ABSTRACT

Titles of Thesis:	COMPATIBILITY IN TEAM COGNITION AND INDIVIDUALS' DECISIONS IN TEAM PERFORMANCE
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Recent conceptualizations of team cognition have suggested that the compatibility of team member's mental representations is a key contributor to team functioning. However, efforts to develop this construct have been limited by imprecise definition. The present work thus proposes a framework and process-oriented theory for describing compatibility in team cognition and its relationship with team performance by integrating existing work from team cognition, goal representation, and goal pursuit. These contributions were instantiated in an agent-based model used to conduct two virtual studies which explored how compatible mental representations engendered patterns of individuals' action choices and patterns of team goal progress resulting in better or worse team performance outcomes. Study 1 indicates team members with compatible mental representations tend to perform better on average but with more variability even without explicit coordination. Study 2 indicates explicit coordination does not impact performance regardless of compatibility or ability to correctly anticipate teammates' behavior.

COMPATIBILITY IN TEAM COGNITION AND INDIVIDUALS' DECISIONS IN TEAM PERFORMANCE

by

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Team performance and related processes are paramount concerns for organizational researchers and practitioners. An increase in research on teams and their performance has paralleled an increased use of teams as the primary unit of operation within organizations (Cascio, 1995; Kozlowski, 2012; Bersin et al., 2017; Mathieu et al., 2019). Antecedents of team performance and process are frequently cited as critical to theory, in establishing nomological networks, and for designing and implementing interventions that increase performance. Team cognition has emerged as a well-recognized and influential factor on these constructs (DeChurch & Mesmer-Magnus, 2010). However, we still know relatively little about how team cognition guides *individual team members'* choices through which team performance emerges.

Theories of team cognition tend to assume that more information available to more members generally facilitates team processes such as coordination and communication (Mohammed et al., 2010). Considerably less attention has been given to more granular questions, namely, "*who* needs to know *what* and *how* does the resultant distribution of knowledge lead *individuals* to contribute positively to effective team processes?" Studies of team cognition oriented around 'similarity' subsequently tend to conceive of team cognition as a property of teams rather than of individuals (Grand et al., 2016). A consequence of this conception has been greater attention devoted to team processes as antecedents to team cognition rather than the bottom-up contributions of individuals acting on their own beliefs and knowledge while they and their environment are influenced by teammates. Mechanisms through which knowledge among teammates leads to important outcomes have been posited, yet the primary focus on similarity among members' team-/task-related cognitions has limited efforts to develop explicit,

contextual, and momentary understanding of the relationship between team (members') cognition and team performance. For example, theory and empirical research on shared mental models posits that the sharedness, or commonality, of concepts within mental models among team members facilitates team performance (Converse, Cannon-Bowers & Salas 1993; Rouse & Morris, 1986). Information commonly held across individuals in a team (i.e., shared) is proposed to enable team members to operate in synchrony as they can rely on shared expectations and understandings to inform their and their teammates' interdependent choices; however, the relationship between members' mental representations and their performance-relevant behaviors is seldom evaluated.

Another popular framework for assessing team cognition, transactive memory systems, affords a more individuated conception of team cognition yet also concentrates around the premise that more knowledge available to more people renders better outcomes. Transactive memory systems characterize team cognition as the extent to which members possess and can access unique/distributed knowledge located across the team through their communication infrastructure (Wegner, Giuliano & Hertel, 1985). Thus, rather than assuming the overlap of mental representations enables members to accomplish team objectives, research on transactive memory systems suggests collective performance is facilitated by members' capacity to access, allocate, and apply expert knowledge towards a team's performance goals (Lewis & Herndon, 2011). Transactive memory systems draws attention to the role of the individual in team cognitive processes, but team cognition itself is represented as a pool of shared (or at least accessible) knowledge which, again, is more beneficial as it grows larger and reaches more people. This theory is also largely silent on the content and structure of knowledge in mental

representations which fails to recognize team members' individuality beyond their existence as interdependent members of a team. Consequently, research and theory on shared mental models and transactive memory systems has tended to obscure team members' heterogeneity, dynamic interaction, and mutual influence (Gorman et al., 2010; Humphrey & Aimes, 2014; Strauss & Grand, in press) by ultimately evaluating shared cognition in terms of *how much knowledge is known by how many* and not of *how individual team members act and interact based on their mental models*.

Recent work on *representational gaps* has sought to address this gap, suggesting that certain knowledge might *not* actually be important to share. Certain knowledge, however, *is* critical to share among team members to avoid generating irreconcilable outputs or unproductive conflict among members (Cronin & Weingart, 2005; 2007; Weingart et al., 2008). The absence or different representations of a concept in one's understanding relative to another's is called a representational gap. Critically, the framework proposed for representational gaps highlights the limitation of similarity in explaining team performance outcomes; if knowledge need not be shared, its sharedness would not afford increased performance. Instead, representational gaps emphasize a recognized but seldom examined concept within team cognition—*compatibility.*

Converse et al. (1993) originally defined compatibility of mental representations as a feature of a set of representations that all lead to compatible expectations, i.e., expectations from which sufficient performance results. Recent work on representational gaps has sought to expand this conceptualization by elaborating how individuals' mental representation of tasks might be compatible through compatibility's effects on team functioning. Weingart and colleagues (Weingart et al., 2008; 2010) propose the source of

compatibility lies principally in the common representation of goals among team members. Team members' divergent understandings of constraints, courses of action, and resources available may render incompatible outcomes of individuals' efforts (in descending order of likelihood), but goals are most consequential. Empirical examinations have found relationships between representational gaps and conflict (Wang et al., 2016) and creativity (Weingart et al., 2010) at the team-level, but the framework also provides a valuable launchpad for specifying how individual team members' actions and interactions are governed by private mental representations, and how sufficiently different beliefs or perceptions, and thus choices, may arise from small structural differences between such representations.

Building on these notions from representational gap research, the present work advances a novel conceptual framework for representing compatibility as a structural property of team members' mental representations and links this representation to how and why individual members make behavioral choices relevant to team task performance. This framework describes each individual team member's understanding of their team's task, including relevant goals, actions by which those goals are achieved, and the team members who perform those actions. I employ this framework to articulate a process-oriented theory and computational model which specifies how differences in individuals' team task representations (TTRs) engender task-relevant decisions capable of producing unique team performance trajectories and outcome patterns. The proposed theory integrates and is informed by insights derived from two general frameworks—goal systems theory (Kruglanski et al., 2002) and transactive goal dynamics (Fitzsimmons, Sackett & Finkel, 2016) — and thus offers a unique perspective relative to existing team

cognition research and theory. Results from two agent-based simulations which implement the logic of this theory are presented to evaluate the internal validity/generative sufficiency of the model (Epstein, 1999) and which identify several potential insights and predictions regarding the effect of compatibility across members' mental representation and team performance. Before describing the model and simulations, I first review relevant research on team cognition, goals, and their integration to provide a foundation to justify the novel synthesis of content, structure, and sharedness of mental representations that inform my proposed theory and model.

Team Cognition

Each of the following review sections describes team cognition as conceived by three popular theories: shared mental models, transactive memory systems, and representational gaps. Understanding *representations* themselves (i.e., from what and how they are composed) and how cognition is conceived at the team level (i.e., the *sharedness* of cognition) is foundational to understanding the mechanisms by which they influence performance through individual team members' action choices (Mohammed et al., 2021).

Shared Mental Models

Shared mental models operate under the key assumption that "effective team performance requires members to hold common or overlapping cognitive representations of task requirements, procedures, and role responsibilities" (Converse et al., 1993, p. 221-222). Effective team performance includes the ability of team members to describe their situation in similar ways, form similar expectations/predictions, and explain processes using similar reasoning (Rouse, Cannon-Bowers & Salas, 1992). Shared mental models

are thus typically described with respect to two characteristics: similarity (degree of overlap between team members' representations) and accuracy (correspondence between members' representations and some real or objective state of a task, Mohammed et al., 2010). In practice though, research has tended to examine similarity rather than accuracy as an antecedent of team-level outcomes (Thompson & Fine, 1999). Descriptions of shared mental models have tended to focus on the type of information held by members (content), team members' organization of information (structure), and how together they generate similar expectations/predictions.

Representations. In their seminal work, Converse et al. (1993) delineated four types of mental models team members may possess delineated by separate yet dependent *content* domains: (1) an equipment model, which includes concepts related to tools and technologies necessary for task completion; (2) a task model, which includes concepts such as procedures, strategies, and plans; (3) a team interaction model, depicting concepts such as members' responsibilities, roles and role-interdependencies, and communication patterns; and (4) a team model, comprised of the preferences, skills, and habits of other team-members. Subsequent research has tended to simplify this conceptualization into a task mental model (comprised of concepts previously divided into equipment and task models) and team mental models (containing team and team interaction models, Mathieu et al., 2000; Jonker, Riemsdijk & Van De Kieft, 2011). Despite the theoretical interdependence among the content contained within these types of mental models, they are frequently treated and examined independently in research and analysis and simplified into task and team mental models. Task mental models tend to include concepts related to means and ends, while team mental models include concepts related

to interpersonal interaction and coordination (Thompson & Fine, 1999; Mathieu et al., 2000; Cooke, Kiekel & Helm, 2001). The inclination of much shared mental model research is to analyze the effects of mental models representing single categories of concepts despite Converse et al.'s (1993) caution that domains of knowledge (i.e., task and team) are interdependent. This separation in analysis potentially limits insight into the importance of connections *across* domains of shared mental model content. For example, new communication technology (equipment) would likely impact team members' interactions. Essentially, teams whose members all know what equipment and strategies to use and when as well as who has which skills and their roles should be more effective in allocating resources, assigning tasks or subtasks, and coordinating their actions.

In this conceptualization of team cognition, specific concepts within team members' mental models are generally described as "related" to one another, but the nature of this relationship (i.e., "why" two concepts are "linked" in a mental model) is rarely specified or explicitly considered in the extant theory or literature.[1] The diversity of measurement tools (e.g., semantic relatedness, sequence, priority rankings; Rentsch et al., 2008; Resick et al., 2010) evidences a notable lack of consensus around the *meaning* of associations between concepts within mental models. Across connotations of team mental model structure, the theory generally proposes that similar expectations arise from mental models with similar structure (e.g., common order of rankings or relatedness networks with ties of the same strength between the same concepts).

[1] Exemplars of a category may be judged as similar based on their shared features, but a cause and effect may also be judged as similar based on their cooccurrence (Medin, 1989; 1993)

Sharedness. Team cognition research assumes that a mental model is shared to the extent that members within a team are aware of the *same* features of a task and exhibit *consistency* among the connections between concepts. The logic of research on shared mental models suggests that having more information organized in similar ways allows individual team members to act in ways that benefit their team in conjunction with others' actions. Despite the intuitive relationship between shared mental models and effective team performance, there are two potential issues with this notion of similarity.

The first is an operationalization issue with consequences for theory building and testing. As similarity results from both content *and* structure, the type of *structure* elicited from team members greatly affects the meaning of similarity and thus how similarity might generate outcomes such as team performance. For example, *similarity of priorities* indicates that concepts hold similar relative values whereas *semantic relatedness* indicates that concepts describe similar referents. The meaning of 'similarity' and thus *how* similarity guides expectations and predictions differs depending on the respect with which similarity is judged (i.e., with respect to value or to meaning; Medin, 1993).

The second issue with similarity as defined by shared mental models is the assumption that more knowledge (organized similarly) should result in higher team effectiveness. In this sense, research on shared mental models tend to approach knowledge sharing as a maximization rather than an optimization problem. However, there are cases in which teams may operate effectively when knowledge/understanding is distributed unevenly across team-members (Wegner, 1987). For example, a computer scientist on a bioinformatics team does need necessarily know how proteins are synthesized, only the structure of amino acids in the finished product. It is difficult to

imagine a situation in which more similar knowledge directly inhibits synchrony and coordination, but teaching the computer scientist all the knowledge the biologist holds is extremely costly (at the very least in time and effort). In this way, the focus in shared mental model research on similarity obscures questions of *which* information should be shared by *who,* what should be common versus what should be distributed, and with whom should knowledge be common or distributed (Mohammed et al., 2010). This question is not one of minimal sufficiency (i.e., what is the bare minimum to render similar expectations), but rather of specificity (i.e., why do *particular* pieces of knowledge help or not help *particular* team members).

In recognition of this shortcoming, Converse et. al. (1993, p. 236) posit "the crucial implication of shared mental model theory is that team members hold *compatible* mental models that lead to common expectations for the task and team" (emphasis added). In practice, however, research has overwhelmingly focused on the *amount* of information held in common across team members as the chief mechanism between team cognition and performance (DeChurch & Mesmer-Magnus, 2010; Mohammed et al., 2010).

Transactive Memory Systems

Wegner, Erber and Raymond (1991, p. 923) define transactive memory as a "shared system for encoding, storing, and retrieving information." Encoding involves labeling information and storage refers to assignment of information to specific internal (i.e., team members) or external (i.e., non-human units, such as computers or physical documents) memory systems (Thompson & Fine, 1999). Retrieval occurs when that information is accessed by anyone within the team. A transactive memory system thus

describes a collection of individual memory systems that interact via interpersonal communication (Wegner, Giuliano, & Hertel, 1985). Theory and research on transactive memory systems highlight several unique aspects of team cognition not addressed in the team cognition as shared mental models approach. Specifically, transactive memory systems advocate the efficacy of compilational rather than compositional knowledge at the team-level (Kozlowski & Klein, 2000); team members may still perform well even if members hold different knowledge.

