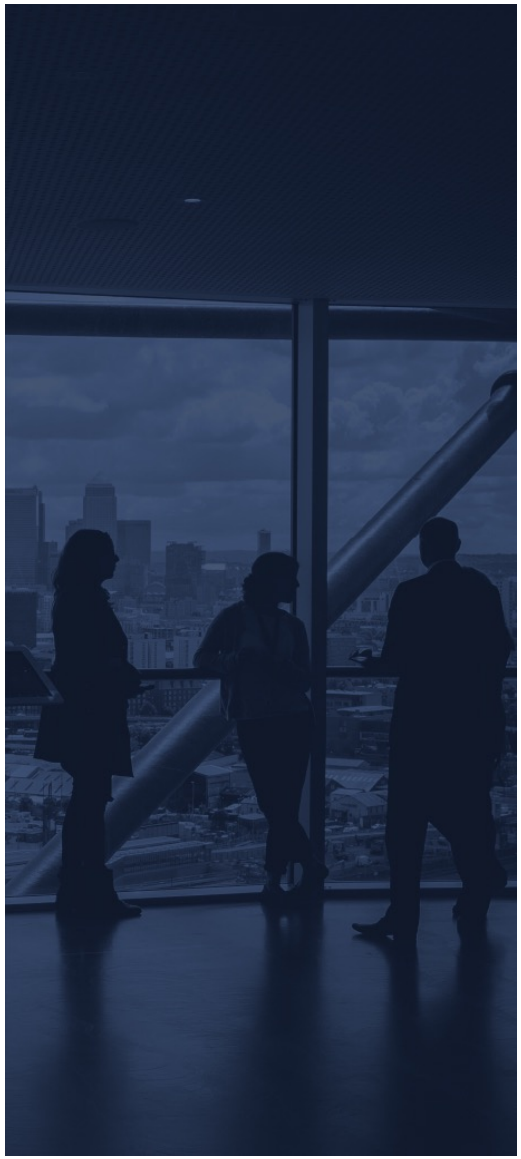


Future Directions in Human-Autonomy Teams Research

Tom O'Neill, PhD
Professor
Director, Individual and Team Performance Lab
Head, Industrial and Organizational Psychology
Department of Psychology
University of Calgary

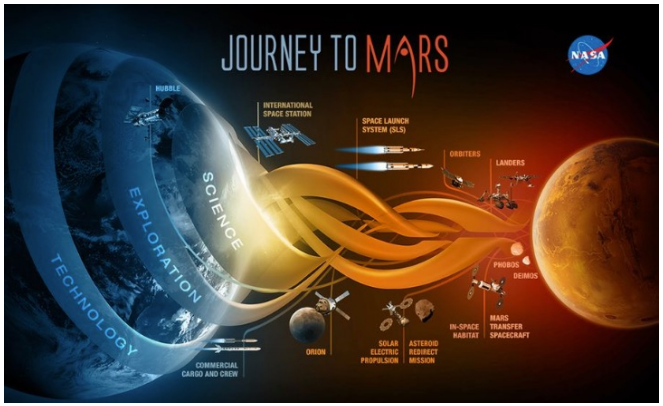
UNIVERSITY OF CALGARY

Individual & Team Performance Lab

Why Teamwork?

Why integrate technology?

1. Complexity of problems (VUCA)
2. Volume of work
3. Speed of work
4. Innovation
5. Error reduction



Individual & Team Performance Lab

What is the state of the Science in Human-Autonomy Teamwork?

Perception that the literature on Human-Autonomy Teamwork scattered…

Why? No systematic review, no broad meta-analysis.
No common criteria defining HATs and intermingling of terminology
Consolidation of the literature was needed

Systematically identify:

How many empirical articles are there?
What variables are studied most?
What are the most important factors for HAT effectiveness?
What models are most utilized?

Answer the question:

Where should we go from here? (Future Research Directions)

Human–Autonomy Teaming: A Review and Analysis of the Empirical Literature

Thomas A. O'Neill, University of Calgary, Canada, Curtin University, WA, Australia, **Nathan J. McNeese**, Clemson University, South Carolina, USA, **Amy Barron**, University of Waterloo, Canada, and **Beau Schelble**, Clemson University, South Carolina, USA

Objective: We define human–autonomy teaming and offer a synthesis of the existing empirical research on the topic. Specifically, we identify the research environments, dependent variables, themes representing the key findings, and critical future research directions.

Background: Whereas a burgeoning literature on high-performance teamwork identifies the factors critical to success, much less is known about how human–autonomy teams (HATs) achieve success. Human–autonomy teamwork involves humans working interdependently toward a common goal along with autonomous agents. Autonomous agents involve a degree of self-government and self-directed behavior (agency), and autonomous agents take on a unique role or set of tasks and work interdependently with human team members to achieve a shared objective.

Method: We searched the literature on human–autonomy teaming. To meet our criteria for inclusion, the paper needed to involve empirical research and meet our definition of human–autonomy teaming. We found 76 articles that met our criteria for inclusion.

