonomy to facilitate horizontal cohesion. Regardless, interaction with machines, from simpler automated systems to more complex autonomy, benefits from accurate expectations and minimizing false hopes (Norman 1994). Agent transparency, using interface elements to inform human operators of agents' inner workings, has facilitated appropriate human calibration of trust in the agent (Chen et al. 2018). Future researchers may be able to extend this line of research and explore how agent transparency influences cohesion as well.

4.2.1.3 Complementarity

We theorize that complementarity is and should be considered a subdimension of cohesion. Complementarity refers to the diverse skill sets that individuals bring to the team, how individuals can slot these skill sets into the team's roles, and how other team members value the diverse skill sets that their teammates bring to their roles. Muchinsky and Monahan (1987, 1) define complementarity as "the match between an individual's talents and the corresponding needs of the environment [in that] the strengths of the individual complement the needs of the environment." Additionally, Piasentin and Chapman (2007, 234) defined perceived

complementarity as "stemming from individuals' perceptions that their differences serve to complement organisational characteristics." This subdimension is built off research into cohesion, role value, and role uncertainty (Yukelson et al. 1984; Zaccaro 1991). Complementarity should occur in formalized teams, where member needs, goals, and roles are established (e.g., sports teams [Tuckman et al. 1977]). Greater cohesion in these teams helps team members familiarize themselves with their teammates' intangible features (e.g., habits, preferences, and approaches—and allow them to stake out more specific roles [Jennings and McRandle 2011; Benson et al. 2013]).

We theorize the complementarity subdimension would fill a significant gap within human–autonomy teams cohesion research as autonomous systems may have skills that augment their human team members' abilities and vice versa. Relatedly, complementarity in a human–autonomy team can have a temporal component relating to initial attraction to a team and an enhanced trust over time (Jordan 1963; Schutte 1999). Therefore, how complementarity affects team cohesion, especially cohesion's development over time, must still be determined

The Fitts list (1951) is an approach to complementarity that has a strong history in the human–machine interaction literature and can be a jumping-off point for further exploration of heterogeneous skill sets in human–autonomy teams (de Winter and Dodou 2014). In assessing the utility of complementarity within human–autonomy teams, future research must first determine the various skills that are required for a particular task and determine which skills can be allocated to a human and which will be augmented by an autonomous teammate, essentially an extension of Fitt's Law. Such skills should complement rather than overlap or conflict with human skills to truly add value to a team. Further, we also argue that complementarity would help strengthen cohesion and divergent thinking within a team and buffer against detriments of too much cohesion such as group think. Future research can examine how the addition of complementary autonomy influences the development of cohesion in teams and the extent to which it mitigates against the detriments of too much cohesion.

4.2.2 Secondary Cohesion (Two Factors: Organizational and Societal Cohesion)

Within the general cohesion literature, secondary cohesion (i.e., organizational and institutional cohesion) has been neglected and only primarily studied within military organizations and teams. Primary cohesion reflects an individual's relationship to their peers and immediate leaders, while secondary cohesion reflects their relationship to their secondary group organization (e.g., their company and institution; Salo 2006). Additionally, secondary cohesion refers to cohesion in the

context of an individual or team's society. Within the military, this would refer to the connection that a Soldier has overall to the Army or military service (beyond the relationship to their immediate peers, squad, platoon, etc.). Specific to secondary cohesion are the factors of organizational cohesion and societal cohesion.

4.2.2.1 Organizational Cohesion

Organizational cohesion illustrates the relationship that an individual has to their organization. It binds small groups to a higher purpose and is particularly relevant to military organizations as these organizations are built upon and grounded in history and personally meaningful traditions (Segal and Kestenbaum 2002). In research, however, the organizational context in which primary group attachments occur is often ignored (Segal and Kestenbaum 2002). Primary group ties are likely to enhance performance and commitment to the extent that they incorporate the norms and goals of the larger organization from which they stem. Without such integration, cohesive groups can develop norms and goals that undermine those of the larger organization.

Additionally, organizational culture may also be an important factor for initial autonomy teaming "buy-in" and effectiveness as the addition of these types of newer technologies can challenge previously established norms (McDermott and Stock 1999). Organizations who are more "flexible" are more likely to adopt a technology "buy-in" mentality and experience more initial success with autonomy adoption, especially if the autonomy is considered useful and easy to use (Zammuto and O'Connor 1992; Cao et al. 2019). As autonomous systems become increasingly integrated into organizations across multiple contexts, research should continue examining how the strength of organizational culture shapes buy-in during adoption of autonomy.

