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Psychometric Properties of Team Resilience and Team Complementarity as Human-Autonomy Team Cohesion Factors

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ABSTRACT

Adopting autonomous systems into human teams will likely affect the development of critical team states like cohesion. Thus, there is a need to understand how to measure team states as they emerge and change within the dynamic operational environment in which human-autonomy teams operate. To address this, we developed a novel self-report scale to assess cohesion in human-autonomy teams. An initial pool of 134 items was created, based on the human team cohesion literature. Following item evaluation by eleven subject matter experts (SMEs), the remaining 82 items were tested for content validity in an online study, which utilized a vignette approach to measure cohesion in human autonomy teams. Results of factor analyses highlighted 'Team Complementarity' as a salient subdimension for cohesion in human autonomy teams and suggest consideration for incorporating two subfactors of the Team Resilience dimension into future team cohesion measurements.

Keywords: Human autonomy teaming, Team complementarity, Team resilience, Team cohesion

INTRODUCTION

There has been increased interest in adopting human-autonomy team structures into military domains as a force multiplier. For this paper, human-autonomy teams consist of one or more human members coupled with one or more autonomous or intelligent agents—that are interdependent and work collaboratively towards common goals (McNeese, Demir, Cooke, & Myers, 2018). Introducing autonomous systems into human teams will change how teams coordinate and communicate, and in turn, affect the development of fundamental constructs like team cohesion. Thus, there is a need to understand how team states emerge within human-autonomy teams and how to effectively measure them. While there are several existing self-report scales for measuring cohesion in human teams, it is unclear how these scales and/or the cohesion factors being measured translate to the context of human-autonomy teams. To address this gap, we developed a novel self-report scale to assess cohesion in human-autonomy teams, of which team resilience and team

complementarity were introduced as possible cohesion factors for consideration (the inclusion of these factors is further discussed in Neubauer et al. 2021). Multiple theoretical facets must be considered to fully understand how these factors fit within the team cohesion literature, including an understanding of previous work in human team cohesion and experimental and psychometric validation of newly incorporated subdimensions. This paper is in line with a larger team cohesion scale development effort (Neubauer et al., 2021), and hereby focuses on the scale development process specifically related to the team resilience and team complementarity aspects of the larger scale.

Team Cohesion

Cohesion can be defined as the tendency for a group to stick together in pursuit of its objectives and/or for the satisfaction of team members' affective needs (Carron and Brawley, 2000). Cohesion is essential to team performance and effectiveness and is, in part, responsible for the motivation to work together and continue as a team (Beal et al. 2003, Mathieu et al. 2015; Salas et al. 2015). Team cohesion is a dynamic state emerging over time and is enhanced as teams work through shared goals together (Widmeyer and Ducharme, 1997). Primarily, research on team cohesion has been conducted within the context of human teaming; however, recent years have seen a push to integrate robotic systems as team members in military operations for increased efficiency and decreased risk to human team members (Cosenzo and Barnes, 2010) as well as to take advantage of unique strengths offered by human and autonomous team members (Metcalfe et al. 2021). Such human-autonomy teams may be especially effective for complex conditions such as combat situations, by aiding in information and task planning and team operations (Chen and Barnes, 2014; Sycara and Sukthankar, 2006). However, the effect of an autonomous agent on team cohesion emergence and maintenance is not well-researched, nor fully understood. Consequently, it is necessary to conduct more research on the nature and emergent structure of human-autonomy teams to fully understand how the introduction of autonomous agents within the team context influences and changes team dynamics and the construct of team cohesion. In this paper, we provide a brief overview of two proposed dimensions used in creating the cohesion scale: team resilience and team complementarity, as well as initial statistical evidence for using these dimensions in future cohesion measurement.

TEAM RESILIENCE

Team resilience goes hand in hand with team cohesion and refers to a process whereby members collectively apply skills, abilities, and resources to prepare for, respond to, and overcome adversity and improve team state in a way that keeps the team in a state of homeostasis (Cato et al. 2018). This process involves a level of behavioural coordination that is consistent with teams that have high cohesion. The relationship between team resilience and team cohesion is especially relevant when teams operate in extreme environments. For example, military teams may face environmental stressors and frequently

changing mission states. As team members face hostile or stressful situations, they require high team cohesion and team resilience in turn to overcome such extremes (Salas et al. 2017). In military teams, having team cohesion has been shown to counteract negative outcomes of stressful environments such as poor mental health and decreased team performance (West et al. 2009). Further, teams that are high in resilience also have high team trust and cohesion (Gittell et al. 2006; Norris et al. 2008; Blatt, 2009), thus it appears that high team resilience and high cohesion have a symbiotic relationship.