Results: We report on research environments and we find that the key independent variables involve autonomous agent characteristics, team composition, task characteristics, human individual differences, training, and communication. We identify themes for each of these and discuss the future research needs.

Conclusion: There are areas where research findings are clear and consistent, but there are many opportunities for future research. Particularly important will be research that identifies mechanisms linking team input to team output variables.

Keywords: teamwork, team processes, team performance, human–autonomy teaming, human–automation interaction, human–agent collaboration

Address correspondence to Thomas A. O'Neill, Department of Psychology, University of Calgary, AB, T2N 1N4, Canada; e-mail: toneill@ucalgary.ca

HUMAN FACTORS
Vol. 00, No. 01, Month XXXX, pp. 1–35
DOI:10.1177/0018720820960865

INTRODUCTION

Recently, research has been using the term human–autonomy teams (HATs) to describe humans and intelligent, autonomous agents working interdependently toward a common goal (Chen et al., 2016; Johnson et al., 2012; Wynne & Lyons, 2018). HAT has been described as at least one human working cooperatively with at least one autonomous agent (McNeese et al., 2018), where an autonomous agent is a computer entity with a partial or high degree of self-governance with respect to decision-making, adaptation, and communication (Demir et al., 2016; Mercado et al., 2016; Myers et al., 2019). As noted by Larson and DeChurch (2020, p. 10), "we are quickly approaching a time when digital technologies are as agentic as are human counterparts." With continuous advancements in artificial intelligence (AI), autonomous agents can perform a greater number of dynamical functions in both teamwork and taskwork than ever before (Seeber et al., 2020), and they are beginning to be viewed as teammates rather than tools (Grimm et al., 2018a; Lyons et al., 2018). For example, autonomous agents can increasingly participate in teamwork activity involving coordination, task reallocation, and continuous interaction with humans and other autonomous agents (Chen et al., 2016; Johnson et al., 2012; Shannon et al., 2017).

The potential of autonomous agents working with humans opens up an interesting question, which involves both articulating a clear definition of HATs as well as identifying the factors that make these teams successful. Indeed, empirical research on HATs is burgeoning. Yet, the findings remain scattered, thereby obscuring a clear perspective on the state of the science. Accordingly, an integrative review is needed, which we offer here. By conducting a review

Open Access!!!

Acknowledgements

SSHRC CRSH
Canada

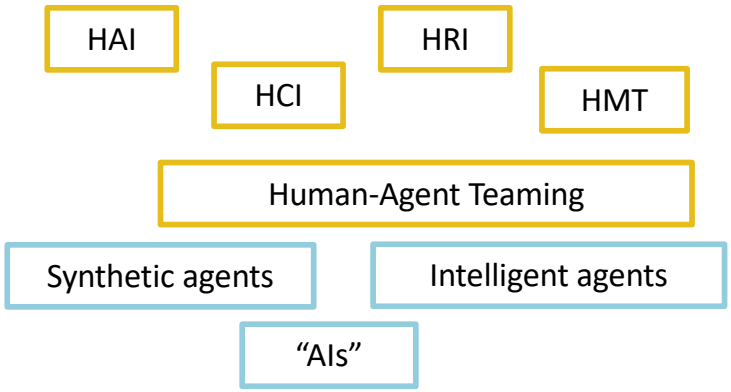
76 empirical studies meeting HAT criteria:

- Team is 2 or more members working **interdependently** toward common goal
- At least one autonomous agent…
- …where the autonomous agent(s) occupy unique roles on the team and possess **degree of agency**

Defining Human-Autonomy Teaming

While Human-Autonomy Teaming in concept is not new, the terminology is and it was being used loosely, confusing automation with HATs.

- Need to draw a line in the sand.
- What is a HAT and what is not?



Levels of Autonomy Continuum

Automation Level	Agent Autonomy Level	Automation or Autonomous Agent Role and Capability
High ↑	High agent autonomy	10. The computer decides everything and acts autonomously, ignoring the human. 9. The computer informs the human only if it, the computer, decides to. 8. The computer informs the human only if asked, or 7. The computer executes automatically, then necessarily informs the human, and
	Partial agent autonomy	6. The computer allows the human a restricted time to veto before automatic execution, or 5. The computer executes that suggestion if the human approves, or
	No autonomy / Manual control	4. The computer suggests one alternative, or 3. The computer narrows the selection down to a few, or 2. The computer offers a complete set of decision/action alternatives, or 1. The computer offers no assistance; the human must take all decisions and actions
Low ↓		

Note. Adapted from Parasuraman et al. (2000) with permission from the Copyright Clearance Center and Rights Link/IEEE.