Representations. Transactive memory systems emphasize the importance of members knowing *where* information is located within a team. It suggests that discrepancies in information labels or insufficiently specified locations among team members may be as detrimental to team functioning as aspects of a representation that are simply absent (Wegner, 1986). Metaknowledge of labels and 'who knows what' is the quintessential content which allows individual team members to complement their own knowledge with that of experts and specialists on their team. Team members may thus draw upon a breadth (from multiple members) and depth (from individual expert members) of knowledge on which to base their own performance-related decisions. Knowledge content of transactive memory systems is constrained to knowledge and skills relevant to a given task, and members' relationships with external entities (Austin, 2003). Little else has been specified about representations themselves as the structure of interpersonal interactions is more central to the theory's raison d'être.

Sharedness. Whereas shared mental models frequently define sharedness as knowledge common to all team-members (Mohammed et al., 2010), units of knowledge in a transactive memory system are said to be shared if any single member has some unit

of knowledge, and the label and location of that knowledge is known by all team members (Wegner, 1986). Transactive memory systems "draws deeply on the analogy between the mental operations of the individual and the processes of the group" (Wegner, 1986, p. 185). Essentially, just as humans need not store information in more than one place in our minds, neither must a team. Sharedness as distribution of knowledge frames team cognition more explicitly as a property of heterogeneous members with changing needs over time than does sharedness as similarity. It also provides theoretical grounding for the lay notion, "I don't really need to know *everything* you do, only what is relevant to me." Still, neither theory discussed offers a language or framework for thinking about how mental representations differences between interdependent actors might engender *worse* outcomes than they would for actors performing independently.

Representation Gaps

Relative to shared mental models and transactive memory systems, representation gaps offer a comparatively newer framework for conceptualizing the nature of team cognition. Primarily motivated by efforts to expand upon notions of compatibility among team members' mental models, theory and research on representation gaps explicitly focuses on information or understanding that is *not* shared between people. In this sense, a representation gap is defined as "a group level phenomenon that arises as a function of the cognition of individuals working together to solve a problem" (Cronin & Weingart, 2007, p. 6).

Representations. Arguably the greatest contribution of research examining representation gaps is the attention it brings to the categories of concepts that exist in members' task representations and which of those categories are important for members

to share. In their original conceptualization of representation gaps, Cronin and Weingart (2007) assert that the specific content contained within a member's task mental model can be categorized as one of four types: goals, assumptions, elements, and operators.[2] To illustrate the differences among these concepts, imagine a trio of jazz musicians performing for a club. *Goals* are representations of objectives and their precedence. In our example, a goal may be 'to be entertaining,' 'to express feeling,' or simply 'to play the whole night without screwing up.' *Assumptions* refer to restrictions and preferences for how goals/objectives should or can be achieved. The key in which the musicians play, or in which they think everyone is playing, is an assumption as it restricts which musical notes members may use. *Elements* are components of a task that individual agents can change or manipulate. Elements in the mental representations of the jazz trio might include their instruments. Finally, *operators* are rules which govern the interaction between agents and elements such as strumming, plucking, or pounding.

Cronin and Weingart (2007) propose that these concepts differ in importance with respect to what should be shared within a team to facilitate effective functioning. Specifically, they posit that it is most important that members of a team share similar goals, followed by shared assumptions, elements, and, lastly, operators. This ordering essentially denotes that team members should agree on and collectively recognize what they should be accomplishing while precise knowledge of how those goals are pursued are potentially less important if they render the same outcomes. In this way, the goals in task performance frame the importance of all other concepts in a representation, denoting *why* other assumptions, elements or operators might be critical (Weingart et al., 2010).

[2] The "GAEO" typology was initially proposed by Hayes & Simon (1974) and Newell & Simon (1972)

Sharedness. Most teams have some degree of both common and distributed knowledge. By instead referring to what is compatible, these knowledge-distributions need not be at odds with each other. For instance, in our jazz trio example, each musician need not know how to play all the others' instruments (i.e., operators), yet all need to know the key in which they are playing and the rules of harmony (i.e., assumptions). As for goals, a member of the trio wanting to inspire people to dance may 'operate' their instrument in a manner incompatible with another member's goal of transposing a moving, yet somber memory into the air. Recognizing the importance of both distributed and common knowledge in their work on representation gaps, Cronin, Weingart, and colleagues (Cronin & Weingart, 2007; Weingart, Todorova & Cronin, 2008; Wang, Mannix & Cronin, 2016) embrace the definition of 'shared' as 'compatible.' Unfortunately, the authors do not provide a definition of compatibility, instead stating that "team success implies that [team members' mental] representations were compatible" (Weingart & Cronin, 2007, p. 13). However, they do advocate the importance of establishing a theoretical definition of compatibility from which measurements may be developed.

Team Cognition Summary

The previously described theories together cover much theoretical ground, and the wealth of research generated within each of these paradigms on team cognition has afforded useful insights. Nevertheless, surveying the landscape of team cognition research reveals several notable gaps. First, the content important to each theory described differs considerably. The typology of content offered by representational gaps theory is compelling because it implies clearly meaningful relationships between

concepts (i.e., elements *are manipulated by* operators *for the achievement of* goals *given* assumptions). However, this typology does not include (or at least indicate the importance of) knowledge and beliefs about team members. Shared mental models explicitly include knowledge about teams and the tasks to which they are assigned, but unlike representational gaps, tends not to address the possibility that mental models containing multiple types of knowledge are important to understanding the relationship between mental model sharedness and team performance. The theory of transactive memory systems draws the most attention to knowledge and beliefs about team members. A more integrative framework of team cognition would thus optimally capture 1) information about both the team *and* the task and 2) others' beliefs about team and task concepts.

Second, the nature of the relationship between concepts in mental representations is ignored by transactive memory systems and underspecified in shared mental models. Discussions of representational gaps imply functional relationships, but empirical work (e.g., Weingart et al., 2010; Wang et al., 2016) has not addressed relationships between concepts as this work focuses explicitly on goals disjointed from other concepts. Similarity of semantic networks may include information regarding, or function similarly to, priority or importance rankings, but it is rare for research to highlight how different interpretations of relatedness (e.g., functional, semantic, importance/priorities) might inform team performance differently. Developing a process-oriented theory is difficult without specifying the meaning of relationships between concepts.

Finally, the process by which one team member's mental representation leads to behaviors in the team context, and why those behaviors and their efficacy might be

affected my other team members' mental representations is not well explicated in the existing team cognition literature. Research on shared mental models and transactive memory systems have identified robust relationships between team performance and team cognition as *both* a compositional (same across members) and compilational (distributed across members) property of teams respectively. Compatibility as proposed by Converse et al. (1993) and revitalized by Cronin & Weingart (2005; 2007) takes a more fine-grained approach in directing attention to concepts which may be more or less consequential for team performance and highlights the importance of individuals' compatibility with each other as opposed to sharedness solely at the team level. They do, however, only define compatibility in terms of its consequences which ignores the structural features of mental representations relative to another's representation which may be identified a priori and predict team performance. Compatibility as defined by Cronin & Weingart (2007) *could* be used to explain the positive relationship between similar or distributed knowledge and team performance. Sharedness as compatibility would benefit from a definition based in structural features of mental representations rather than their outcomes. Such useful conceptualization of compatibility would also explain performance outcomes resulting from some structural feature *through* actions performed by *individual* team members considering their interdependence (a central property of teams). To this end, the following section introduces goal systems theory and transactive goal dynamics theory as potential frameworks for developing a more unified conceptualization of team cognition by offering a means for conceptualizing the content and structure of team members' mental representations as well as providing an account

for how individuals' mental representations inform action choices of interdependent actors.

Goal Systems and Goal Pursuit

Lending credence to the value Cronin & Weingart place on goals in task representations, Steiner (1972, p. 15) defines a 'task' as "a set of specifications identifying the goal that is to be achieved and the procedures that an individual or group may employ when attempting to achieve it." Indeed, tasks are often defined *as* a set of goals needing achievement (West & Anderson, 1996). In this sense, task performance bears a strong resemblance to *goal pursuit* and suggests that efforts to map the impact of team's mental representations on team performance outcomes would benefit from more concerted efforts to incorporate goals into discussions of team cognition.

Goal Systems

To this end, Kruglanski et al.'s (2002) theory of goal systems offers a compelling foundation for incorporating the content and structure of goal representations with the types of mental model conceptualizations commonly discussed in the team cognition literature. Goal representations are argued to capture the cognitive aspect of motivation: how one's drives and desires are represented in the mind. Goal representations are individuals' internal models of a given goal system. Goal systems are most commonly characterized as hierarchically organized networks of means (i.e., actions) and ends (i.e., goals).

Goal systems theory also specifies the meaning of connections between concepts. "Vertical" associations describe the extent to which the lower-level concept is *uniquely instrumental* to the higher-level concepts (e.g., between actions and tasks).

Instrumentality describes the extent to which a particular action is effective at reducing the discrepancy between one's current state and goal attainment. In a goal system, actions and goals may reduce *or* increase the discrepancy of one *or more* goals. *Unifinal* actions reduce discrepancy for a single focal goal. *Multifinal* actions reduce discrepancy for more than one goal. Finally, *counterfinal* actions reduce discrepancy for one or more goals while *increasing* discrepancy for one or more alternative goals. Beyond instrumentality, the strength of vertical associations between actions and goals hinges on a given association's uniqueness – how few alternative actions also connect to a focal goal. In this way, "lateral" associations within a level of the goal hierarchy describe the competition among actions as they vie for an individual's limited attention. Kruglanski et al.'s (2002) theory postulates that attention, based on actions' instrumentality and their unique ability to advance a target goal, ultimately results in action selection and subsequent performance.

Integrating the terminology and theoretical assumptions from goal systems theory with theories of team cognition thus offers a launch point to answer Cronin, Weingart, and colleagues (e.g., Cronin & Weingart 2007, Weingart et al., 2008; 2010) call to focus on compatibility of mental representations centered around goals. Both goals and actions (representation content) as well as their interrelationships (representation structure) provide the cognitive underpinnings describing individuals' motivated action directed towards task completion. As a theory of individuals, however, goal systems theory provides a basis for what *could* be shared. However, this same individual-centered theory affords no explicit claims about individuals' representations of goals pursued with

interdependent others, i.e., teammates, and thus how sharedness (particularly compatibility) might impact goal pursuit.

Transactive Goal Dynamics

Transactive goal dynamics (Fitzsimmons, Finkel & vanDellen, 2015; Fitzsimmons, Sackett & Finkel, 2016; Fitzsimmons & Finkel, 2019) builds upon many of the basic concepts of goal systems by extending them into the context of interdependent collectives. In doing so, the principles of goal systems theory become more immediately applicable to the circumstances relevant to a discussion of team cognition: team goal pursuit. Transactive goal dynamics was also developed to explain the process and outcomes of collective goal *pursuit* beyond describing internal cognitive-motivational states. The addition of other interdependent actors in individuals' goal networks and consequent dynamics of interdependent goal pursuit attempt to answer nearly the same question as research on representational gaps: how do interdependent individuals' goal pursuit unfold given their understanding of their team's goal system?

Similar to Kruglanski et al.'s (2002) conceptualization of a goal system, a transactive goal system is characterized as a network of actions and goals; however, those actions and goals may be distributed across interdependent actors (e.g., teammates, relationship partners, etc.). In this sense, individuals may pursue goals that have no intrinsic or direct value to themselves through their action choices or potentially realize goal outcomes of personal significance without directed effort. Thus, the transactive goal dynamics framework recognizes that members of a team may not only pursue goals that are of personal relevance, but also those that are valued by *other members* or the *team as a unit* (i.e., team performance). For example, a member may direct effort towards

facilitating another's goal accomplishment (e.g., teaching another to swim), setting goals for others (e.g., wanting another to know how to swim), or they may experience outcomes based on others' goal achievements (e.g., feeling pride for another's competitive swim time).

Another core intention of transactive goal dynamics theory is to explain levels of commitment to a collective based on experiences interacting with others. For collective commitment to develop in, for example, a team, the team must have some degree of transactive density. Transactive density describes the amount of interdependence between actors – the number of actors who pursue others' goals, set goals for others, and enjoy the fruits of others' labor. According to the theory, transactive goal systems are as dense as there are opportunities for interdependence and individuals are motivated to use those opportunities. Transactive density then informs more positive or negative outcomes to the extent that actors coordinate. Goal coordination is accomplished by performing multifinal actions that may benefit interdependent others and not performing counterfinal actions which increase discrepancy or halt progress towards a goal held by another. The degree of coordination exhibited in a system then informs outcomes' positivity/negativity (i.e., goals complete or incomplete), which the theory terms "transactive gain/loss," and how goal pursuit may persist after the collective dissolves. Ultimately, transactive gain/loss informs commitment to the team which feeds back into the motivation to engender transactive density and use consequent opportunities effectively.

The final component of transactive goal dynamics comprises two explanatory variables for goal coordination: relational orientation and skills and shared goal representations. As transactive goal dynamics is first and foremost a theory of

interdependent *goal pursuit*, the authors defer to literature on team cognition to explain how shared representations impact coordination. Specifically, the authors invoke the theory of shared mental models in proposing teams allocate effort most effectively when team members, "agree about the goals, pursuits, and outcomes for each team member" (Fitzsimmons et al., 2016, p. 144). The nature of "agreement," however, is more an issue of team cognition and the subject of the present work.