This symbiotic relationship is reflected in the factors that make up both cohesion and resilience. For measurement purposes, team resilience has been described as comprising specific factors of cohesion, which include collective efficacy, shared mental models, and familiarity (Bowers et al. 2017). Another study developed a human team resilience scale that identified 10 sub dimensions of team resilience: task design, team composition, group norms, team learning orientation, team flexibility, network ties, shared language, trust, perceived efficacy of team members and perceived efficacy for collective team action (Sharma and Sharma, 2016). Of these, characteristics such as task design, group norms, trust, and perceived efficacy of team members, are factors of human team cohesion measurement as well. Thus, resilience may be a key feature for the development of highly cohesive human teams. Because human-autonomy teams will inevitably face similar challenges as human teams, it is likewise necessary for human-autonomy teams to have unit resilience in order to overcome such challenges.

TEAM COMPLEMENTARITY

Complementarity, a recently proposed dimension of cohesion (Lakhmani et al. 2022), has elements that are consistently associated with both social and task cohesion. Team complementarity describes the interconnecting nature of group members' diverse skillsets and how such skillsets meet the needs of the group environment (Muchinsky and Monahan, 1987). When team members' skills are unique but complementary to each other, we expect teams to become more cohesive. In this way, team member strengths counteract other team members' weaknesses. Thus, team complementarity is expected to counteract detriments of too much cohesion, such as groupthink (Janis, 1982). In the context of human-autonomy teaming, an autonomous system can have skills that enhance their teammates' skills or abilities. For example, autonomous systems can provide information visualization techniques that can help teammates make sense of information and thereby enhance their situation awareness of their mission/tasking environments (Chen and Barnes, 2014).

METHODS

The methods described herewith focus on the validation of the team resilience and team complementarity subdimensions of human-autonomy team cohesion, which are part of a larger human-autonomy team cohesion scale development project (Neubauer et al. 2021).

Table 1. Visualization of the five cohesion dimensions and subfactors included in the scale. This paper will focus on the bolded items.

Team Resilience	Team Complementarity	Function-based Task Cohesion	Structural Cohesion	Interpersonal Cohesion
Shared Language		Function	Exclusivity	Team Pride
Perceived Efficacy for Collective Team Action		Exclusivity	Attraction to the Group	Social Cohesion
Team Learning Orientation			Leadership Direction	Belongingness
Team Flexibility Orientation				Morale

Initial Item Pool Development

We created an initial pool of 134 items from the human team literature, selected to include the following five dimensions listed in Table 1: function-based task cohesion, structural cohesion (Griffith, 1988), interpersonal cohesion (Carron et al. 1985), and the two novel dimensions: team complementarity (Piasentin & Chapman, 2007), and team resilience (Cato et al. 2018). Eleven subject matter experts (SMEs) in team cohesion or human-autonomy teams from various academic and government institutions agreed to review these items. They were provided background information about the scale and were instructed to rate the relevance of scale items as "extremely important to include in the scale", "important to include in the scale", or "should not be included in the scale" in accordance with the procedures outlined in Lawshe (1975). We also collected qualitative feedback on each item, recommendations for the scale design, and suggested items to add into the scale. The resilience and complementarity pieces of that analysis are reported here.

Scale items were analysed using the Content Validity Ratio (CVR) (Lawshe, 1975), shown below.

CVR = (ne-N/2) / (N/2).
ne = Number of SMES indicating an item as extremely important
N = Total number of SMEs

With 11 subject matter experts reviewing our items, our criterion value ratio was set at .59 (see Lawshe, 1975). Items with a CVR below this .59 were removed.