4.2.2.2 Societal Cohesion

Societal cohesion refers to the relationship between an individual or team and the society it serves; one can understand it as a step beyond organizational cohesion. Furthermore, societal cohesion functions as the cultural, economic, and political heritage between the specific organization and the society to which it belongs. Societal cohesion corresponds to military unit cohesion, both of which reflect large, long-lived, hierarchical organization from which the group member cannot easily leave (Siebold 2006).

There may be differences in the cross-cultural perspective of autonomy usage, where cultural tendencies may impact automation trust and cohesion in a human–autonomy team. For example, Huang and Bashir (2018) found that

individuals with strong cultural tendencies surrounding horizontal collectivism and individualism were more inclined to trust automation. Thus, societal differences may impact initial attraction to a human–autonomy team and hence cohesion long term. Future researchers can investigate perceptions of autonomy across countries and determine the extent to which different societal factors influence the development of cohesion in human–autonomy teams.

4.3 Team Resilience

We propose team resilience is the third dimension of team cohesion. One can define team resilience as "a multi-phasic process in which members of the unit deliberately and collectively apply skills, abilities, and resources to prepare the unit for adversity by planning and anticipating adverse events, successfully respond to challenging events by withstanding or adapting to stressors, and recover after the event, which involves the unit returning to homeostasis (e.g., bouncing back) or an improved state through post-event learning and growth" (Cato et al. 2018, 53). The positive relationship between cohesion and resilience has been well established (Gittell et al. 2006; Norris et al. 2008; Blatt 2009), with some researchers, such as Bowers and associates (2017), conceptualizing team resilience as a combination of other team states, including cohesion. Additionally, theoretical models of team resilience propose it is a multilevel factor, with many suggesting that team resilience results from other emergent states in the team (Marks et al. 2001; Sharma and Sharma 2016; Bowers et al. 2017).

Although team resilience studies have primarily focused on human teams, the presence of an autonomous teammate may impact team resilience due to the autonomy's complementary skills and abilities. Autonomous teammates can carry more task-related knowledge than human team members (Ziemke 1998). Given this capability, human team members may feel more at ease and safer, in the context of a high-stress or high-risk situation, through reliance on autonomous teammates. Autonomy may have additional effects on human teammates, including making human team members feel more confident in missions, facilitating team resilience by increasing team readiness for tasks, and engendering overall team confidence (Berg et al. 2021).

At the network level, systems are resilient against cyber-attacks through authentication of communication and detection of outside intrusion (Mitra et al. 2019). In a human–autonomy context, this is beneficial to the team as autonomous agents protect and secure sensitive team information. Resilience in humans is far more emotion-based, with a focus on reacting to stress situations and overcoming them. While these two approaches seem disparate, using common frameworks that

encompass both (e.g., network theory) may provide future researchers a perspective on the development of resilience in human–autonomy teams that would not come to light if looking at human resilience or system resilience separately (Fraccascia et al. 2018).

5. Why is Cohesion Important: Benefits and Detriments of Cohesion

Team cohesion has a positive association with performance (Beal et al. 2003), job satisfaction and psychological well-being (Dion 2000; Ahronson and Cameron 2007), team viability (Tekleab et al. 2009), collective efficacy (Grossman 2014), and emotional resilience (Neubauer et al. 2016). However, cohesion can also lead to potential detriments in team performance, such as social loafing (Høigaard et al. 2006) and so-called "groupthink" (Janis 1982). Figure 1 illustrates the somewhat polarizing nature of the benefits and detriments of cohesion on team performance, using Yerkes-Dodson's inverted-U model of arousal (1908) as a model.