Goal Systems and Goal Pursuit Summary

The reviewed theories of goals and motivation speak directly to discussed issues of mental representation content and structure and invite less directly issues of sharedness as compatibility and its mechanism of effect on team performance. Mental representations according to transactive goal dynamics include both team concepts (i.e., members) as well as task concepts (i.e., actions and goals) linked by 'effectiveness' as postulated by goal systems theory. Representing an entire transactive goal system is proposed to let individuals make decisions which advance the most progress towards the greatest number of team members' goals as they understand the consequences of their and their teammates' actions for each other and for their success as a unit. However, the configural features of transactive goal representations which afford such understanding is so far unspecified. The theoretical framework outlined in the following section adapts the transactive goal dynamic paradigm to the representation of a single team task to propose how certain configural differences between team members' mental representations may facilitate or impede team performance.

Team Task Representations

Integrating the diverse conceptualizations of team cognition with the foundational principles from the theories of goals systems and transactive goal dynamics, I propose that the mental representations held by members within a team can be usefully operationalized as associative networks linking goals, actions, and members termed a *team task representation* (TTR). More specifically, a TTR depicts a *single* member's representation of the goals relevant to an assigned task, the actions associated with accomplishing those goals, and the members within the team/collective (including oneself) capable of performing those actions.

Figure 1 visualizes one team member's hypothetical TTR in which a shared team task is decomposed into two goals (Goal 1 and Goal 2). Goals can represent subtasks, such as the paper and presentation components of a student's project or different dimensions of a product/service such as the novelty and utility of a phone application. The TTR in Figure 1 also depicts three goal-relevant actions (Action 1, Action 2, and Action 3) which can be performed and impact the attainment of one or both goals. In this example, Actions 1 and 3 represent unifinal actions such that enacting these behaviors only advances a single goal (Goal 1 or Goal 2, respectively); in contrast, Action 2 reflects a multifinal action such that enacting this behavior simultaneously advances both goals. Lastly, the TTR in Figure 1 depicts members of a team can perform each action. Consequently, a TTR depicts a team member's beliefs regarding *who* (members) can *do what* (actions) and *why* (goals).

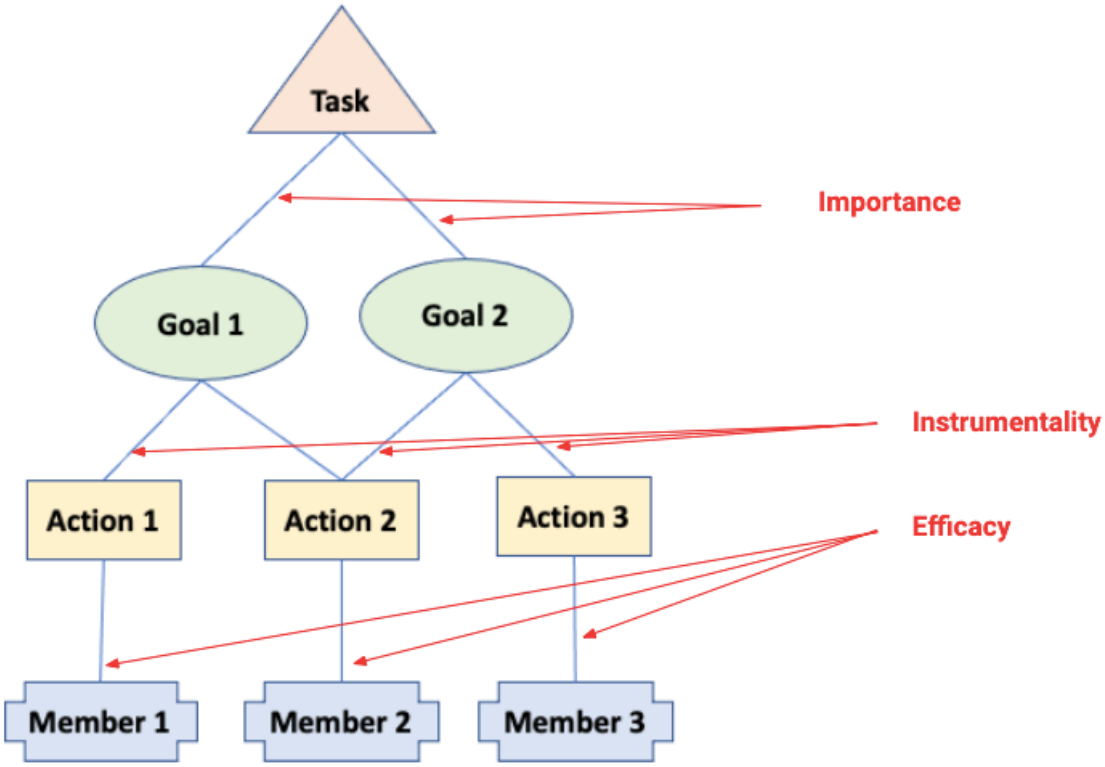

Figure 1. Example of a Team Members' TTR. The TTR above contains all types of concepts which can be represented in a TTR and how to interpret the connections between concepts. The team task represented here is composed of two goals which may be advanced by three actions, each of which may only be performed by one of three team members.

The TTR framework was developed to address key limitations of previous operationalizations of previous team cognition research. Specifically, a TTR (a) includes both team and task concepts; (b) clearly delineates the association between concepts as functional relationships (causes with their effects); (c) affords a process explanation through which individuals' cognition is translated into performance in a team context; and (d) offers a means for defining compatibility as a structural feature of mental representations. Team (members) and task (action, goal, and task) concepts together allow TTRs to describe the entire team-task problem space. Information about other team members' habits and preferences (traditionally the domain of team mental models) are captured in the connections between members and actions. Likewise, the connections

between members through actions to goals capture roles and responsibilities. Strategies (traditionally the domain of task mental models) also emerge from TTRs as sets of actions.

TTRs also borrow goal systems theory's definition of structural associations between concepts (indicated in Figure 1). In a TTR, goals lie below the task to emphasize the centrality of tasks to construing performance. Every concept present in a TTR is present *because* they are associated with the task. Goals in a TTR comprise the task, representing standards needing achievement upon which task success is measured. Goal-to-task links indicate the *perceived importance* of a goal to the task. For example, the task of writing and presenting a term paper is only successful to the degree both paper and presentation are completed, but one task-goal may be worth more points than the other. This organization also allows actions to feed directly into goals. Rather than organizing the TTR hierarchy by immediacy and concreteness, the link between actions and goals represents the rationale for why an action would be performed. Specifically, actions are chosen because they are *instrumental* to goals. Finally, the association between members and actions represents members' *efficacy* in performing actions. Efficacy is not explicitly highlighted in goal systems theory, but efficacy can alter the realized instrumentality of an action chosen as one might be too unskilled or nervous to perform an action effectively and so should be considered in problems of goal pursuit (Neal et al., 2017). Connections between concepts in a TTR differ qualitatively depending on the types of concepts connected (importance between goals and a task, instrumentality between actions and goals, and efficacy between members and actions) yet they all homologize *effectiveness*.

As in goal systems theory, TTRs' content and structure can be used to describe *choices*. This point is paramount as the present framework proposes team cognition (as described using TTRs) influences performance *through the choices that individual team members make.* In contrast to goal systems, the addition of 'members' to TTRs let them depict beliefs not only about *which* actions should be performed to achieve which goals, but *who* should perform *which actions given their team's goals.* These beliefs result from comparing actions *by a member* in terms of the member-action combination's consequences for progress across goals. In this way, TTRs depict a single team member's *subjective belief* about how one's team can complete its task given what one knows about one's team's members, actions, and task goals. The beliefs depicted in a TTR serve as premises upon which team members apply logic of action choice. For example, imagine a student project team assigned a term paper evaluated on novelty of conclusions and course content-informed reasoning. The value of actions involved such as 'conduct literature review' and 'brainstorm' gain importance through their ability to accomplish those goals. Team members who disagree about the priority of these two goals may be frustrated when observing their teammate perform an action they see as less important. Similarly, both members will form beliefs about who should be engaging in which action. If one member is more creative while another is more detail oriented, task completion is most effectively pursued by having the creative brainstorm and the doctrinaire gather information. If team members do not agree on what *everyone on one's team* should do, individual team members may perform actions which impede others' actions, are inefficient relative to other actions, or redouble actions no longer necessary.

Compatibility, in the present framework, captures the degree to which team member's makes the same decision about who does what in team performance (e.g., both teammates, Sam and Alex, agree on Sam's reviewing research and Alex's brainstorming novel ideas). The structural characteristic of TTRs here proposed to explain difference in team performance is the degree of agreement exhibited by team members' TTRs. Agreement, as an operationalization of TTR compatibility describes the similarity *specifically of two or more team members' rank-order of a category of concepts*. Specifically, disagreement about which goal deserves higher priority is proposed to lead team members to perform actions which do not advance task completion optimally (i.e., more than alternative combinations of members' actions over time).

Compatibility (through agreement) of team members' TTRs can be judged by outside observers, but members may also assume or infer each other's TTRs and develop a sense of their own compatibility. However, it is quite possible for members to be incorrect about their teammates' beliefs. Shared mental models propose that shared expectations are what allow team members to coordinate and synchronize. By knowing another's beliefs about which goals are important, which actions are instrumental, and which members can perform those actions, team members could alter their behavior to optimize action choice *depending on their teammate's choice*. For example, a linebacker on a football team might believe a long pass is the best play, in which case they should choose to hold the line and give the receivers enough time to hit their marks and the quarterback enough time to find an open receiver. If the linebacker, however, knows the quarterback likes to fake passes and run the ball, the most effective action would be to make some room for the quarterback to get through. If the linebacker does not condition

their action choice on the quarterback's action choice, even if they are right about the optimal play, their team would do better if the linebacker performs the action which supports their quarterback. In this way, team members themselves may develop a sense of agreement, but whether those aspects of compatibility inform optimal action choice depends on whether they are correct about their teammates upcoming choices. The following section describes how TTRs, emergent compatibility, and their mechanism of effect on performance through discrete decisions based on correctly assumed expectations come together in a process-oriented theory of dynamic team performance.

Modeling Team Task Representations

In addition to providing a means for representing compatibility among team member mental models, a significant advantage of the TTR framework is that it provides a direct means for representing (a) how a member's TTR is proposed to translate into performance-relevant behaviors and (b) how differences across TTRs within a team may lead to unique patterns of team outcomes. To explicate the implications of these representations more directly, an agent-based computational model is developed which integrates the key structural elements of TTRs (e.g., Figure 1) as a goal system with dynamic models of goal pursuit. Agent-based models are particularly well suited to examining questions involve complex and dynamic processes unfolding over time across interdependent entities/individuals (Strauss & Grand, in press.). Furthermore, developing such a model of TTRs within teams affords the capacity to probe the underlying logic between team cognition and team performance within the proposed framework as well as advance unique insights, predictions, and propositions for future research.

There have been several recent notable efforts at developing dynamic and computational models of goal pursuit at the individual-level (e.g., Ballard et al., 2016; Samuelson, 2019; Vancouver et al., 2010). The present model builds upon these foundational models in four important ways. First, the present model expands the existing representations of goal pursuit to encompass situations with multiple individuals simultaneously choosing and engaging in task-relevant actions for the purposes of accomplishing shared/interdependent outcomes. Second, the model incorporates the potential for individual agents to engage in *counterfinal* actions such that members may behave in ways that advance some goals at the direct expense of other goals in the team's environment. Third, the present model enables the representation of TTRs and/or aspects of goal systems to be systematically varied across members (i.e., differences in actions, perceived/actual instrumentalities, goal priorities, etc.) that allow for more precise and nuanced examinations of the relationship between team cognition and performance to be explored. Lastly, the present model introduces the potential for incorporating how individuals in a team may adjust their behavioral choices in response to both observed goal progress and beliefs/perceptions about their team members' task understanding (i.e., anticipating others' behaviors).

The agent-based model developed for this present research represents team performance as a series of choices in the pursuit of task goals. In its simplest form (e.g., one actor and one goal), goal pursuit requires setting a specific referent to be contrasted with one's current state, pursuing that goal with instrumental actions, observing the reduction in discrepancy between current and referent states, and updating one's knowledge of their new current state accordingly (Carver & Scheier, 1982). As

previously discussed, however, the underlying goal systems for team tasks are often more complex and may involve multiple goals, actions, and members.

Consequently, the team task instantiated for purposes of the present research was kept purposefully simple (i.e., few elements in the goal system, low interdependence, minimal differences across mental representations) so that the sufficiency and fundamental mechanics relating TTR compatibility to performance could be evaluated. Figure 2 provides a visualization of the goal system portrayed in each member's TTR. In brief, the simulated architecture represents two teammates (Member 1 and Member 2) faced with accomplishing a single task under a deadline. The task is comprised of two goals that must be completed. Members have five actions they may perform at each time step, with each action affecting progress on one or more goals. The following section details the formalization of the model and process by which members' goal-priorities guide their action choices in this team task context.