Autonomous Agent

- *An autonomous agent in the context of HATs is a computer-based entity that is recognized as occupying a distinct role on the team. The autonomous agent is more likely to be recognized as a team member if humans and autonomous agents are interdependent and the autonomous agents are perceived as agentic (we strictly adhere to the use the term "autonomous agent" in this article).*

HAT

- *A HAT can be defined as interdependence in activity and outcomes involving one or more humans and one or more autonomous agents, wherein each human and autonomous agent is recognized as a unique team member occupying a distinct role on the team, and in which the members strive to achieve a common goal as a collective. The "autonomy" aspect of human–autonomy teaming refers to the autonomous agent.*

DESCRIPTIVE FINDINGS

What are Researchers Looking at as Outcomes?

Most Commonly Assessed DVs		
Dependent Variable	**# of Studies**	**DV Type**
Team and/or Individual Performance	70	Output for Stakeholders
Workload	39	Process
Trust	24	Affective State or Cognitive Appraisal
Situational Awareness	23	Cognitive state
Coordination	15	Process
Shared Mental Models	6	Cognitive state

Future Research Need #1:
All DVs have degree of dynamicity, but almost never studied this way (in favor of static).

What are Researchers Looking at as Outcomes?

Most Commonly Assessed DVs		
Dependent Variable	**# of Studies**	**DV Type**
Team and/or Individual Performance	70	Output for Stakeholders
Workload	39	Process
Trust	24	Affective State or Cognitive Appraisal
Situational Awareness	23	Cognitive state
Team Coordination	15	Process
Shared Mental Models	6	Cognitive state

Future Research Need #2:

Utilize theories of team effectiveness on DV side. Narrow selection of DVs and haphazard.

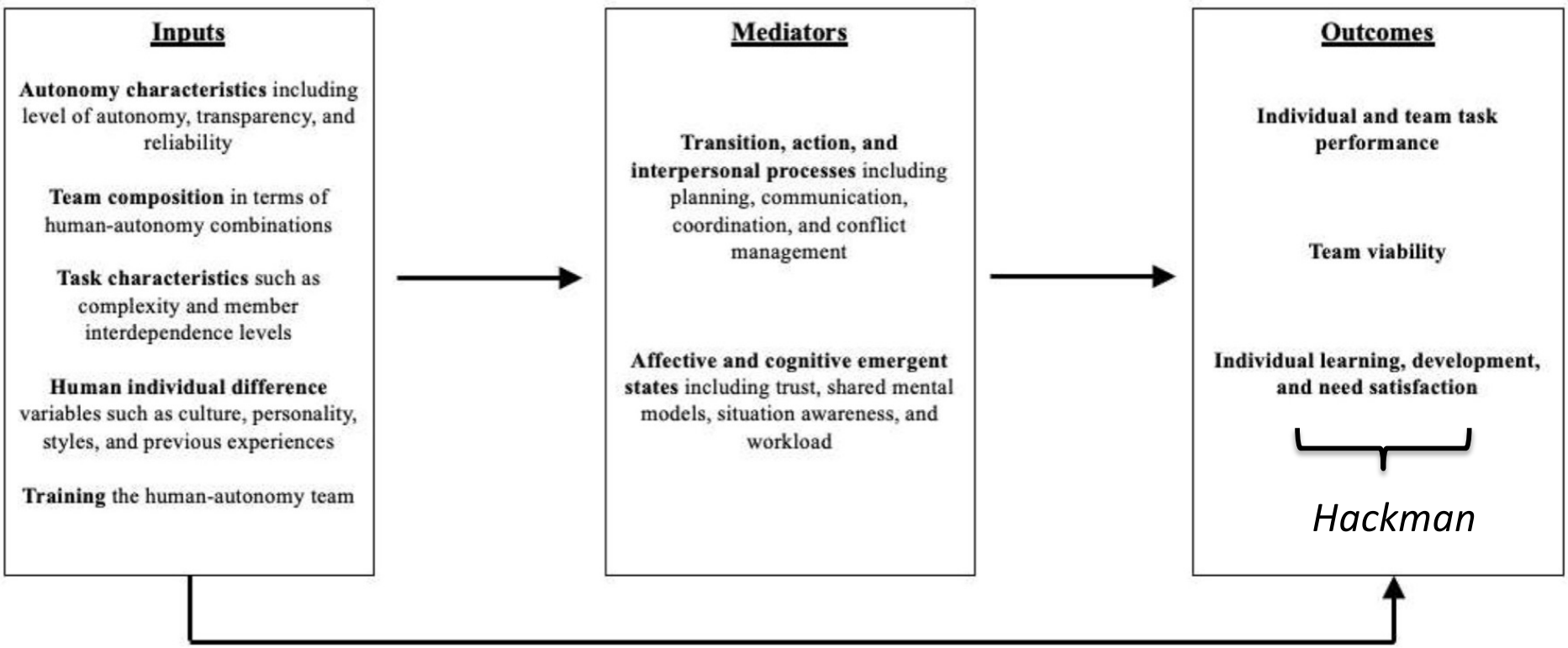
What are Researchers Looking at as Outcomes?