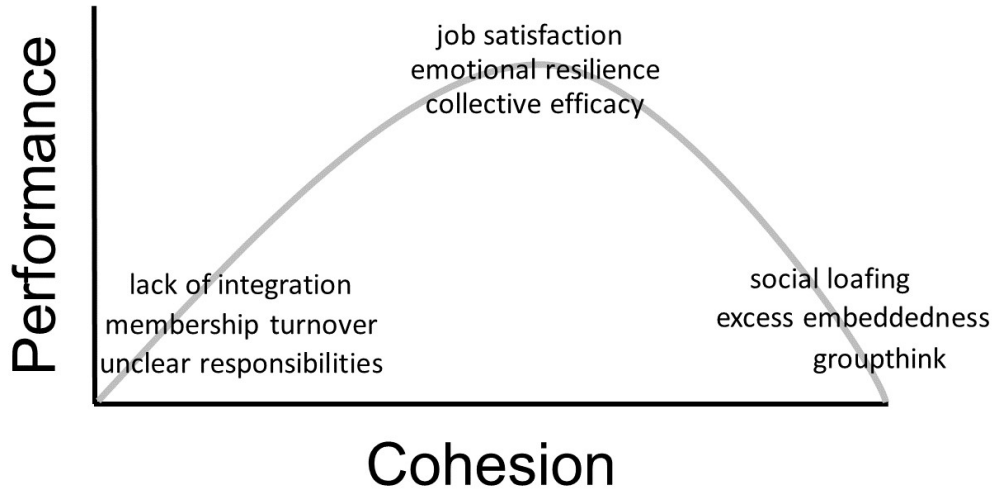

Fig. 1 Effects of cohesion on team behavior and performance

5.1 Benefits

5.1.1 Team Performance and Viability

The relationship between team cohesion and performance is well documented (Beal et al. 2003; Chiocchio and Essiembre 2009). High cohesion is predictive of group performance (Oliver et al. 1999), performance behaviors (Beal et al. 2003), and team decision making (Zaccaro et al. 1995). This association is evident in military teams (Oliver et al. 1999; Ahronson and Cameron 2007), sports teams (Gammage et al. 2001), and project teams (Chiocchio and Essiembre 2009). However,

performance is not necessarily associated solely with generalized group cohesion. Some evidence suggests that, specifically, greater task cohesiveness in a group yields better performance (Zaccaro et al. 1995; Hung and Gatica-Perez 2010). Social cohesion, however, can interact with factors such as team heterogeneity (Chiocchio and Essiembre 2009) or performance norms (Ramos-Villagrasa et al. 2018) to relate to team performance. Autonomy, as a team member, can conceivably contribute to task cohesion through the pursuit of team goals, and therefore, while not able to experience the individual attitude of cohesion, may be able to contribute to the development of a group's cohesion and subsequent performance outcomes (Bradshaw et al. 2009; Abrams et al. 2020).

Team cohesion is important for a newly formulated team and a critical element of team viability. Viability is the degree to which group members wish to work together as a team in the future (Barrick et al. 1998; Grossman 2014). Expectations of lasting relationships encourage team members to exchange and debate conflicting ideas and information more effectively without worrying that task-related conflict will transform into personal conflict (Murnighan and Conlon 1991; Jehn 1995; Simons and Peterson 2000). These expectations align with what Walker (2010) called interactive social flow that occurs during highly interdependent situations. Specifically, highly cohesive teams agree on goals, procedures, roles, and patterns of interpersonal relations (Mullen and Copper 1994; Hackman et al. 2000). Autonomous teammates can contribute to team viability by assessing the team and increased communication (Demir et al. 2015; Mostafa et al. 2019). Autonomous agents can transmit information between teams and allow the team to make effective decisions based on that information (Sycara et al. 2006). By engaging in these behaviors, autonomous team members should facilitate cohesion and, by extension, team viability.

5.1.2 Job Satisfaction

Cohesion has also been positively related to outcomes such as job satisfaction (Ahronson and Cameron 2007; MacCoun and Hix 2010). For example, Iskandar (2019) found a direct, positive influence of group cohesion on job satisfaction, which the author asserts stem from social relationships, social support, and subsequent stress reduction that accompanies highly cohesive groups. With respect to sports teams, when athletes provide social support and training, their teams are considered more cohesive and are hypothesized to result in greater athlete satisfaction (Vincer and Loughead 2010). With respect to military teams, Oliver et al. (1999) showed that cohesion correlates more strongly with job satisfaction than other outcomes such as group performance, individual performance, retention, well-being, and readiness. Accordingly, Carron et al. (1998) propose a potential rationale for these findings, namely, that members' emotional needs are met in

highly cohesive groups, which in turn leads to job satisfaction. Even so, the relationship between cohesion and job satisfaction is not simple and not always direct (Urien et al. 2017). In those instances where cohesion indirectly influences job satisfaction, it likely acts as a buffer due to the sense of identity and support encountered in highly cohesive teams.

Further, researchers have described cohesion as a "protective factor" that helps counter the adverse effects of job demands on attitudes of employees that work in stressful occupations (Steinhardt et al. 2003; Li et al. 2014). While we can assume that cohesion will have similar beneficial effects in human–autonomy teams, more research is needed. However, the implementation of autonomous systems in a team is important as it will ensure that all team members have a purposeful role in the team (Smids et al. 2020). Having each team member serving a purposeful role will, subsequently, safeguard the team members' sense of contribution and reduce the incidence of team members feeling isolated from each other, which plays a critical role in job satisfaction and can lead to better team outcomes.