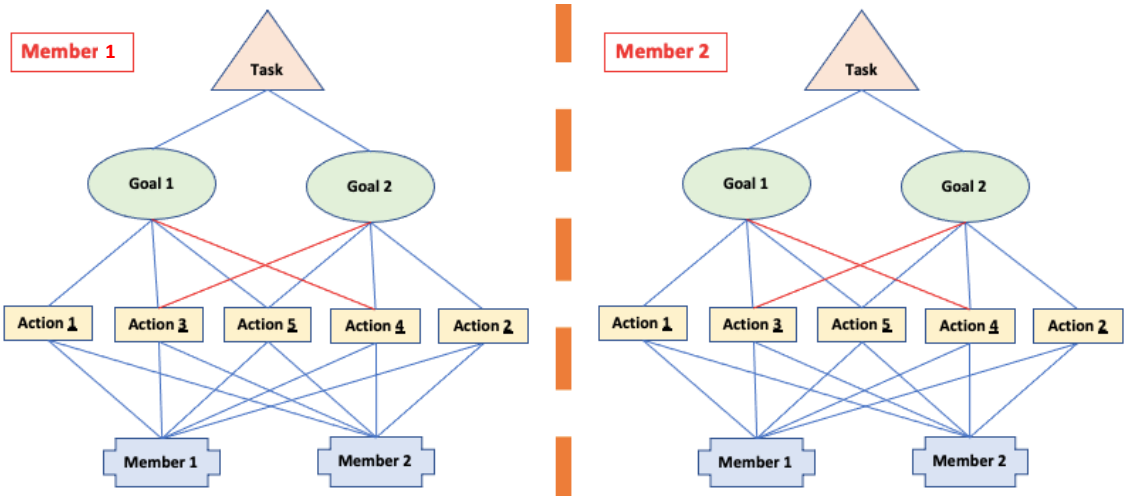

Figure 2. Both Simulated Team Members' TTRs. The left-hand pane portrays M1's TTR and the right-hand pane portrays M2's TTR. Blue lines represent positive relationships (i.e., actions that reduce discrepancy in their target action) while red lines represent negative relationships. The TTRs in this figure represent a task assigned to a two-member team. The task is comprised of two goals which may be pursued using a set of five actions. Actions 1 and 2 are unifinal, and Actions 3 and 4 are counterfinal to Goal 1 and 2 respectively, and Action 5 is multifinal to both goals. Each member may perform any of the five actions during performance. See Tables 3 for action-to-goal, "instrumentality," connection values. Goal-to-task,

"importance," connection value is manipulated in Study 1 and 2 as described by Tables 4 and 7 respectively. Efficacy from both members to all actions are all implicitly set to '1.'

Model Specifications

Table 1 summarizes the model pseudocode (i.e., steps and procedural rules describing the sequence of activities/computations carried out in the model) and Table 2 presents the equations used to model each dynamic variable. The model was specified in the computer language 'R' (R Core Team, 2013).

Table 1
Pseudocode for the Interdependent Goal Pursuit Model

Step	Action
1	Initialize time clock $t = 0$.
Means Choice	
2	***Each member*** calculates each goal's *valence* as a function of the number of units left to attain of the goal (i.e., *discrepancy between a goal's current state and reference*) and *value to the task.*
3	***Each member*** calculates each action's *expectancy* from time remaining before the deadline, time-to-completion for each action-goal connection (i.e., *instrumentality*), and *time sensitivity* (i.e., the individual's sensitivity to deadlines).
4	***Each member*** calculates each action's *expected utility* by combining its connected goals' *valences* and *expectancies* associated that action's use.
5	***Each member*** selects the action with the greatest *expected utility*.
Goal Network Updates	
6	Based on the means chosen, determine the impact made on each goal's new current state as a function of the selected action's *instrumentality*.
7	Increment time clock $t = t + 1$.
8	If $t <$ *deadline* and at least one task goal's *current state* > 0, repeat Steps 2 – 7.
9	End.

Note. t = current time. Equations employed in each step of this process are presented in Table 2.

In Step 1 of the model, the time is set to $t = 0$ and the parameters for the goal system and each team member M_n (where n = number of team members) are initialized. In Step 2, members calculate the discrepancy (d) for each goal G_j (where j = number of goals in a

task) as the difference between the goal's current state (c) at the timestep and its reference/ideal state (r):

$$d_j = r_j - c_j \tag{1}$$

Members' perceived valence (v) or momentary value for each goal is then computed as a product of the goal's perceived importance to the task (k) and its discrepancy:

$$v_{nj} = \kappa_{nj} \cdot d_j \tag{2}$$

The computation of valence thus captures that members' perceptions of how valuable a goal is at a given moment is a function of the person's beliefs regarding the importance/significance of the goal to task accomplishment and how close that goal is to being accomplished.

Following the computation of each goal's valence, members next compute the perceived expectancy (e) associated with all available actions A_i (where i = total number of available actions; Step 3). Expectancy represents the likelihood that goal G_j will be completed given the available time/resources if action A_i is used. Expectancy is therefore dependent on the instrumentality of A_i to G_j ($Inst_{ij}$) given the discrepancy for goal G_j at time t and the time available to complete the goal (TA). Consistent with prior goal pursuit models, an individual's sensitivity (γ) to deadlines is also represented as an individual difference factor that affects how strongly changes in the time remaining for goal completion affects one's perceptions of goal expectancy. The final formula for expectancy is thus:

$$e_{nji} = \begin{cases} 1 \,/\, (1 + \exp\left[-\gamma_n (TA - (d_j \cdot Inst_{ij}))\right]), & Inst_{ij} \geq 0 \\ 0\,, & Inst_{ij} < 0 \end{cases} \tag{3}$$

Equation (3) is consistent with prior models of goal pursuit for when the instrumentality of an action towards a given goal is positive ($Inst_{ij} \geq 0$, Ballard et al.,

2016; Samuelson, 2019; Vancouver et al., 2010). However, the present model also introduces the potential for an action to have a non-positive instrumentality towards a goal (i.e., a counterfinal action that actively works against progress on a goal). Because expectancy represents a probability/likelihood and is thus bound between [0, 1], an action with a negative instrumentality would result in a negative expectancy. Consequently, the expectancy for any action-goal association with a negative instrumentality is set to zero. Note that this formulation is still consistent with the definition of expectancy: an action that actively obstructs progress on a given goal should thus be perceived as having a 0% chance of completing the goal if it is used.

In Step 4 of the model, the previous computations of valence and expectancy are used by members to compute the expected utility (*EU*) of each action (actions' momentary value). Specifically, each member computes the *EU* of an action by multiplying its associated expectancy and valences and summing this product across all goals affected by that action:

$$EU_{ni} = \sum_{G=1}^{j} v_{nj} \cdot e_{jni} \tag{4}$$

The action chosen (*AC*) at the given time step for M_n is subsequently determined by selecting the action with the highest expected utility (Step 5):

$$AC_n = \max(EU_{ni}) \tag{5}$$

After all members choose an action, goal progress and the subsequent state for all goals in the modeled system are advanced by summing the instrumentality across each member's chosen action (i.e., $c + \sum_{n=1}^{n} Inst(AC_n)$) and advancing time by 1. This procedure is then repeated until either (a) both goals' current states equal their reference

state (i.e., all goals have been accomplished) or (b) the current time equals the deadline (i.e., team has run out of time to complete the task).

Table 2
Model Equations for Study 1

Value	**Formula**
Time Available (*TA*)	$TA = deadline - t$
Discrepancy (*d*)	$d_j = r_j(t) - c_j(t)$
Valence (*v*)	$v_j(t) = k_j(t) \cdot d_j(t)$
Time Sensitivity (γ)	*see Table 3*
Expectancy (*e*)	$e_{ji}(t) = 1 / (1 + \exp[-\gamma(TA_j(t) - (d_j(t) \cdot Inst_{ij}(t)))])$
Expected Utility (*EU*)	$EU_i(t) = \Sigma[v_j(t) \cdot e_{ji}(t)]$
Action-choice (*AC*)	$AC = max(EU_i)$

Note. t = current time. γ = time sensitivity. r_j = reference state for G_j. c_j = current state for G_j. k_j = importance of for G_j. $Inst_{ij}$ = instrumentality of A_i to G_j.

In sum, the proposed computational model conceptualizes an individual team member's TTR as a goal system comprised of goals, actions, and members. How a member's TTR affects their evaluation and choice of performance-relevant actions in the model is subsequently represented as a dynamic goal pursuit process that unfolds over time and across team members. Furthermore, differences across members in both the structure of a TTR and the associated perceptions of elements within a TTR (i.e., goal importance, instrumentality, etc.) can be represented and systematically manipulated using the model to explore how different configurations of team cognition may impact patterns of action and emergent team performance. The remainder of the paper describes two simulation studies conducted using the proposed model of TTRs to explore its

implications as a representation of team cognition and its relation to emergent team performance.

Study 1

The primary purpose of Study 1 was to explore the operationalization of compatibility within the TTR framework and evaluate its implications for team functioning and performance outcomes. For purposes of the present simulation, compatibility was represented as differences in team members' perceived importance of task goals. The aim of the first simulation was thus to establish how differences in the representation of goal prioritization within team members' TTRs affect action choice and team performance outcomes:

RQ1: How do differences in team members' prioritization of goals i.e., agreement between their TTRs influence individual action choice and team performance?

To facilitate interpretation of the simulation results, the interdependence among team members in Study 1 was kept purposefully simplistic. Specifically, members only influenced one another's action choices "indirectly" as result of the consequences that members' selected actions exerted on task goal completion. That is, each agent was sensitive and responsive to changes in task goal completion that occurred from both their own and their teammate's actions, but agents pursued task goals in parallel and with no consideration or anticipation of one another's choices. In this sense, no deliberate coordination occurs between agents task goal completion efforts. Operationally, each agent's TTR in Study 1 resemble the TTRs in Figure 2. Each agent member represents the other member in their TTR indicating awareness of their teammate, yet they do not behave as if their teammate's contribution is expected or predictable. Instead, they only

incorporate information about the effect of their teammate's action in their next choice of action as both members mutually experienced the outcomes (goal progress) of both their own and their teammate's actions. Consequently, the results from Study 1 are intended to provide a baseline evaluation of the effects of compatibility (operationalized as agreement on task goal priorities) within members' TTRs and serve as a point of comparison for building on additional layers of complexity in future simulations (i.e., Study 2).

Simulation Design

Table 3 summarizes the model parameters and values used for Study 1. The primary manipulation in Study 1 concerned members' perceptions of each goal's importance. Four conditions were constructed to represent different configurations of mental representation compatibility within a team as described in Table 4. The conditions were formed by manipulating the degree to which team members TTR reflected the same belief about the relative importance (k) of the available task goals.[3] More specifically, the conditions were constructed by manipulating the number of members in the team who expressed a preference for one goal (i.e., $k_1 \neq k_2$) and whether both members agreed about this preference. Condition 1 thus simulated teams in which both members believed both task goals were equally important ($k_1 = k_2$); Condition 2 simulated teams in which one member believed both task goals were equally important, but the other member believed one goal was more important than the other goal ($k_1 > k_2$); Condition 3 simulated teams in which both members believed the same task goal was more important than the other goal; and Condition 4 simulated teams in which members held differing beliefs about which

[3] k_i was allowed to randomly vary across members and simulation runs within these constraints.

goal was most important (i.e., Member 1 believed $k_1 > k_2$, whereas Member 2 believe $k_1 < k_2$). All remaining model parameters in the simulation were held constant (see Table 3).[4] 500 teams were simulated in each condition for a total of 2000 runs of the model.

With respect to the task environment, five actions were created for members to use in goal pursuit. Two actions were unifinal and exhibited a strong net instrumentality towards goal progress (A_1, A_2), two were counterfinal and exhibited a moderate net instrumentality (A_3, A_4), and one was multifinal with a weak net instrumentality (A_5; see Table 3 for selected parameter values). Given this action set, members had the option to pursue one goal without affecting the other (select actions A_1 or A_2), pursue one goal at the expense of another (select actions A_3 or A_4), or pursue both goals simultaneously (select action A_5). The multifinal action (A_5) was intentionally assigned a small net instrumentality (2 total units of goal progress, one toward each goal) to encourage agents' in the simulation to select alternative action choice in light of Samuelson's (2019) finding that multifinal actions tend to dominate action choice when they exhibit even moderate instrumentality.

[4] The constellation of mentioned goal- and member-parameters yields low time-pressure.

Table 3
Study 1 Parameters

Parameter	**Value**	**Manipulated**
Goals (All)	*2*	*No*
Deadline	50 timesteps	*No*
Reference State (r)	100	*No*
Actions	*5*	*No*
Action1 (Inst)	***5** (Goal1), **0** (Goal2); Unifinal*	*No*
Action2 (Inst)	***0** (Goal1), **5** (Goal2); Unifinal*	*No*
Action3 (Inst)	***7** (Goal1), **-3** (Goal); Counterfinal*	*No*
Action4 (Inst)	***-3** (Goal1), **7** (Goal); Counterfinal*	*No*
Action5 (Inst)	***1** (Goal1), **1** (Goal); Multifinal*	*No*
Members (all)	*2*	*No*
Time Sensitivity (γ)	1	*No*
Members' Goal Importance (k)	*See Table 4.*	***Yes***

Note. t = current time. Parameters were consistent across all runs (teams) in each condition except for *members' goal importance* which was manipulated resulting in four configurations across four conditions described in Table 4. Efficacy from both members to all actions are all implicitly set to '1.'