Most Commonly Assessed DVs		
Dependent Variable	**# of Studies**	**DV Type**
Team and/or Individual Performance	70	Output for Stakeholders
Workload	39	Process
Trust	24	Affective State or Cognitive Appraisal
Situational Awareness	23	Cognitive state
Team Coordination	15	Process
Shared Mental Models	6	Cognitive state

Future Research Need #3:
Theorize and study across levels. Level of analysis often ignored or not part of theorizing or mismatched across IVs and DVs.

SELECTED FINDINGS

Organized by IPO – McGrath, 1964; Steiner, 1972; Hackman, 1987; Marks, Mathieu, & Zaccaro, 2001



Future Research Need #4:

To understand WHY does an input transform into an output, test mechanisms/mediators. The IV – DV approach overlooks the complexity that process models could address.

HAT-Specific Findings

Higher levels of agent autonomy tends to result in better outcomes.

HATs tend to lag in performance relative to teams comprised only of humans.

Interdependence leads to positive outcomes in HATs.

Autonomous agents were not more useful in high difficulty tasks.

Autonomous agents need to be better at anticipating other team member needs, instead of engaging mostly in reactive or pre-programmed behavior.

Other Findings

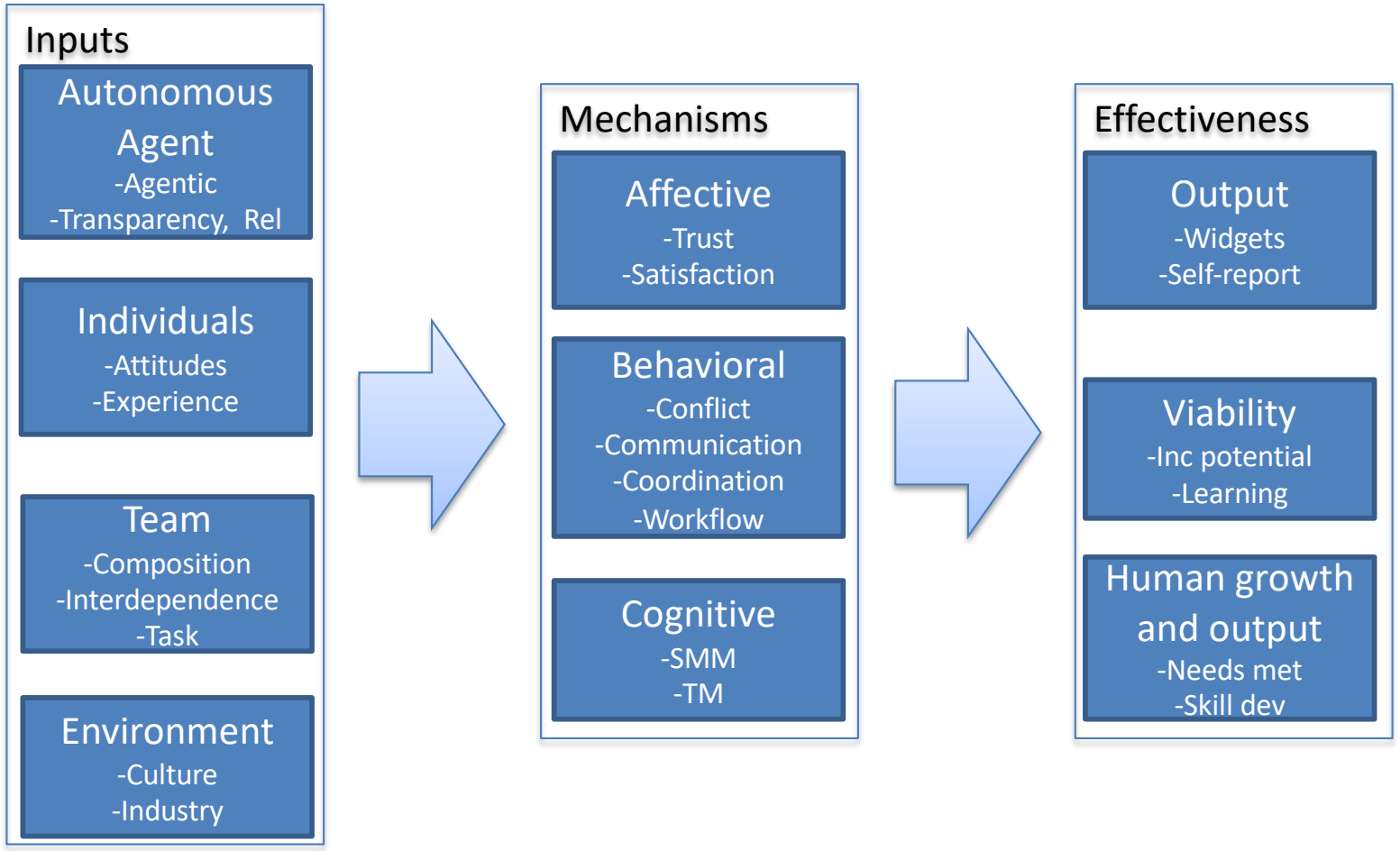
Training the HAT to work as a team produced consistently positive improvements