5.1.3 Psychological Well-Being

In general, the literature indicates that being part of a highly cohesive team plays a significant role in the well-being experienced by team members (Vanhove and Herian 2015). There appears to be a reciprocal relationship between these two constructs, as individual well-being can also impact cohesion (Vanhove and Herian 2015). Although defined in numerous ways, psychological well-being is a characterized by low levels of psychological distress (e.g., stress, depression, loneliness, and anxiety; Ahronson and Cameron 2007). Some authors recommend that well-being is multidimensional and comprises low levels of distress and the presence of positive affect (Vanhove and Herian 2015; Cramm and Nieboer 2015). Research has identified some of the mechanisms at work in the relationship between cohesion and well-being, pointing to group identification as an indicator of psychological adjustment (Cameron 1999). In addition, Schuster (2020) suggests that quality interactions between group members and the emotional gains they derive from group membership contribute to the sense of belonging and well-being in teams. Cohesive teams frequently engage in interactions aimed at exchanging information and collaborating, which in turn leads to group member growth, group member development, and, subsequently, a greater sense of individual well-being (Markova and Perry 2014).

In addition to psychological well-being, some scholars have even found evidence that team cohesion is a critical factor in emotional resilience following periods of stress (Neubauer et al. 2016), reducing workplace stressors and increasing feelings of personal value to the team (Ladegård 2011; Foy et al. 2019). The expression of

both positive and negative emotions can help enhance resilience to stress due to their ability to help facilitate constructive solutions to problems, but only when all team members share in the burden of listening and comprehending negative expressions (Stephens and Carmeli 2016). Overall, unit cohesion, or cohesion with direct team members, has been linked to improved unit resilience and mental health resilience needed for team effectiveness (Brailey et al. 2007; Kanesarajah et al. 2016; Williams et al. 2016; McAndrew et al. 2017; Zemba et al. 2019). Therefore, autonomous systems could enhance the psychological well-being of team members to the degree that they fulfill their task commitments and help reduce the task load of other team members. This course of events would reduce the workload experienced by team members and create opportunities for more constructive problem-solving. Further, enabling a bidirectional communication capability or feedback mechanism between humans and autonomy may help foster positive interactions that contribute to the team's overall well-being. Given that autonomous systems are relatively novel, the ability to contribute to well-being may be a gradual process as team members learn about autonomous capabilities and "adopt" them as team members.

5.2 Detriments

5.2.1 Groupthink

High levels of cohesion may lead to rigid adherence to group norms and hostility to those who may violate or challenge those norms. For example, excessive social cohesion, particularly elements of exclusivity and adherence to group norms, may lead to hostility toward outside ideas or opinions (Janis 1982). This excess cohesion may manifest as groupthink, in which deviation from group norms leads to ostracization or even banishment from the group (Janis 1982). Elements of groupthink contributed to the Challenger shuttle disaster and the failure of the Bay of Pigs Invasion (Janis 1991). While groupthink results in deliberate and demonstrative reinforcement of group norms and ideas, excessive cohesion may achieve similar outcomes through more subtle phenomena. The common knowledge effect arises when individuals in highly cohesive groups become less critical of common knowledge due to an assumption that group members have already vetted that information and achieved a consensus (Gigone and Hastie 1993; Gruenfeld et al. 1996; Kim 1997). Less prone to analyze such information critically, the group becomes more susceptible to mistakes and misinformation. High cohesion can contribute to excessive embeddedness, limiting the group's exposure to novel information and ultimately hindering its adaptability and performance (Gargiulo and Benassi 2000; Uzzi and Gillespie 2002; Owen-Smith and Powell 2003).

Including autonomous teammates can help mitigate risks associated with groupthink, as autonomous agents do not feel human pressures of conformity. While autonomous agents may help facilitate cohesion in groups, they may also limit excessive cohesion. Lacking fear of ostracization, autonomy will be less likely to be overly concerned with conformity. Less prone to social pressures and influences of tribalism, autonomy seems unlikely to be hostile to outside ideas or opinions unless explicitly programmed to do so. As a result, autonomy may suppress these kinds of behaviors in groups. Furthermore, to the extent that autonomy does not push group members toward excessive adherence to group norms, often to the point of excluding outsiders, autonomy may help prevent groupthink.

5.2.2 Reduced Creativity and Innovation

The strength of interpersonal ties among team members also influences innovation—but not how managers may think. Open debate is critical to the process of innovation. However, groups with high social cohesion focus more on maintaining relationships–seeking concurrence. One study found that increased social ties among members led to reduced innovation in its new product (Sethi et al. 2002). Again, team context is an important consideration. Cohesion is deemed critical in teams that require high levels of coordination and communication, have high degrees of interdependence, work in complex or dynamic task environments, and work in hazardous environments. In each situation, convergence and social support are central to team success; therefore, innovation and creativity may suffer when high cohesion is a prerequisite for team success (Bell and Brown 2015). As such, autonomous teammates will have to be tailored to the specific teams they join to emphasize innovation or social support as necessary. An improper match between the autonomy and the team may stifle innovation or jeopardize task performance in high-risk environments.