CONTENT VALIDATION

Following item reduction and extraction of factors, the remaining 82 items were tested in an online study in collaboration with the United States Military Academy (USMA). 294 USMA cadets were recruited through the USMA SONA system to complete the online study through Qualtrics. Data were collected from Cadets who ranged in age from 18 to 23 years (M= 19.97,

SD= 1.49). For this study, we asked participants to imagine they were part of a human agent team that was instructed to work together. They viewed video clips pulled from The Clone Wars (Filoni, 2008) illustrating these scenarios, which were chosen to reflect the various dimensions and subdimensions presented in the item pool (e.g., a video clip reflecting a human-autonomy team illustrating high functional cohesion). These video clips featured high and low cohesive teams consisting of human and robot team members performing various collaborative tasks. Following the clip, participants rated their perceived level of the team's cohesion using items developed from one or more subdimensions of our newly developed human-autonomy team cohesion scale. Participants also filled out a modified version of the Group Environment Questionnaire (GEQ-10), a widely used cohesion scale, which served as a criterion measure, with which we compared the responses from our scale (Carless and DePaola, 2000).

Although we believe that all five dimensions are useful for understanding cohesion in human-autonomy teams, further analysis is warranted to evaluate the two new subdimensions of team resilience and team complementarity. Therefore, the current paper focuses on the psychometric properties of team resilience and team complementarity. The results were used to determine possible removal of unnecessary items and identification of the range of differences between items. An initial factor analysis was conducted to ensure the items follow standard cohesion theory. To evaluate our items and their corresponding subfactors, we defined several criteria for inclusion in subsequent research: internal consistency (i.e., whether different items measure the same underlying factor), invariance (i.e., whether items retain their meaning across contexts), sensitivity to depictions of high and low cohesion scenarios, and being both distinct from, and correlated with, the task and social cohesion subfactors from the GEQ-10.

Team Complementarity

For the complementarity-based cohesion items, participants tended to report higher scores for the high cohesion scenario compared with the low cohesion scenario. The single-factor model for our team complementarity items did not fit the data well for high, $\chi^2(44) = 166.118$, $p < .001$, or low cohesion scenarios, $\chi^2(44) = 201.301$, $p < .001$. After removing all but four items, our single-factor model fit the data for both high, $\chi^2(2) = 1.394$, $p = .498$, and low cohesion scenarios, $\chi^2(2) = 5.541$, $p = .063$. The lambda values of the four items in this model are presented in Table 2. Internal consistency was excellent for the high and low cohesion scenarios, McDonald's $\omega = .90$ and McDonald's $\omega = .85$, respectfully, indicating that these four items reliably reflect the same construct.

Our metric-invariant model fit the data well, $\chi^2(23) = 24.987$, $p = .351$, as did our configural-invariant model, $\chi^2(19) = 14.580$, $p = .749$, and our scalar invariant model, $\chi^2(29) = 37.864$, $p = .125$. These results indicate that the four-item measure of complementarity has desirable psychometric properties and would be worth including in future measures of human-autonomy team cohesion.

Table 2. Team complementarity item lambda values from high cohesion and low cohesion scenarios.

Team Complementarity Items	Lambda Statistic	
	High Cohesion	Low Cohesion
Individual members of the team are important because they offer skills and abilities that work well together	.833	.741
The skills of the autonomous teammate(s) complement me in things I am not good at	.847	.799
My teammates rely on me because I have skills that they do not have	.760	.653
The other members and I compensate for each other's weaknesses	.897	.845

Overall, these results suggest that the four-item measure of complementarity has good psychometric properties of scalar invariance, strong internal consistency, sensitivity to depictions of high and low cohesion, and is separate from and correlated with social and task cohesion, as measured by the GEQ-10.

Team Resilience

Of the four team resilience subfactors listed in Table 1, only the Perceived Efficacy for Collective Team Action (PECTA) and Shared Language subfactors had internal consistency and model fit in the three-factor exploratory and configural-invariant models. For the scope of this work, only these two subfactors of the Team Resilience dimension will be discussed.

Perceived Efficacy for Collective Team Action

For the PECTA items, participants generally reported higher scores for the high cohesion versus the low cohesion scenario. We did not get a model to fit the data with more than three PECTA items and selected these items in our final model, outlined in Table 3. This three-item model had excellent internal consistency for both high and low cohesion scenarios, McDonald's $\omega = .90$ and McDonald's $\omega = .92$, respectively. Our configural-invariant model fit the data well, $\chi^2(8) = 6.445$, $p = .598$, but the metric-invariant model did not, $\chi^2(11) = 29.203$, $p = .002$ due to one metric invariant item, "The team

Table 3. Team resilience (PECTA) item lambda values from high cohesion and low cohesion scenarios.