Table 4
Study 1 Condition Parameters

Condition	**Member 1**	**Member 2**	**Agreement**	**Preferences**
1	$G_1 = G_2$	$G_1 = G_2$	True	0
2	$G_1 = G_2$	$G_1 > G_2$	False	1
3	$G_1 > G_2$	$G_1 > G_2$	True	2
4	$G_1 > G_2$	$G_1 < G_2$	False	2

Note. G_1 = Goal 1; G_2 = Goal 2. The 'Member 1' and 'Member 2' columns indicate the relative value or 'priority' each member placed on the two task goals. Goal importance within person summed to 100. The importance for Goal 1 was either set to 50, randomly set to a value between (51, 99), or randomly set to a value between (1, 49). Goal 2 was set equal to the difference between 100 and Goal 1's importance. This was done independently for each agent. Only priority (which goal was more important than the other) was manipulated so the actual importance of each goal over the other for members with preferences ($G_1 \neq G_2$) was free to vary across runs (teams) within condition. For example, in Condition 1, Member 1 and Members 2 both placed equal value on Goals 1 and 2. In Condition 2, Member 1 valued both goals equally whereas Member 2 valued goal 1 more than goal 2. The 'Agreement' column indicates whether agents team agreed on which goals were perceived as most valuable. The 'Preferences' column indicates the number of agents on the team who placed higher value on one goal over the other.

Measures

The primary outcome variables recorded in the simulation included the actions chosen by members at each time step, goal progress (i.e., the amount by which goal discrepancies changed) at each time step, and task completion[5] (the total number of steps required to complete both goals). Changes in goal valences and action utilities were also tracked over time to confirm the internal validity of the model.

Study 1 Results

The analysis of results from Study 1 begins by summarizing trends in agents' perception of goal valances and action utilities over time to verify the internal validity of the model (i.e., ensuring values unfolded in the general shape expected and that trends aligned across measured values). These examinations also provide opportunities to identify unique/unanticipated patterns resulting from compatibility that could provide insight into the primary performance outcomes. Following the internal validity checks, performance outcomes are analyzed and interpreted across conditions to examine the impact of the primary study manipulations (TTR compatibility/agreement of goals and presence of goal preferences. Note that for all reported simulations, all "Member 1 agents" (M_1) and all "Member 2 agents" (M_2) are functionally identical *within* a given

[5] Because task completion is measured as the total number of steps needed to complete both goals, lower numbers on this metric indicate better/faster performance.

condition (i.e. all M_1s within Condition 1 are parameterized the same). Consequently, it is appropriate to draw inferences and make between-agent comparisons in the aggregate within each condition (i.e., comparing behaviors/outcomes of M_1 vs. M_2 in each condition).

Valences

Changes in valence over time are presented in Figure 3. Each plot depicts the trajectory of changes over time (x-axis) in perceived valence (y-axis) of each goal for each member in each simulated run. The valences for M_1 are depicted in the left column and the valences for M_2 in the right column. Each row of plots in Figure 3 corresponds to the condition labels presented in Table 4. Initial valences for each goal and each member correspond with the manipulated differences in perceived importance represented in member's TTRs (e.g., initial valence for G_1 and G_2 are equal for M_1 and M_2 in Condition 1, initial valence for G_1 > initial valence for G_2 for Member 2 in Condition 2, etc.). Perceived valences of goals decrease over time as members make goal progress; and once

a goal has been completed, its valence becomes zero. Taken together, these patterns indicate that the core model mechanisms operated as intended.

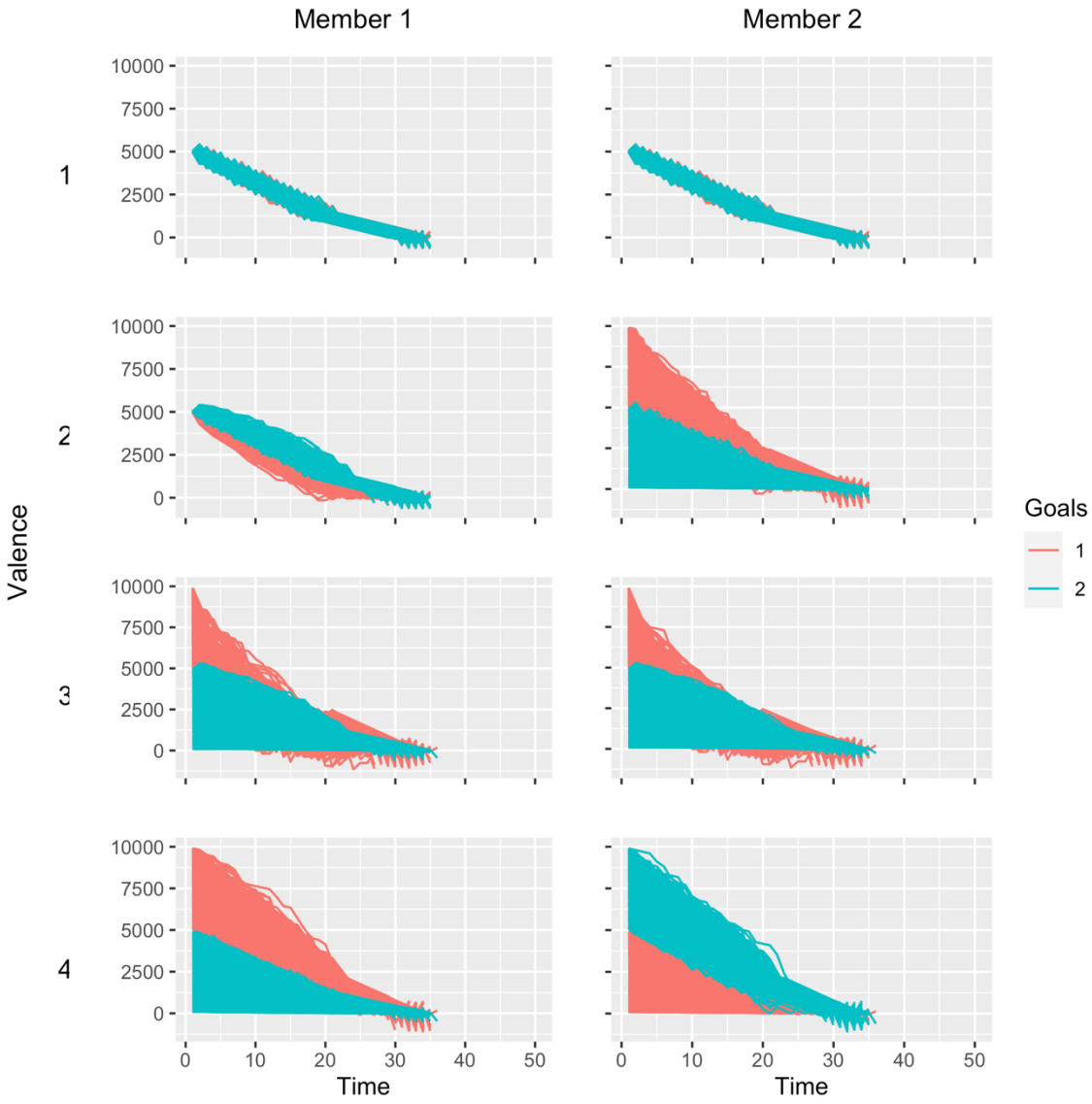

Figure 3. Change in Goal Valences for Members over Time (Study 1). Trajectory of change in each goal's valence (y-axis) is plotted over time (x-axis). Each of these eight plots depicts the trajectories of change in each goal's valence (denoted by color) for either member (denoted by columns of plots) in all 500 runs (teams) within a condition (denoted by rows of plots). Each member held equivalent goal priorities in all teams within condition (identical rank-order of goals' importance).

Beyond establishing the internal validity of the model, Figure 3 reveals two important principles for understanding mental representations of goals. First, initial

representations of goal values are insufficient to explain dynamic performance simply because they contain no dynamic information. For example, both members in Condition 3 *always* begin valuing G_1 over G_2, yet Figure 3 shows several instances in which pursuing G_2 becomes more important than pursuing G_1 (where blue lines rise above red lines) for members. This observation underscores the need to investigate mental representations as dynamic constructs which influence behavior and are reciprocally influenced by the consequences of that behavior.

Second, differences in the pattern of change for each team member's valences across conditions cannot be explained by the focal team member's goal preferences alone. This can be seen in the difference in valence plots for M_1 in Condition 1 versus in Condition 2. In both conditions, M_1 began with both goals represented with equal importance. Nevertheless, M_1 consistently values G_2 above G_1 after the first timestep due to differences in M_2's goal preferences. Specifically, when M_2 has no preference, M_1 begins with no preferences and never clearly prioritizes one goal over the other. However, when M_2 prioritizes G_1 over G_2, M_1 with still no initial preferences tends to prioritize G_2 throughout performance. In this way, both team member's TTR values informs each's own action choice despite members never directly considering their teammate's TTR. One member's valences change as a function of *both* their own TTR values *and the consequences of team members' TTR-driven actions*.

Expected Utility of Actions

Expected utilities change over time as goals' valences and expectancies change. As described previously, valences change according to changes in discrepancy. Expectancies change as a function of discrepancy *relative* to an action's instrumentality

and time remaining.[6] Figure 4 depicts changes in actions' expected utility (*EU*; y-axis) over time (x-axis). As in Figure 3, the *EU* for each action (color) are plotted for each member (column) aggregated within condition (row). Although Figure 4 appears to represent only three *EU*s for five actions, the *EU* for some actions perfectly overlap. Specifically, EU_1 and EU_3 are valued identically and consistently for both members in all teams throughout performance, as are EU_2 and EU_4. The green lines in Figure 3 thus represent the *EU* for actions benefitting G_1, blue lines represent the *EU* for actions benefitting G_2, and purple lines represent the multifinal action.

This pattern supports internal validity of the present model yet elicits questions of its external validity. Counterfinal actions' negative instrumentality is discounted as negative instrumentality increases the likelihood of goal accomplishment to the same degree as null instrumentality: by '0.' Additionally, the difference in positive instrumentality towards uni- and counterfinal actions' focal goal in this model was insufficient to render different expectancies as both types of actions could be used to complete their focal goal (ignoring the alternative goal) at any point during performance. The model did compute *EU*s correctly, but whether a human would disregard the difference between null and negative instrumentality or the small differences in positive instrumentalities cannot be answered here.

[6] Expectancies were not tracked because they were not intended to play a major role in goal pursuit given the lack of time pressure. A post hoc measurement showed no expectancies changed except for A_5.

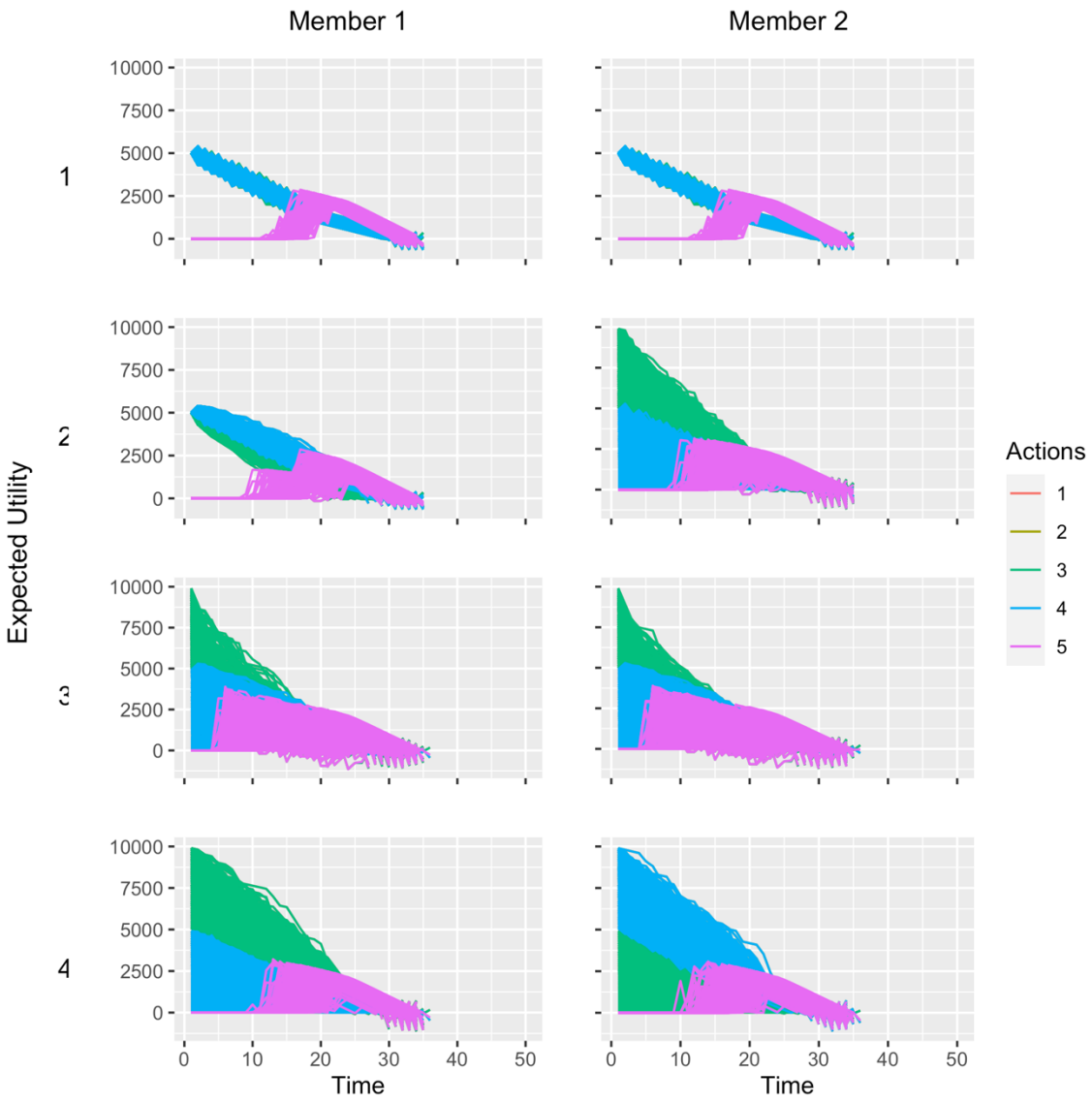

Figure 4. Change in Actions' Expected Utilities (EU) for Members over Time (Study 1). Trajectory of change in each action's EU (y-axis) is plotted over time (x-axis). Each of these eight plots depicts the trajectories of change in each action's EU (denoted by color) for either member (denoted by columns of plots) in all 500 runs (teams) within a condition (denoted by rows of plots). Each member held equivalent goal priorities in all teams within condition (identical rank-order of goals' importance).