5.2.3 Social Loafing

Cohesion shapes not only how individuals express ideas to the group but also how they behave. Increased cohesion leads to increased conformity to group norms, but norms for counterproductive behavior can link high group cohesion and poor group performance. Specifically, when teams have high social cohesion coupled with low task cohesion or low-performance norms, they may encounter increased antisocial behavior (such as social loafing) due to a lack of deterrents to such behavior (Høigaard et al. 2006). However, teams with low social cohesion but high-performance norms tend to inoculate the team against perceived social loafing. Thus, cohesiveness may have adverse effects if the group norms do not support the team's productivity (Driskell and Salas 2006). The presence of autonomy on a team

may help prevent social loafing if its human teammates do not influence the autonomy's productivity norms. However, autonomy whose work ethic does not wane may contribute to a new type of loafing in the group, one in which individuals become overly reliant on the autonomy. Similar patterns of overreliance have been well documented with autonomous driving aids (Arakawa and Oi 2016; Takeda et al. 2016; Arakawa 2018; Fu et al. 2020); therefore, teams will need to account for this tendency.

6. Cohesion when Teammates Are Autonomous

Autonomy, in and of itself, is a system; specifically, it is an entity that performs a function without additional human intervention. Furthermore, a human–autonomy team is a parent system, containing at least one autonomous system and at least one human—if there are multiple humans, they form a group, which can be viewed as another, larger system (Wilson 2014). By viewing human–autonomy teaming from both a human teamwork perspective and a systems-oriented perspective, we can examine how cohesion emerges as both a dynamic property of a team and an interaction of interrelated components in a larger team system (Marks et al. 2001; Wilson 2014). By examining the different systems and interactions that occur in a human–autonomy team, we will be able to identify potential points of leverage that we can use to steer these team systems into preferable outcomes.

6.1 Collaboration and Interdependence

The difference between human collaboration and human–autonomy collaboration is relevant to establishing cohesion in human–autonomy teams. In order to successfully collaborate, human teams require some level of interdependence of action among their members in pursuit of shared goals (Mathieu et al. 2008; Bradshaw et al. 2012). Cohesion helps teams collaborate by enabling effective communication, coordination, and synchronization, thus facilitating teammate interdependence (Pescosolido and Saavedra 2012).

Only some autonomous systems are collaborative, however. For example, collaborative robots, or co-bots (Colgate et al. 1996), are skilled technological manufacturing systems able to work in conjunction with humans in the same workspace, improving efficiency, flexibility, and quality (Bauer et al. 2016). Co-bots differ from robots in their level of human interaction while performing a task (e.g., an assembly task). Further, co-bots are more interactive with human workers and are more flexible in their capabilities, whereas robots are physically separate from the human worker and maintain a fixed position (Cassioli et al. 2021). Advances in both sensors and data processing capabilities will enable autonomy to

work at an increased capacity with others, potentially as a full-fledged team member rather than just a tool (Colgate et al. 1996; Johnson et al. 2012). As autonomous capabilities advance and full-autonomy collaboration become possible, an autonomous agent must support interdependent actions with their human teammates (Bradshaw et al. 2012) to maintain team effectiveness and cohesion. However, establishing this level of interdependence between humans and autonomous teammates can be challenging (Mathieu et al. 2008; Bradshaw et al. 2012).

One way to promote interdependence between humans and autonomy is by manipulating structural task interdependence, which refers to the degree to which group members perform tasks interdependently or independently (Wageman and Gordon 2005). The complex, joint activity envisioned in future robot collaboration can degrade team performance if interdependencies are not properly managed (Wageman and Gordon 2005; Johnson et al. 2012). Another way to promote human–autonomy interdependence is by developing a mixed-initiative interaction strategy, where each team member, human and autonomous, negotiates their level of responsibility and contribution to the team objective based on their strengths, where possible (Allen et al. 1999). Through the negotiation process, humans can develop the social structures needed to build interpersonal cohesion with each other and with their autonomous teammates (Bradshaw et al. 2003; Walliser et al. 2019). Lastly, bringing end users into the design process early so they understand the capabilities and benefit of autonomy is key for gaining acceptance and a willingness to depend on the systems (Bauer et al. 2016).