Quality of communication more consistently beneficial than the frequency of communication

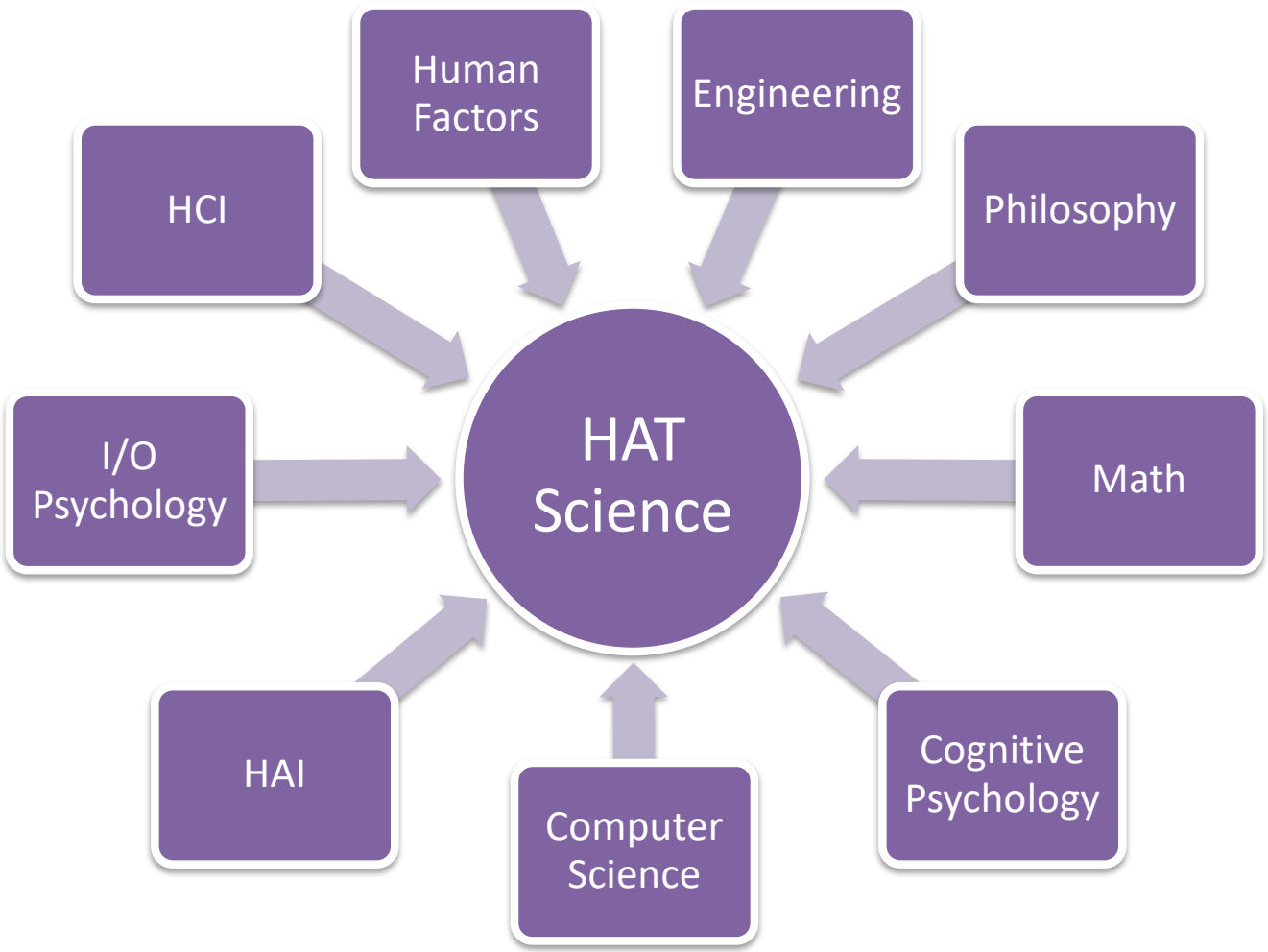
REFLECTION

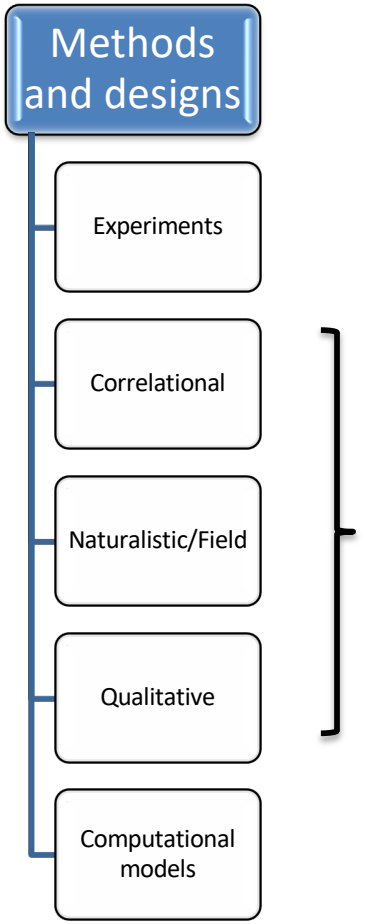
Future Research Need #5:

Variable and model selection feels haphazard. Need for integrative, dynamical, multilevel theory followed by systematic empirical quantitative and qualitative research testing the theoretical linkages



This will be an interdisciplinary and multi-method effort



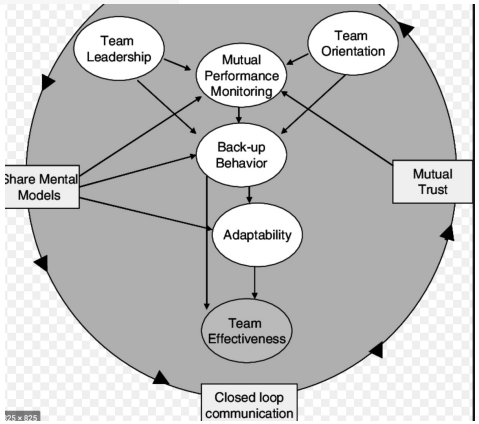


Future Research Need 6/7:

How do we design autonomous agents to be effective team members, and to do WHAT?

CATME

Salas et al., 2005 Big Five in Teamwork



I. Interpersonal KSAs
- A. Conflict Resolution KSAs
  1. The KSA to recognize and encourage desirable, but discourage undesirable team conflict.
  2. The KSA to recognize the type and source of conflict confronting the team and implement an appropriate resolution strategy.
  3. The KSA to employ an integrative (win-win) negotiation strategy, rather than the traditional distributive (win-lose) strategy.
- B. Collaborative Problem Solving KSAs
  4. The KSA to identify situations requiring participative group problem solving and to utilize the proper degree and type of participation.
  5. The KSA to recognize the obstacles to collaborative group problem solving and implement appropriate corrective actions.
- C. Communication KSAs
  6. The KSA to understand communication networks, and to utilize decentralized networks to enhance communication where possible.
  7. The KSA to communicate openly and supportively, that is, to send messages which are (a) behavior- or event-oriented, (b) congruent, (c) validating, (d) conjunctive, and (e) owned.
  8. The KSA to listen nonevaluatively and to appropriately use active listening techniques.
  9. The KSA to maximize the consonance between nonverbal and verbal messages and to recognize and interpret the nonverbal messages of others.
  10. The KSA to engage in small talk and ritual greetings and a recognition of their importance.

II. Self-management KSAs
- D. Goal Setting and Performance Management KSAs
  11. The KSA to help establish specific, challenging, and accepted team goals.
  12. The KSA to monitor, evaluate, and provide feedback on both overall team performance and individual team member performance.
- E. Planning and Task Coordination KSAs
  13. The KSA to coordinate and synchronize activities, information, and tasks between team members.
  14. The KSA to help establish task and role assignments for individual team members and ensure proper balancing of workload.

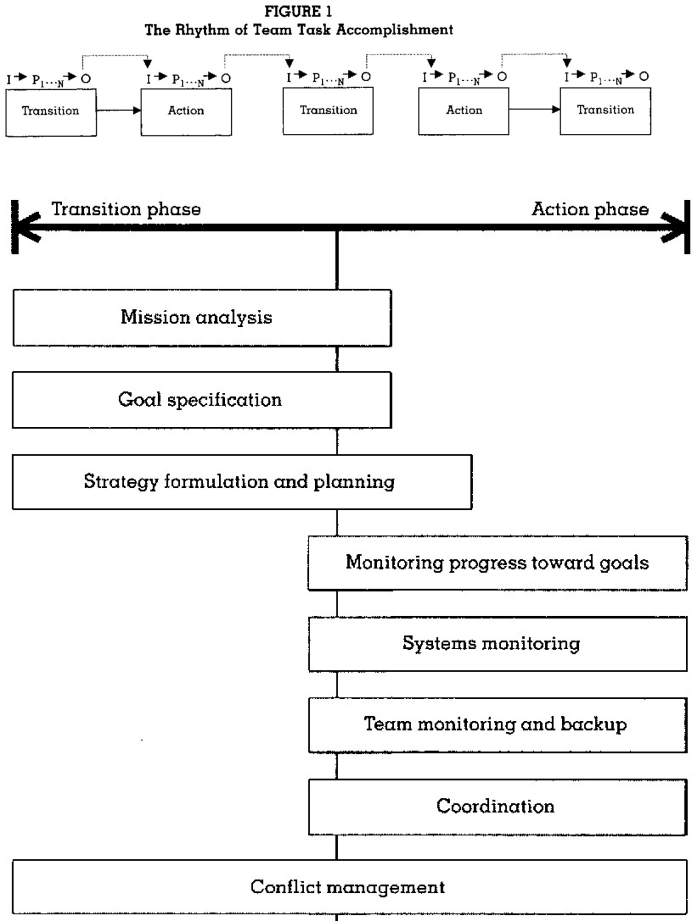
Notes: From "The Knowledge, Skill, and Ability Requirements for Teamwork: Implications for Human Resource Management" by M. J. Stevens and M. A. Campion, 1994, *Journal of Management, 20*, p. 305. Copyright 1994 by JAI Press. Reprinted by permission