EU trajectories for actions benefitting G_1 correspond closely to the trajectories of G_1's valence in Figure 3 indicating expectancy played little if any role in dynamic *EU* values. The trajectory of EU_5, however, differs acutely from the general downward trend of the other *EU*s *across members and conditions*. Instead of starting at some positive value and declining toward zero, EU_5 universally starts at '0,' climbs precipitously near

the middle of performance until it reaches its maximum and begins a gradual decent back to '0.' This pattern indicates the effect of expectancy on weakly instrumental actions whereby an action will be devalued (have lower expectancy) if it is unlikely for that action to eliminate remaining goal discrepancy given time remaining.

The general shape of EU_5's trajectory is ubiquitous in the data, yet the onset, duration, and variability thereof differ notably between conditions. EU_5 rises above '0' the earliest ever in Condition 3 (in which members agreed on the priority of G_1 over G_2) although the point at which it does is incredibly variable for both members. EU_5 in Condition 1, in which members also agreed goal values were equal, rises above '0' much later and does so at a relatively consistent point during performance for both members. The difference in trajectory variances between these two conditions is partly a consequence of the allowed variance in TTR values (goal values cannot vary if they are set equal and have a constant sum). The earliest point at which the value of EU_5 rises above '0' for any observed team is still far earlier in Condition 3 than in either Conditions 2 or 4 in which members disagreed on goal priorities. The unique patterns of *EU* trajectory distributions across conditions supports the conclusion: both a member's own TTR and the consequences of their teammate's TTR-driven actions guide changes in *actions'* perceived values section over the course of performance. This finding complements the analogous conclusion from the previous section regarding influences on the perceived value of goals.

Action Choice

Figure 5 plots the Proportion of teams (y-axis) in which M_1 and M_2 (columns of plots) chose an action (denoted by color) at each timestep (x-axis) within each condition

(rows of plots). As suggested by the equivalent *EU*s for uni- and counterfinal actions which benefit the same goal, A_1 and A_3 are selected at nearly equal proportions at each timestep for both members in all conditions as are A_2 and A_4. The time by which A_5 is predominantly selected across members and conditions also reflects the patterns of expected utility observed in Figure 3 whereby its value starts low but becomes higher toward the middle of performance then again declines toward the end.

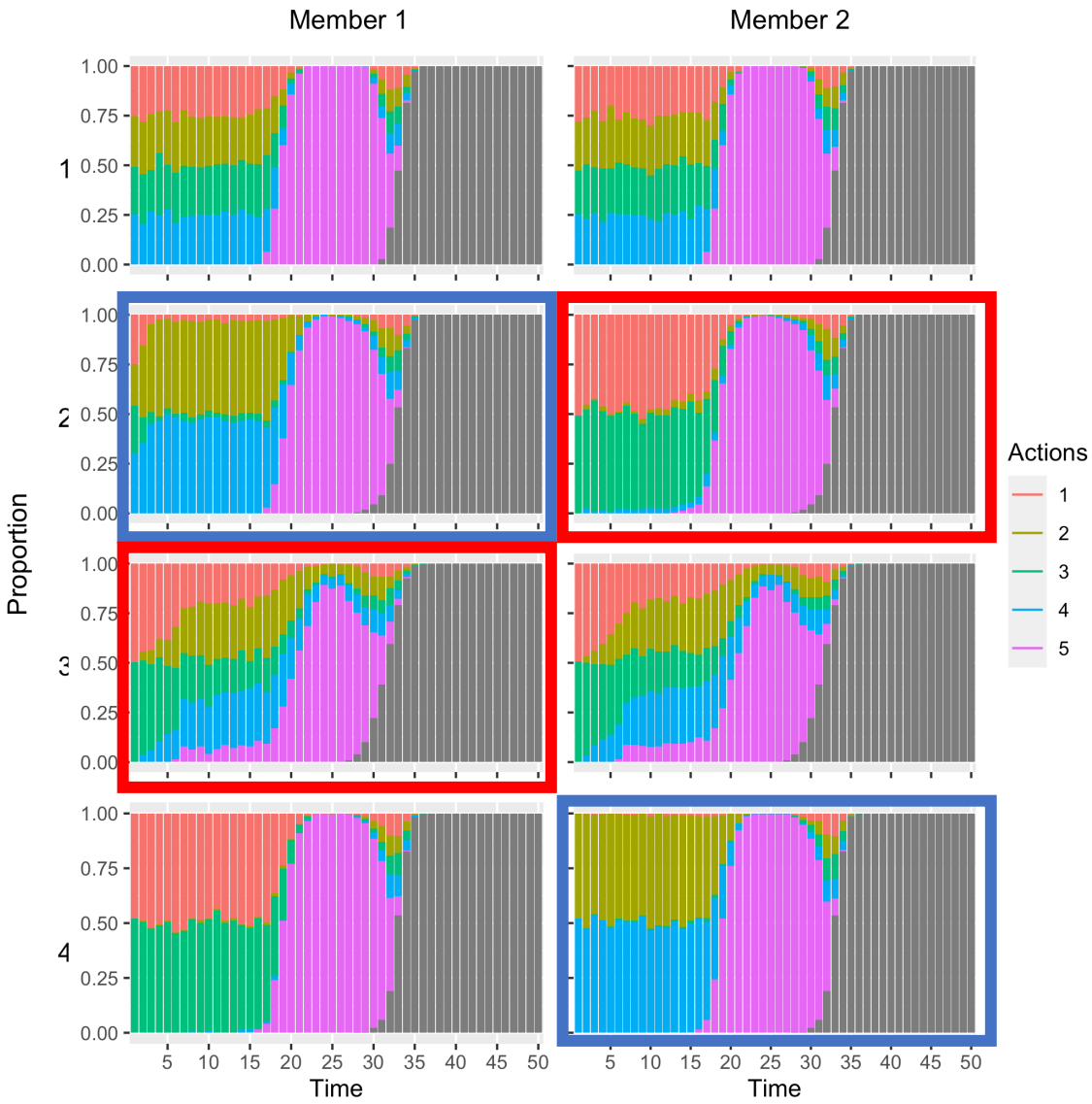

Figure 5. Proportion of agents choosing each action at each time step (Study 1) Proportion of teams (y-axis) in which a team member chose each action (denoted by color) is plotted over time (x-axis). Proportions of actions chosen across time is grouped by member (denoted by column of plots) within each condition (denoted by rows of plots). For example, Member 1 performed Actions 1, 2, 3, and 4 in roughly

equal proportions (~25%) of teams in Condition 1 between timesteps (1, 17). Each member held equivalent goal priorities in all teams within condition (identical rank-order of goals' importance).

During early stages of task completion, the multifinal action is perceived as too ineffective to achieve the team's goals until sufficient goal progress makes it seem a viable option. Interestingly, the multifinal action (A_5) is only perceived as inadequate because neither agent member can account for the other's actions. If both members were to choose this action at every time step, they would complete both goals by the specified deadline in the simulation (e.g., 1 unit of progress * 2 members * 50 timesteps = 100 units of progress on *each* goal). As a result, this observed pattern may not have manifested had members been able to coordinate and not simply react to the consequences of their teammate's behavior.

The point at which A_5 becomes the dominant choice is similar for both M_1 and M_2 across all conditions. Despite potential differences in agents' agreement and preferences for mentally represented goals (i.e., compatibility of their TTRs), it appears that *all* simulated members eventually converged on preferring/selecting the same (multifinal) action at roughly the same time. Although agents in three of four conditions held different beliefs regarding the absolute importance of goals, all other agent parameters were held constant and task parameters were common across members (i.e., instrumentality, time sensitivity, goal referents, etc., Table 3). To the extent these parameters were to vary (i.e., agents had different views on goal progress or goal requirements, agents perceived the instrumentality of actions differently, etc.), the transition to the multifinal mean would have been less ubiquitous. Nevertheless, these results demonstrate that differences in the compatibility of agents' TTR does not

guarantee complete divergence in preference for performance-relevant decisions/behaviors.

The effect of interdependence alluded to in previous sections on valence and EU is highlighted by the colored boxes in Figure 5 around actions for both members in Condition 2, M_1 in Condition 3, and M_2 in Condition 4. The red boxes around M_1 in Condition 2 and M_2 in Condition 4 identify agents with *different* goal preferences/priorities behaving *similarly* in the aggregate. The blue boxes around M_2 in Condition 2 and M_1 in Condition 3 identify agents with *similar* goal preferences/priorities behaving *differently* in the aggregate. The only difference between plots in boxes of the same color is the *preferences held by the other member.* These observations further support the notion that individual team members' performance should be seen as a function of the individual's TTR and the mutually experienced consequences of all teammates' actions.

Finally, the primary differences between members actions for those on teams exhibiting agreement (Conditions 1 and 3) and disagreement (Conditions 2 and 4) is the degree to which "specialization" emerges. Members in teams with agreement were more likely to perform actions that reduce discrepancy toward either goal (using only A_1 and A_3 *or* A_2 and A_4) at some point during performance while members in teams with disagreement tended to specialize in actions which make progress towards the goal their teammate deems less-important. This observation indicates the role of agreement without considering teammates' role in team task performance. Both goals need to be satisfied to complete the task, so when members agree on the greater importance of one goal over another, one or both members *will* have to perform actions aimed at reducing the

alternative goal's discrepancy at *some* point. On the other hand, members on teams exhibiting disagreement may never need to pursue their disfavored goal because that goal is favored and pursued by the teammate.

Goal Progress

Figure 6 depicts change in the difference between the amount of cumulative progress made on G_1 versus G_2 over time for all simulated teams within each condition (i.e., positive values = more progress on G_1; negative values = more progress on G_2; zero = equal progress on both goals) over time. Each of the four plots corresponds to each of the four simulated conditions. All trajectories in all plots begin and end at zero, when no progress on either goal has been made and when both goals have been completed, but the trajectory between varies across and within condition. Each manipulated variable, compatibility via agreement and the presence or absence of preference, explain these observations.