6.2 Communication

Communication is another interaction factor that affects the development of team cohesion. Humans and autonomous systems communicate differently, which can significantly impact collaboration and team identity, affecting team cohesion (Mesmer-Magnus and DeChurch 2009; Grossman 2014; Lu 2015). When humans communicate face-to-face, they transfer information to others using both verbal (e.g., speech, prosody) and nonverbal cues (e.g., proximity, gestures) in order to coordinate with their teammates, building common ground and trust (Mesmer-Magnus et al. 2011; Grossman 2014). When humans are at a distance, they communicate through technology using a myriad of channels, some richer (e.g., video conferencing, phone) and some leaner (e.g., text messaging, email [Lu 2015; Stawnicza 2015]). Human teams using rich communication channels can develop performance-enhancing affective states (i.e., cohesion) more quickly, maintain robustness to challenges that may undermine those states, and reduce perceptions of social loafing (Bryant et al. 2009). Human teams using leaner communication

channels are more susceptible to conflict, diminished social ties, and protracted rapport development, all of which result in a decreased sense of cohesion between team members (Morrison-Smith and Ruiz 2020). Autonomy, however, does not necessarily have to mimic face-to-face or technology-mediated human–human communication to convey information to human teammates with adequate richness.

Autonomy's physical components can shape not only its physical interactions, but also its cognitive and social interactions with its human teammates (Wilson 2014; Fiore and Wiltshire 2016). Autonomy can modulate their communication channels—varying speech prosody, facial expressions, and gestures—to enrich human–autonomy interaction, bolster teammates' perception of the autonomy, and, by extension, bolster the team's cohesion (Niewiadomski et al. 2010). Further, autonomy is capable of presenting information to humans in several different ways (e.g., visualizations, text, audio alerts, artificial speech, and haptic feedback [Jones and Schmidlin 2011; Chhan et al. 2020; Perelman et al. 2020]), which enables human–systems interactions that facilitate team coordination and the building of shared knowledge (Sycara and Sukthankar 2006; Demir et al. 2015). These behaviors can facilitate cohesion by encouraging productive, positive interactions with human team members (Lyons and Havig 2014). Research suggests that promoting bidirectional communication and providing opportunities for team members to establish connections are successful strategies in facilitating cohesion in teams where members cannot communicate face-to-face (Hung and Gatica-Perez 2010; Grossman 2014; Lu 2015). Autonomy that uses multiple channels to exchange media-rich information with their human teammates can help establish a "person–device–person" interaction network (Wilson 2014, 8) to coordinate and build shared knowledge may promote high team cohesion.

6.3 Role and Hierarchy of Autonomy in Human–Autonomy Teams

The role—or echelons on the organizational hierarchy—that autonomy takes within a team, as a part of a larger sociotechnical system—is an additional factor relevant to human–autonomy team cohesion (Karsh et al. 2014). When not used solely as a tool, autonomy usually fills a subordinate role, rarely fills the role of peer, and scarcely, if ever, serves as a task leader (Walliser et al. 2019). Each of these roles has different responsibilities and can facilitate different types of cohesion (e.g., vertical cohesion, horizontal cohesion). Human trust in autonomous team members is closely affected by how reliable the autonomous agents are in their tasks (Hancock et al. 2011) and, consequently, trust is positively related to task cohesion (Grossman 2014). Thus, when autonomous systems are less than fully reliable in

executing their roles and responsibilities, their human team members will lose trust in them, damaging cohesion.

Within human teams, subordinates respond negatively to a supervisor when they do not have the commensurate skills or authority (Hinds et al. 2004). In studies on human–robot dyads, humans were critical of robot supervisors, blamed robot supervisors for failure, and ceded task responsibility to robot supervisors (Hinds et al. 2004; Lei and Rau 2021). In one study examining responsibility attribution in human–robot collaborations, participants ceded responsibility for failures to their robotic supervisor, but shared the blame with autonomous peers and subordinates (Lei et al. 2021). If these behaviors persist in multi-human, human–autonomy teams, then the use of autonomous supervisors will be disadvantageous in many situations. Additionally, the perception that a teammate is an autonomous agent hampered team dynamics and subsequent team behaviors for human teammates in a multi-human, human–autonomy team (Demir et al. 2018). Despite the disadvantages of using autonomous supervisors, managers can still work with developers to match autonomy's roles in teams. Matching agent capabilities with its role can ensure successful autonomy implementation and mitigate the negative repercussions of autonomy's failure to perform its responsibilities.

6.4 Autonomy and Building Cohesion over Time

Previous research has shown that time is a critical factor in human–autonomy teams, with elements such as trust and relationships evolving as time progresses (You and Robert 2018). Task and interpersonal cohesion in human teams develop over time as well, both in-person and when mediated by technology (Irmer et al. 2000; Salas et al. 2015a). Given these findings and hypotheses, we expect that autonomy may be well suited for facilitating the growth of cohesion over time in a human–autonomy team if the previously mentioned factors and considerations are effectively planned for and implemented.