1004 × 1130

Stevens and Campion, 1994

Future Research Need #8/9:

How do we design autonomous agents to be effective team members, and to do WHAT?



What Happens When Humans Believe Their Teammate is an AI? An Investigation into Humans Teaming with Autonomy

Geoff Musick [a,*], Thomas A. O'Neill [b], Beau G. Schelble [a], Nathan J. McNeese [a], Jonn B. Henke [b]

[a] Clemson University, School of Computing, 821 McMillan Road, Clemson, SC, 29631, [illegible]
[b] University of Calgary, Department of Psychology, 2500 University Dr NW, Calgary, AB, T2N 1N4, Canada

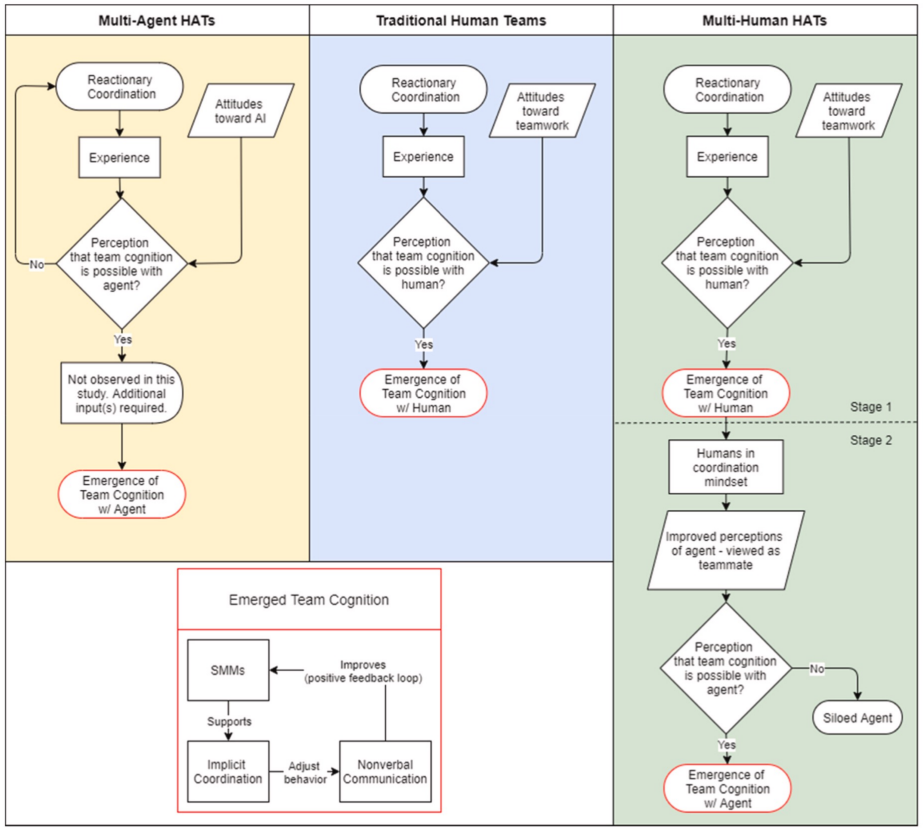


Fig. 4. A Model of Team Cognition and its Emergence in HAT Action Teams.

Communication

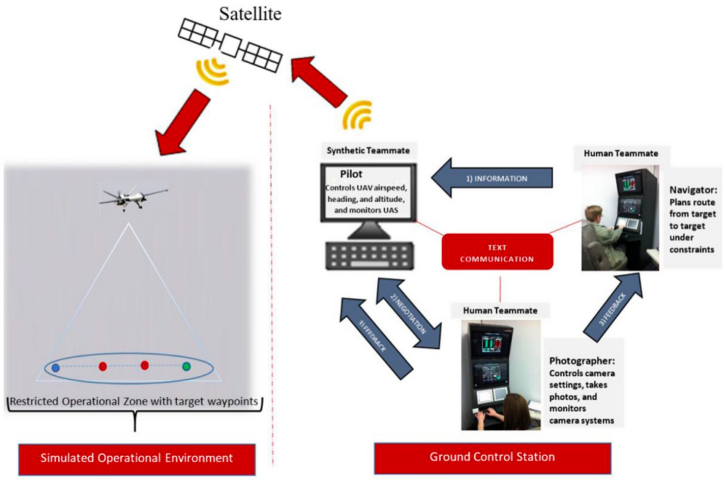
Team situation awareness within the context of human-autonomy teaming