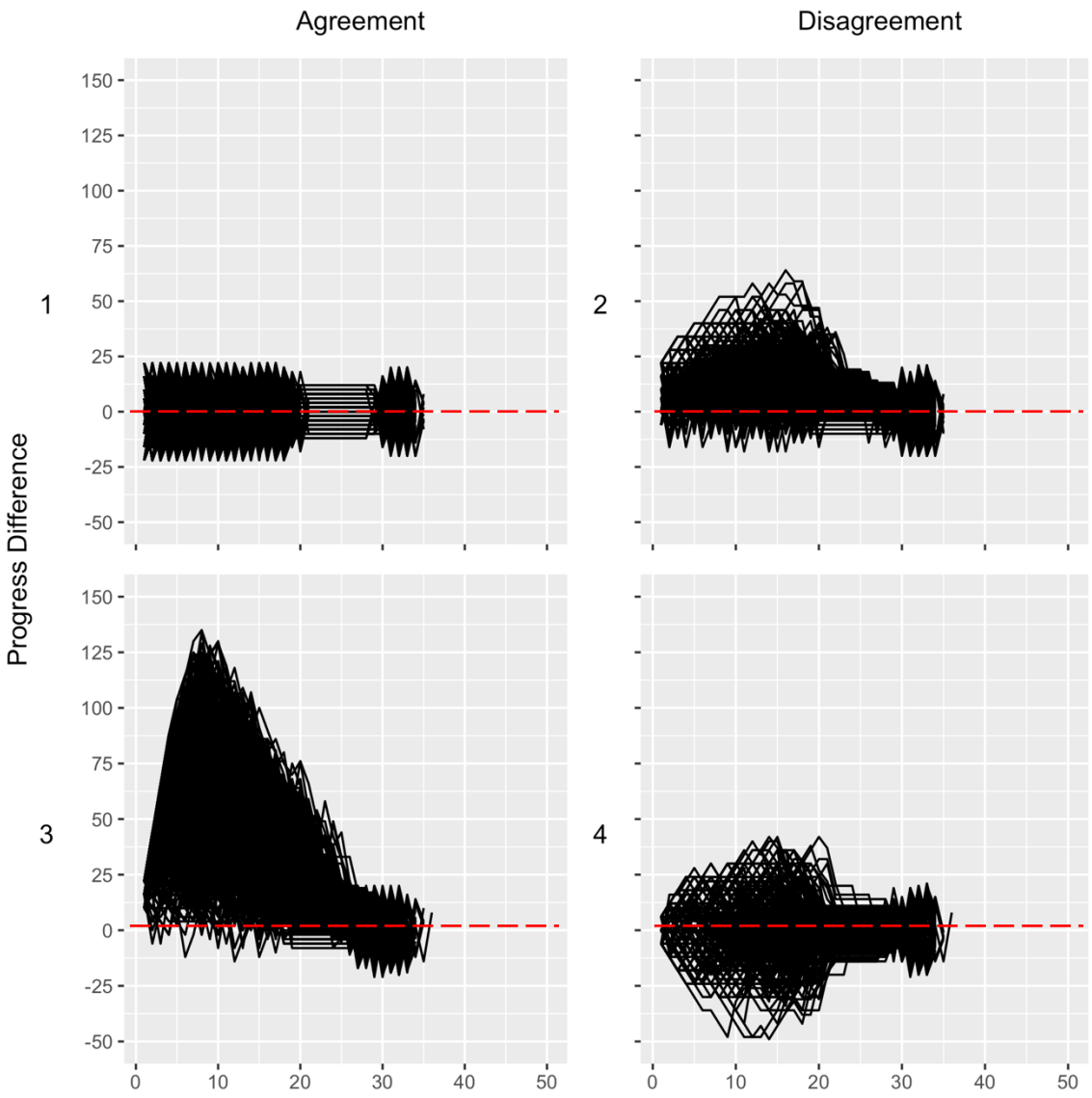

Figure 6. Change in Relative Difference in Progress over Time for Simulated Teams (Goal 1's Progress minus Goal 2's progress; Study 1). Values along the y-axis represent the number of units made towards G1 minus the number of units made towards G2. Positive values therefore represent more cumulative progress having been made on G_1 and negative values represent more progress having been made on G_2. Each plot depicts the trajectory of change in relative progress differences over time (x-axis) resulting from both members' actions' instrumentality in every timestep.

The rate of change in the difference of progress on G_1 versus G_2 is informed by agreement as well as the presence and strength of preferences. In Condition 1, performance difference stayed near '0,' but the sharp 'peaks' of performance difference (reaching local maxima and minima at y = ~25 and -25) indicate generally steep slopes

until approximately timestep 20. Performance difference trajectories in Condition 3 are also mostly peaked, characterized by a steep slope up to a maximum (reaching as high as $y = 130$) and then a nearly-as-steep downward slope towards or past '0.' The rise and fall of progress differences in Conditions 2 and 4 (in which team members held incompatible TTRs) is comparatively gradual.

The rates at which goal progress differences change across levels of agreement are explained by the allocation of teams' effort within a single timestep. Members who agree on goal priorities are more likely to judge the same actions (those which progress towards the prioritized goal) similarly and thus choose them at similar instances. Conversely, members who disagree on goal priorities are less likely to select actions benefiting the same goal at the same time. Compatibility thus guides teams' net allocation of effort across their goals at each decision point. Specifically, teams with compatible TTRs have more members direct effort towards fewer goals at each time step.

Members' goal preferences inform the amplitude of global maximums in trajectories plotted in Figure 6. Momentarily excluding Condition 4, one can see that more members with a (same) preference (comparing across Condition 1, to 2, to 3) corresponds to an increase in the average height of difference trajectories across conditions. The variance of trajectories' maxima *within* conditions further illustrates that *the point at which the team switches its net attention is some function of members' net preferences* as the magnitude of members' preferences was all that varied across teams within condition. Members in Condition 3 had the highest potential net-preference magnitude and frequently reached the highest maxima of any condition at over 100 units of progress more on G_1 than G_2. This effect of net-preference magnitude could also

explain why progress difference trajectories in Condition 1 and 4 had similar average maxima despite trajectories in Condition 1 appearing steeper and peaked and trajectories in Condition 4 appearing relatively more gradual and smoother. In sum, team members' goal preferences inform how much relative discrepancy the team collectively tolerates and *compatibility informs how much progress any goal is advanced in a single timestep due to members' concurrent or dispersed contributions*.

Task Completion

Figure 7 presents the distributions for team performance as task completion speed. Teams are plotted according to the timestep at which the task was completed. Lower numbers of steps to complete both goals indicates better performance. Each panel also offers the descriptive statistics for each condition's task completion. Despite differences in their performance dynamics, the *average* speed of task completion across all conditions was generally similar. However, there were several observable differences in the variance on this metric. Most notably, teams in Condition 3 exhibited a larger variance in performance outcomes and the nominally fastest mean rate of task completion. Further, Figure 7 shows the distribution of task completion rates by teams in this condition was flatter and the least negatively skewed. Together, these distribution parameters indicate that speed of task completion in Condition 3 was more variable than in other conditions but tended to be faster. Indeed, Condition 3 had the lowest minimum time to task completion, indicating that agreement between more members with preferences facilitates task completion.

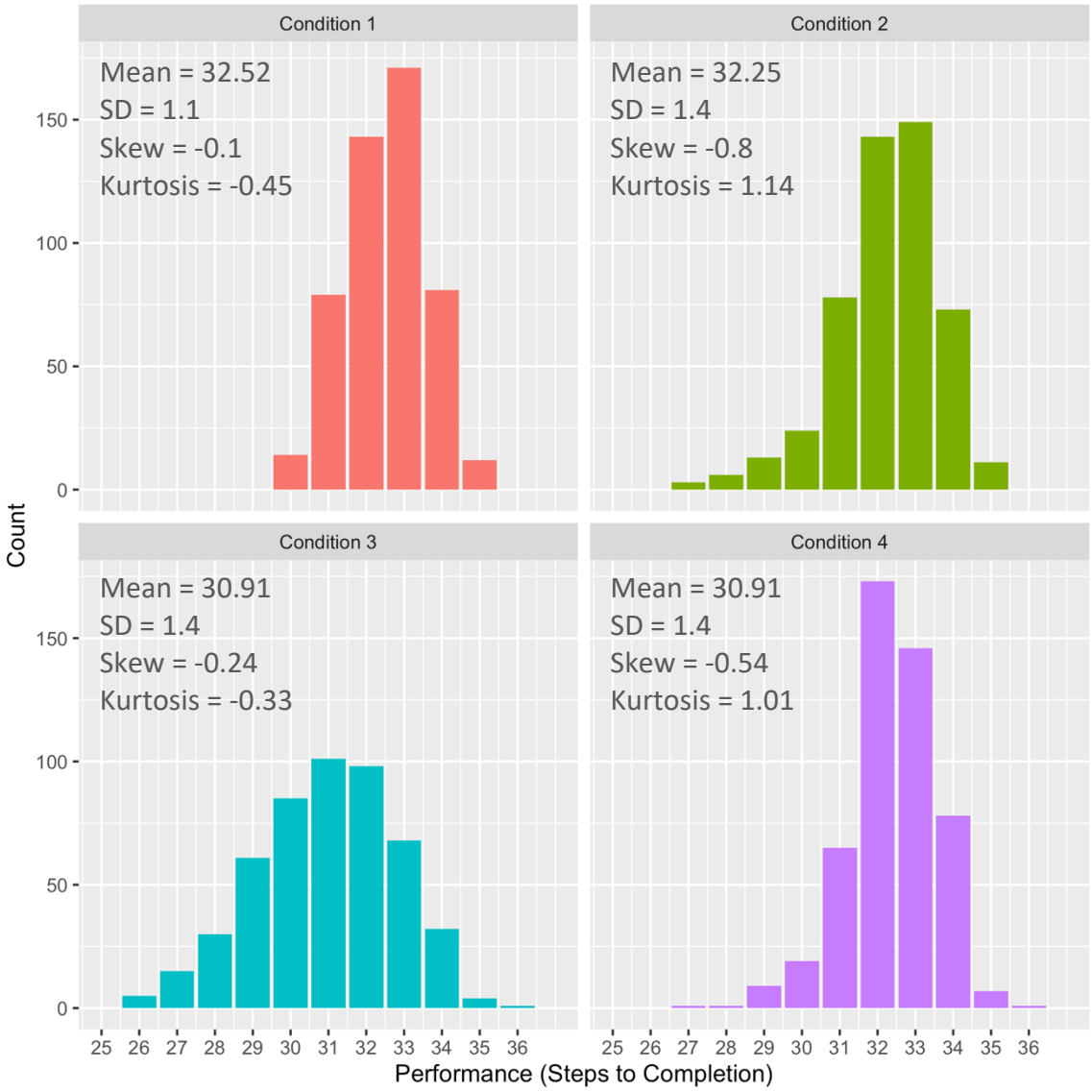

Figure 7. Time to Task Completion for Simulated Teams (Study 1). Four plots represent the distributions of performance outcomes for each condition. Values along the x-axis represent the speed of task completion whereby lower numbers indicate quicker task completion (higher performance). The y-axis indicates how many teams completed their task by each timestep. Each panel also presents the mean, standard deviation, skew, and kurtosis for each condition.

The marginal effects of the two variables manipulated in the simulation (agreement/compatibility and number of goal preferences) on time to task completion were also explored. Figure 8 shows the team performance outcomes broken apart by whether members TTR's exhibited agreement on goal preferences. Overall, the performance distribution for teams with members holding compatible TTRs was slightly

flatter and less negatively skewed towards a lower minimum (faster task completion). It can thus be concluded that team members with compatible TTRs are more likely perform better, although which teams finish quickly is hard to determine from condition membership alone – completion speed varies considerably.

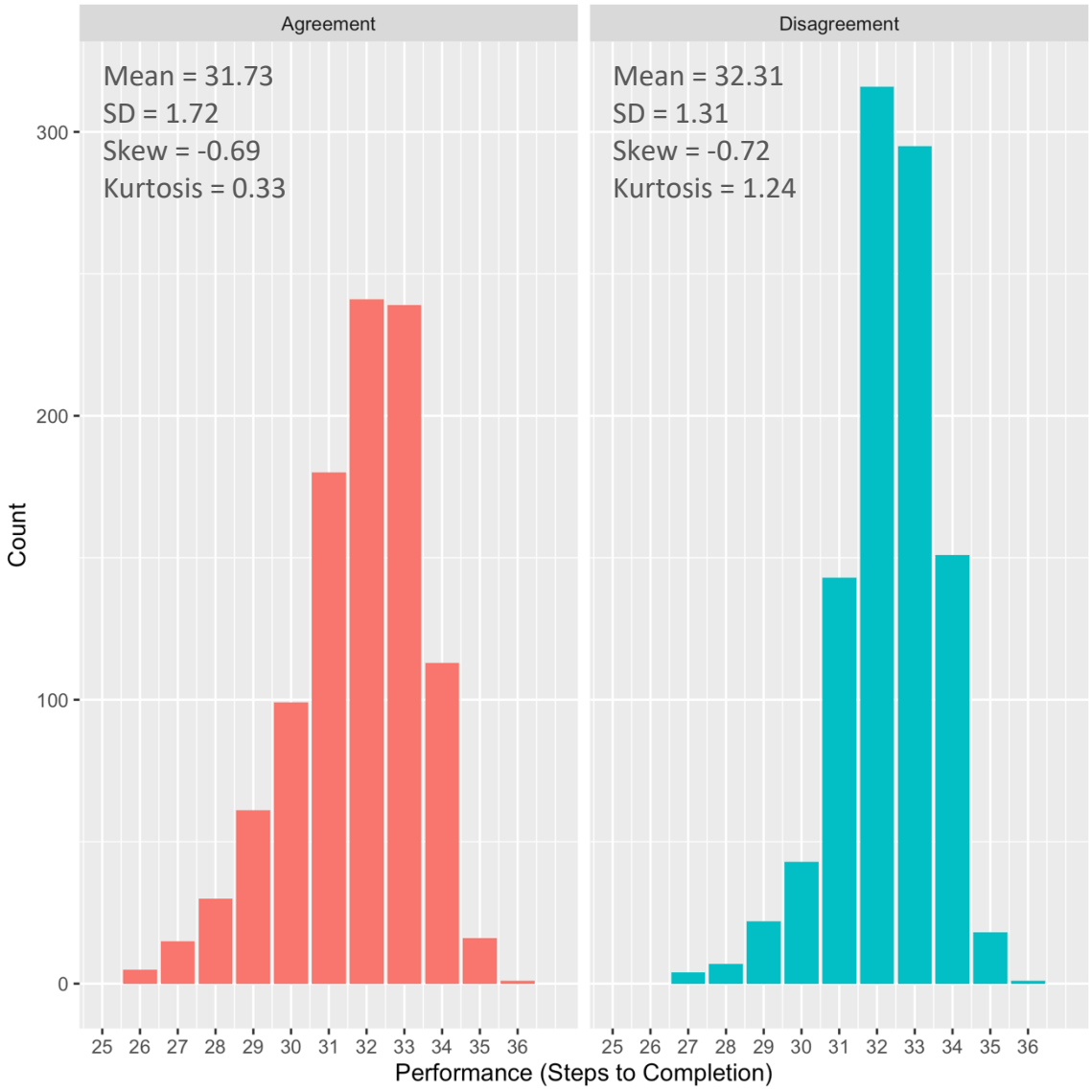

Figure 8. Time to Task Completion for Simulated Teams with Compatible (Agreement) Versus Incompatible (Disagreement) TTRs (Study 1). Values along the x-axis represent the speed of task completion whereby lower numbers indicate quicker task completion (higher performance). The y-axis indicates how many teams completed their task by each timestep.