In human teams, task cohesion may be the initial "force" that ties team members together, with interpersonal cohesion developing later in the team's life as members interact more with one another (Tuckman and Jensen 1977; Grossman 2014; Lu 2015). Further, autonomy is expected to be well suited to promoting task cohesion in teams, given its in-built commitment to the team's shared tasks (Zaccaro et al. 1995; Abrams et al. 2020). If that is the case, then autonomy that is seen to facilitate task cohesion can also facilitate social cohesion by keeping team members together and attracted to the group while more interpersonal cohesion develops.

Autonomy may also be uniquely suited to promote cohesion in short-lived teams. The military—an organization planning to use more human–autonomy teams in the

future—often uses temporary teams with a steady rotation of team members (Siebold 2006; David and Nielsen 2016). Soldiers trained to work with autonomous teammates (or working with system interfaces simple enough to avoid a steep learning curve) may work with autonomous systems serving as stable team members in these temporary teams. Not only would autonomy's steady performance scaffold the development of cohesion in temporary teams, but they could establish a reputation for steady performance. For example, past experiences with animals in human–animal teams provide humans with expectations in future human–animal relationships (Wilson 1994). Thus, experience with specific autonomous systems in a cohesive temporary team may yield a more rapid acceptance of the individual system's capabilities and the overall team operations. So, autonomy can model consistent, productive behavior over time, using task cohesion to bind the team together while interpersonal relationships, and then interpersonal cohesion, develop.

6.5 Individual Differences and Human–Autonomy Teams

When humans work with other humans, individual difference factors such as personality are relevant to cohesion. Conscientiousness and agreeableness contribute to better team performance outcomes and task cohesion (van Vianen and De Dreu 2001). Extraversion has a strong positive link with social cohesion, and neuroticism is negatively associated with both (Aeron and Pathak 2012). Autonomy, however, is a constructed entity different from humans, so the individual difference factors specific to human–autonomy interaction will also influence cohesion in human–autonomy teams. When humans work with autonomy, different individual difference factors, such as working memory capacity, perceived attentional control, and spatial ability, are relevant to effective human–autonomy team performance outcomes (Wright et al. 2013, 2018). Working memory capacity positively correlates with task performance, situation awareness scores, and trust (de Visser et al. 2010; Rovira et al. 2017; Wright et al. 2017, 2020). Greater attentional control is associated with higher reported confidence in evaluations of autonomy reliability (Wright et al. 2020). Higher spatial ability supports improved route planning and target identification (Wright et al. 2013). Introducing an autonomous teammate introduces this new set of factors, each of which can potentially affect team cohesion. Where relevant to the task, autonomy complementing these skill sets in humans may not only drive improved performance outcomes but also increased cohesion. In human–autonomy interaction, designers can shape autonomous systems to adapt to meet individual human needs, facilitating task cohesion (Sycara et al. 2006; Sukthankar et al. 2012). For example, suppose autonomy possesses the capability to consider the task-

related individual differences of its human teammates, as well as their current states (e.g., stressed, fatigued), and can offer them assistance. In that case, the autonomy would be acting in a similar fashion to a human teammate and therefore would serve to increase task cohesion and potentially social cohesion as well. Although not feasible today, there are indicators that future capabilities will enable this type of activity between humans and autonomous systems (Johnson et al. 2012).

7. Conclusions and Future Research

The objective of this report has been to explore the emergent state of cohesion—its definitions, factors, and effects in different contexts—and determine how the inclusion of autonomous team members might affect it. By aggregating and synthesizing information from both the human cohesion literature and the human–autonomy interaction literature, we conclude the following:

1) An autonomous agent differs from its human counterpart in that it cannot experience the feelings associated with cohesion. Rather than managing its own (non-existent) emotions, autonomy can contribute to other team members' individual and group-level feelings of cohesion. The capabilities a specific agent is endowed with and uses during a teaming interaction should be leveraged to strengthen cohesion by exhibiting consistent and desirable team behaviors.

2) Autonomy is better at performing certain behaviors (e.g., complex, repetitive tasks) than others (e.g., building social relationships), and consequently, will better facilitate certain factors of cohesion (e.g., task cohesion) than others (e.g., belongingness). Consequently, autonomy's unique strengths may be better suited to certain contexts rather than others. For example, in a task with a high-risk outcome where behaviors associated with high task cohesion (e.g., ability and reliability) are paramount, an autonomous team member may be a desirable addition to its human counterparts due to the straightforward nature of its ability to augment the team's skills. In a task that requires high social cohesion and closeness, however, including an autonomous teammate may be more difficult. Those cohesion subdimensions take time to develop and have an emotional component, which autonomous agents cannot express as well as their human counterparts.