PECTA Items	Lambda Statistic	
	High Cohesion	Low Cohesion
The team can handle even the most difficult situations	.839	.951
The team is able to work together to accomplish the mission	.869	.879
The team learns from challenges they face	.887	.850

learns from challenges they face". Thus, the PECTA may be too problematic for future measurement use.

The three-factor exploratory model fit well for the high cohesion scenario, $\chi^2(12) = 10.714$, $p = .554$, and for the low cohesion scenario, $\chi^2(12) = 5.127$, $p = .954$. In both scenarios, the three-factor model separated GEQ social, GEQ task, and PECTA items into separate factors.

Shared Language

For the shared language items, participants generally reported higher scores for the high cohesion compared with the low cohesion scenario. The single-factor model of shared language fit the data well for high cohesion scenario, $\chi^2(2) = 4.945$, $p = .103$, but did not fit well for the low cohesion scenarios, $\chi^2(2) = 6.994$, $p = .030$. We removed one item with very low factor loadings and retained the three items listed in Table 4. This model had good internal consistency for both high (McDonald's $\omega = .85$) and low cohesion scenarios (McDonald's $\omega = .85$).

The configural invariant model fit the data well, $\chi^2(8) = 6.897$, $p = .548$. Interestingly, each item tested on its own was both metric and scalar invariant, but when tested together they were not. The three-factor exploratory model fit well for both the high, $\chi^2(12) = 18.247$, $p = .108$, and for the low cohesion scenario, $\chi^2(12) = 7.735$, $p = .806$. In both scenarios, the three-factor model separated the shared language, GEQ social, and GEQ task items into separate factors.

Factor Analysis Results Summary

In our analyses of team complementarity, we found four items that met our inclusion criteria. Our findings suggest that team complementarity should be included in future human-autonomy team cohesion scales. In our analyses of team resilience, we first separated items into several subfactors: Team Learning Orientation, Shared Language, Team Functioning, and Perceived Efficacy (Berg et al. 2021; Morgan et al. 2013). The PECTA subfactor had excellent internal consistency and configural-invariant model fit, but because the metric-invariant model did not fit, it does not meet our inclusion criteria. The Shared Language subfactor had good internal consistency and met

Table 4. Team resilience (shared language) item lambda values from high cohesion and low cohesion scenarios.

Shared Language Items	Lambda Statistic	
	High Cohesion	Low Cohesion
Team members use understandable communication patterns	.815	.836
Both human and autonomous team members use common terms to understand one another	.782	.760
Team members are successful in understanding each other during missions	.829	.824

criteria for partial scalar invariance but did not have model fit across several other tested models. Despite the issues associated with the PECTA and Shared Language subfactors, their partial criteria for inclusion suggest that these items may deserve further inquiry as potential subfactors of cohesion. Overall, these results provide some initial recommendations for future measures of human-autonomy team cohesion.

CONCLUSIONS AND PATH FORWARD

There is a need for an effective human-autonomy team cohesion scale that captures multiple dimensions of team cohesion. Using factor analysis methods, we were able to assess the validity of our proposed Team Resilience and Team Complementarity subdimensions as measures of cohesion and removed items with low factor loadings and non-invariance. The Team Complementarity subdimension contained four items that had scalar invariance, excellent internal consistency, sensitivity to depictions of high and low cohesion, and were correlated as well as distinct from task and social cohesion. Thus, team complementarity appears to have support for inclusion as a cohesion subdimension. However, the team resilience analysis results suggested that a majority of the subfactors did not meet inclusion criteria for being kept in the larger scale. The PECTA subdimension of team resilience had good measurement properties but the items were not invariant, indicating that respondents may not interpret these statements about perceived efficacy in the same way in different contexts. Future work should include further analysis of perceived efficacy as a subfactor of team cohesion. The results of the aforementioned analyses suggest that future human-autonomy team cohesion scales should include Team Complementarity, but additional study on the Team Resilience dimension is warranted. The findings presented here will be further validated in a follow-up study.

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