Mustafa Demir *, Nathan J. McNeese, Nancy J. Cooke

Teaming With a Synthetic Teammate: Insights into Human-Autonomy Teaming

Nathan J. McNeese, Clemson University, South Carolina, **Mustafa Demir**, **Nancy J. Cooke**, Arizona State University, Mesa, and **Christopher Myers**, Air Force Research Laboratory, Wright-Patterson Air Force Base, Ohio

Cog Eng Research on Team Tasks, UAV - Synthetic Task Environment (CERTT UAV-STE)



- Human–human teams were the most dynamic in their coordination behavior and HATs were the least dynamic.
- Teams that performed the best were all human teams that had an expert serving as one of the three roles in the team.
- These latter teams exhibited meta-stability or a hybrid style; specifically, they exhibited stability versus dynamics in communication as the situation called for it.

TABLE 3: Team Verbal Behaviors

Behaviors	Push/Pull	Description
General status updates	Push	Informing other team members about current status
Repeated requests	Pull	Requesting the same information or action from other team member(s)
Inquiry about status of others	Pull	Inquiring about current status of others and expressing concerns
Suggestions	Push	Making suggestions to the other team members
Planning ahead	Push	Anticipating next steps and creating rules for future encounters
Positive communication	NA	Helping out team members by providing information and acknowledgement of member's speech
Negative communication	NA	Argument among the team members due to conflicting goals or incorrect destination
Unclear communications	NA	Sending information with misspellings and ambiguous terms that experimenters cannot understand

Future Research Need 9:

Interaction Process Analysis needed, microdynamics

Conclusion & Summary of Future Research Directions: We know quite a bit, we need to know a lot more

FD #	Future Direction
1	All DVs have degree of dynamicity, but almost never studied this way (in favor of static).
2	Integrate theories of team effectiveness on DV side. Narrow assortment of DVs and not systematic.
3	Theorize and study across levels.
4	To understand WHY does an input transform into an output, test mechanisms/mediators.
5	Need for integrative, dynamical, multilevel theory followed by systematic empirical quantitative and qualitative research testing the theoretical linkages
6	Use multi-disciplinary and broader array of designs and methods
7/8	How do we design autonomous agents to be effective team members, and to do WHAT?
9	Interaction Process Analysis needed, microdynamics
10/11	Study training program effects to test theory and develop interventions; examine human individual difference variables (attitudes, experience, personality, cultural orientations)
12	How do we design autonomous agents to be perceived as having agency, and therefore legit team members? What are the most important communication functions to possess?

Conclusion & Summary of Future Research Directions: We know quite a bit, we need to know a lot more

76 empirical studies meeting HAT criteria:

- Team is 2 or more members working **interdependently** toward common goal
- At least one autonomous agent…
- …where the autonomous agent(s) occupy unique roles on the team and possess **degree of agency**

Levels of Autonomy Continuum

Automation Level	Agent Autonomy Level	Automation or Autonomous Agent Role and Capability
High ↑	High agent autonomy	10. The computer decides everything and acts autonomously, ignoring the human. 9. The computer informs the human only if it, the computer, decides to. 8. The computer informs the human only if asked, or 7. The computer executes automatically, then necessarily informs the human, and
	Partial agent autonomy	6. The computer allows the human a restricted time to veto before automatic execution, or 5. The computer executes that suggestion if the human approves, or
	No autonomy / Manual control	4. The computer suggests one alternative, or 3. The computer narrows the selection down to a few, or 2. The computer offers a complete set of decision/action alternatives, or 1. The computer offers no assistance; the human must take all decisions and actions
Low ↓		

Note. Adapted from Parasuraman et al. (2000) with permission from the Copyright Clearance Center and Rights Link/IEEE.

Need to further evaluate whether this is sufficient way of defining autonomous agent so it is treated as a teammate rather than a tool

Support

SSHRC CRSH

Curtin University
FUTURE OF WORK INSTITUTE

Haydn Williams Fellowship 2019–2020

Taylor Institute for Teaching & Learning

INNOVATION.CA
CANADA FOUNDATION FOR INNOVATION | FONDATION CANADIENNE POUR L'INNOVATION

NSERC CRSNG

Alberta SPOR SUPPORT Unit

Alberta Innovates Health Solutions

SUNCOR ENERGY | SUNCOR ENERGY FOUNDATION

SPARTAN ENGINEERING INC

HOIF
HEALTH OUTCOMES IMPROVEMENT FUND

SCHULICH School of Engineering
UNIVERSITY OF CALGARY

Individual & Team Performance Lab

Thank you!

QUESTIONS?

Contact Tom O'Neill or Nathan McNeese with any comments or suggestions:
toneill@ucalgary.ca
mcneese@clemson.edu

Open Access @ *Human Factors*