3) Autonomous team members can mitigate some of the adverse effects of excessive cohesion since they are not subject to humans' same cognitive biases and normative or social influences.

4) If an autonomous system is present in a multi-human team as an independent team member, its presence will affect the group's dynamic. A team with a subordinate autonomous system that communicates richly with its human team members to accomplish shared tasks over an extended period will tend to report higher cohesion than a team where the autonomy's role, level of interdependence, communication capabilities, or time with the team differs.

5) Features of human–autonomy interaction (e.g., communication medium, richness) will shape the development of cohesion by enabling or constraining the development of specific cohesion factors.

Reviewing this information has led us to identify specific gaps in the literature that future research could address. The first such gap includes identifying dimensions, subdimensions, and cohesion factors relevant to human–autonomy teams. This report identifies factors (i.e., resilience and complementarity) relevant to human–autonomy teaming and should be considered cohesion factors in human–autonomy teams. Future research should explore how autonomy can support the cohesion factors described previously and whether more relevant factors to human–autonomy team cohesion exist. Relatedly, future research ought to confirm that constructs of cohesion previously validated with human teams also achieve validity in human–autonomy teams. Any subsequently theorized human–autonomy team cohesion factors identified (including resilience and complementarity) should also be validated. Efforts to measure human–autonomy cohesion are underway (Berg et al. 2021; Neubauer et al. 2021).

Another area for future research to explore is team makeup. Team size plays a role in cohesion development. The ratio of autonomous agents to persons has been examined, mainly pertaining to how many agents an individual can manage (Miller et al. 2002; Murphy 2004; Mitchell and Cummings 2005; Goodrich and Schultz 2008). Teams may have many more autonomous agents than humans, many more humans than agents, or roughly even splits between them; how cohesion varies in these different configurations deserves future attention.

While this report discusses team cohesion in different topical contexts, another factor for future research to consider is cultural and generational context. According to recent surveys from Pew Research Centre (2020), Americans under and over 50 and Asian and European countries differed in their perceptions of autonomy and their acceptance of the role of autonomy in daily life. Recognizing and understanding these cultural and cohort effects on trust in autonomy will be critical for anticipating their impacts on human–autonomy team cohesion and for building effective human–autonomy teams.

In this report we endeavored to aggregate and synthesize existing research, thereby establishing reasonable expectations for cohesion in human–autonomy teams upon which future researchers can build. The expectations for future autonomy, however, are still in flux. Future development focuses on elevating autonomous systems to the level of full "teammate," thereby enhancing the collaborative partnership between humans and autonomous team members and subsequently creating more-cohesive human–autonomy teams. In fact, as technologies such as artificial intelligence (AI) and machine learning (ML) continue to evolve and endow autonomous systems with increasing capabilities, it becomes more reasonable to expect human–autonomy teams to replicate the teamwork behaviors (Lyons et al. 2021) that are so critical for human team effectiveness and the development of cohesion. For example, deep learning algorithms can enable autonomous systems to learn and adapt—a hallmark of effective team members (Salas et al. 2009). Whether human or autonomy, teammates must learn to adapt in ways that complement their teammate's actions or behavior—in other words, adaptation must be mutual among team members (Lyons et al. 2021). Advances in AI and ML shows promise for enabling autonomy to become more adept socially, making human–autonomy interactions more pleasant, and facilitating better teamwork, collaboration, and cohesion (You and Robert 2018; Traeger et al. 2020).

Further, as noted throughout the report, we have described the importance of autonomy having agency, being able to communicate actions and intentions to their human partners in ways that are easily understood and being able to develop shared mental models of the team and its tasks (Lyons et al. 2021)—which will benefit from the evolution of autonomous capabilities. However, when incorporating advanced autonomy, care must be taken so as not to disrupt the team dynamic and/or create a team environment conducive to groupthink.

As development proceeds in this direction, researchers will discover new and more relevant factors of autonomy and human–autonomy interaction contributing to a deeper understanding of human–autonomy team dynamics and cohesion. With this new information, future researchers will get closer to finding the inflexion point where autonomous systems transition to synthetic teammates.

8. References

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List of Symbols, Abbreviations, and Acronyms

AI	artificial intelligence
ARL	Army Research Laboratory
DEVCOM	US Army Combat Capabilities Development Command
HABA-MABA	Humans Are Better At, Machines are Better At
MABA-MABA	Men Are Better At, Machines Are Better At
ML	machine learning

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