The task completion distributions based on number of members with goals preferences in each simulated team are similarly depicted in Figure 9. As the number of members with preferences on a team increase, the distribution of time to task completion tends to become flatter and wider indicating more variance in task completion. This trend is best explained by the amount of variance in the distributions of members' goal values input into the model for each condition. Quintessentially, both goal values for both members were the same for each team in Condition 1 which consequently exhibits the least variance in task completion. The differences in distributions between number of members with preferences per team is thus more likely a consequence of initial conditions rather than the present model's mechanisms.

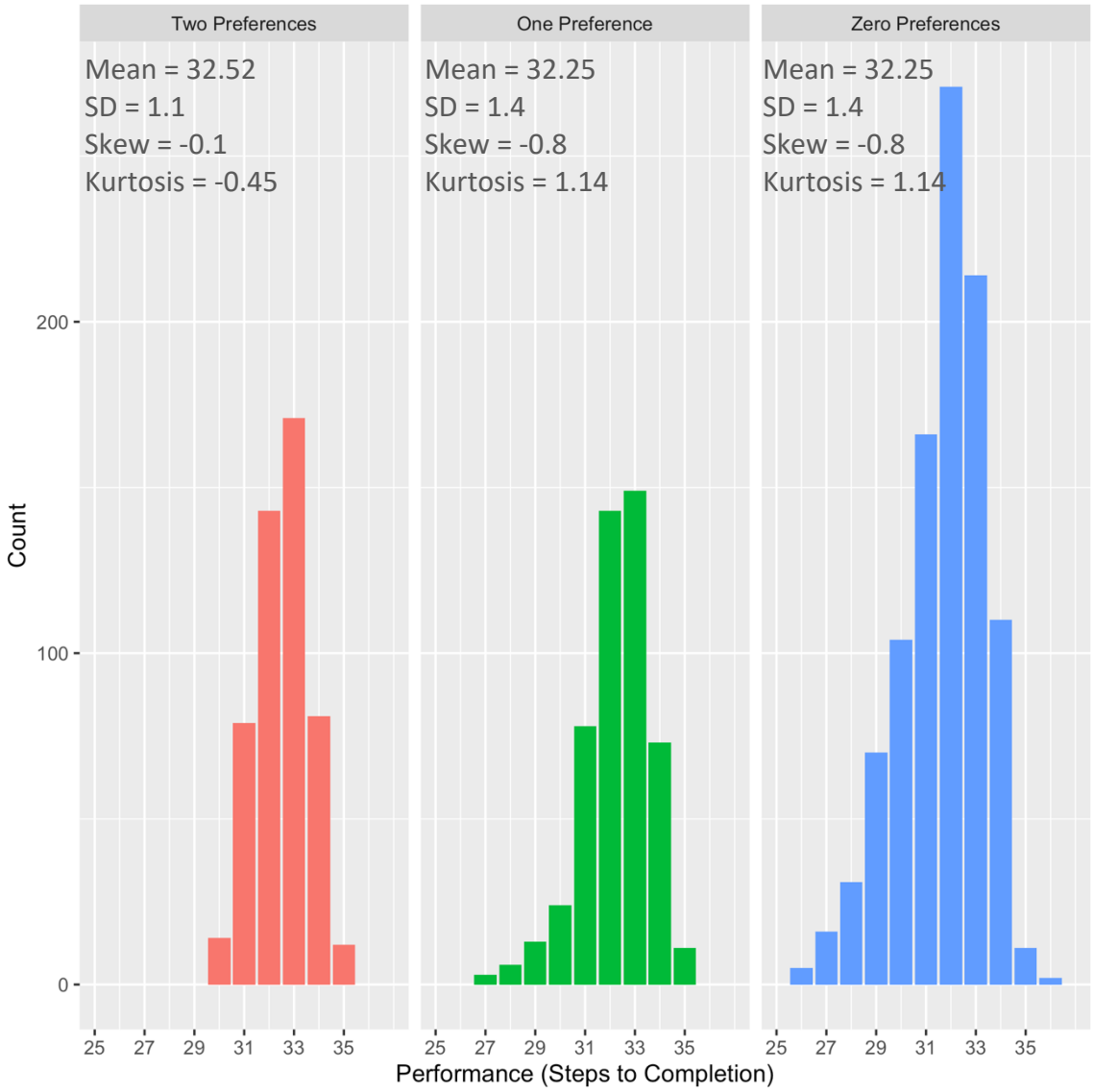

Figure 9. Time to Task Completion for Simulated Teams Based on Number of Members with Goal Preferences (Study 1). Values along the x-axis represent the speed of task completion whereby lower numbers indicate quicker task completion (higher performance). The y-axis indicates how many teams completed their task by each timestep.

Figure 10 depicts the same progress trajectories as did Figure 6 but grouped by the number of steps taken to complete the task (e.g., the first panel, labeled "Done at Step 25," presents the goal progress trajectories for all teams that completed the task in 24 timesteps) and condition (i.e., line color). Figure 10 links compatibility *through* teams' patterns of goal pursuit to performance outcomes. Teams which prioritize progress on

one goal over the other, characteristic of teams whose members hold compatible TTRs and preferences, tended to complete the task more quickly. Figure 10 thus demonstrates that particular goal distributions characterized by compatibility and preference rouse relatively consistent patterns of goal pursuit, but those patterns of pursuit are much more loosely related to task completion. Most critically, this pattern also appears related to the speed with which teams complete their task which indicates agreement (and preferences) affect team performance outcomes through action choices. In this model, agreement as a structural feature of interdependent TTRs does not determine, but rather increases the probability of viable combinations of behavioral outcomes.

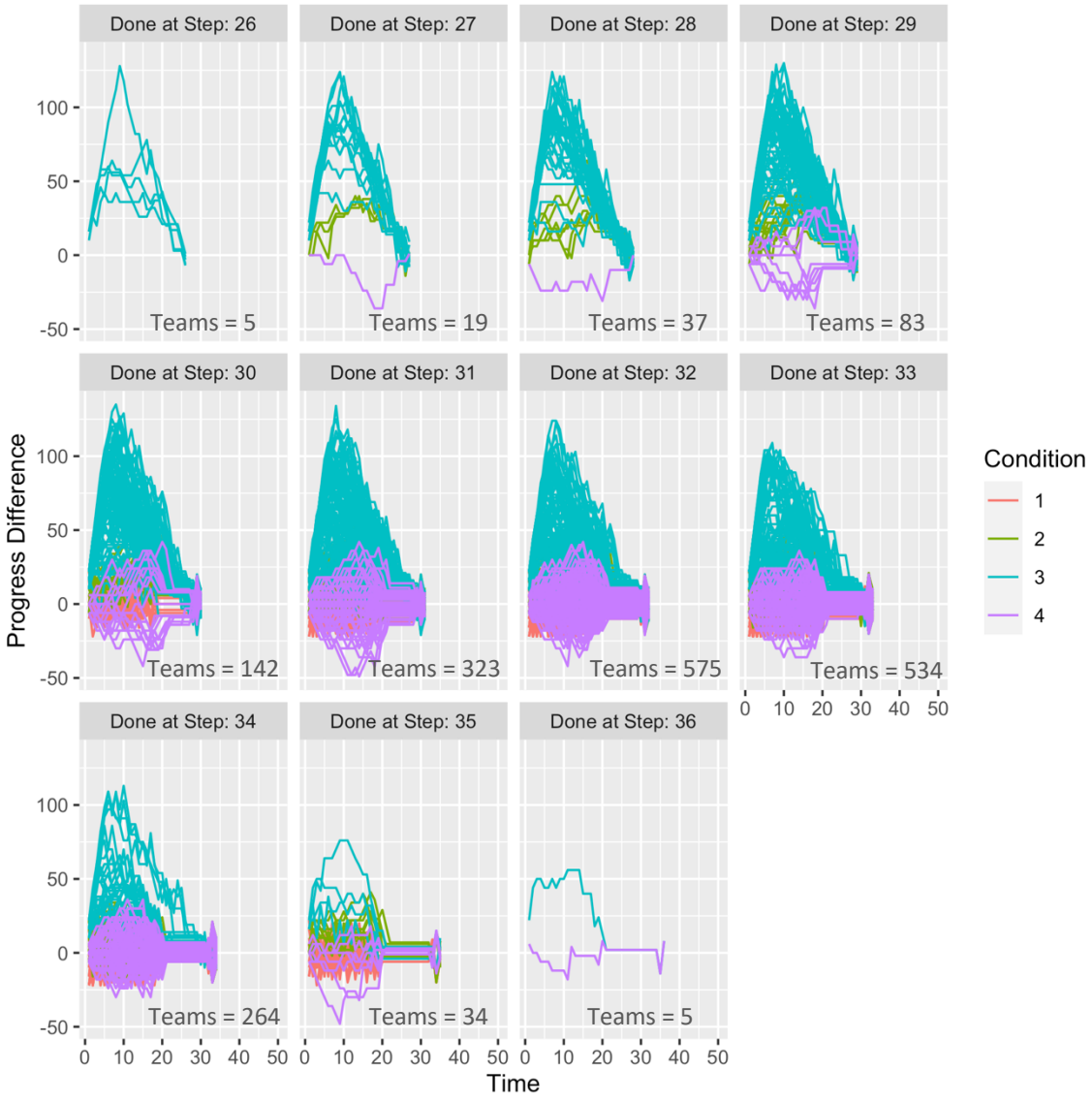

Figure 10. Change in Relative Difference in Progress over Time by Time-to-Task Completion (Study 1). Values along the y-axis represent the number of units made towards G1 minus the number of units made towards G2. Positive values therefore represent more progress having been made on G_1 and negative values represent more progress having been made on G_2. Each plot represents the trajectory of progress differences for teams that completed the task at each timestep. Trajectories' color denotes the condition to which they belonged. The total number of teams to finish at each timestep is denoted by 'n' in each plot.

Study 1 Discussion

Study 1 explored how individual team members behaved when their TTRs were compatible versus incompatible with those of their teammates. Measures of valence and expected utility (*EU*) confirm simulations unfolded according to the mechanisms and

parameters specified in the computational model. Agent-members' interdependence was visible even without agents explicitly using any information about their teammate in their own action choices. The distribution of goal values *within* individual members' TTRs guided their action choices consistently and predictably whereby members performed actions progressing goals they perceived as more important. However, distributions of goal priorities *across* members of a team also demonstrably impacted their performance behaviors. Members with identical TTRs could engage in different patterns of action depending on their *teammate's* TTR (and members with different TTRs could perform the same patterns of action) discrepancy reduced by a member's teammate impacted the current state used to calculate valence and *EU*.

The effect of compatibility as a configural feature of goal value distributions, characterized by similar relative rank-ordering of goals, can be traced through distinctive patterns of action choice and goal pursuit strategies to properties of performance outcome distributions. Team members with compatible TTRs (who preferred the same goal) performed actions to advance progress toward the same goal until one or both members needed to switch attention to the alternative goal (as task completion depended on satisfying both goals) which prevented specialization. Team members with incompatible TTRs (who preferred different goals), by contrast, were (or quickly) specialized – directing effort mostly towards the teammate's disfavored goal. As a result, team members who agreed on goal priorities (compatibility) tended to work towards the same goal at the same time, whereas team members in disagreement more often simultaneously worked towards different goals. While there were few differences in performance outcome distributions, teams with compatible TTRs whose members preferred one goal

to its alternative (Condition 3) performed slightly better on average than other conditions, but outcomes did vary more than any other condition. In this way, emergent patterns of cognition described at the team level in terms of compatibility led agents to choose actions which accumulated into a pattern of interdependent goal pursuit with the best average outcomes.

Beyond compatibility, however, the presence and strength of preferences impacted performance processes and outcomes. Strength of preference dictated how tolerant members were to differences between goals' progress (i.e., how much progress can be made on one goal before a member feels the need to switch attention and effort to the alternative goal). The absence of preference thus restricted variance of initial circumstances within condition besides reducing tolerance of differential goal progress to near zero. Strength of preference should be emphasized in future work. As the present studies were conducted to assess differences in rank order of goal importance, no member in the following study will represent both goals as equally important.

Study 1 demonstrated that compatibility of individual team members' goal preferences leads to modest differences in performance outcomes through different patterns of interdependent goal pursuit without members ever explicitly coordinating with their teammate. Consequences of one's teammate's actions notably impacted individual members' own action choices in addition to one's own beliefs as represented by their TTR. Research on shared mental models has popularized the notion that shared cognition impacts team performance through setting mutual expectations which allow team members to intentionally plan their actions to help or avoid hindering teammates (Mohammed et al., 2010; Rouse et al., 1992). Study 2 probes the role of planful

coordination in translating compatible mental models into beneficial performance outcomes beyond the emergent synchrony observed in Study 1 by expressly incorporating in the present model a set of functions allowing members to predict which their teammate's action in the following timestep and adjust their own choice of action accordingly.

Study 2

Study 2 builds upon Study 1 by allowing agent-members to hold beliefs about their teammate's values and allowing the accuracy or 'correctness' of those beliefs to vary. This is accomplished in the present study by allowing each member to hold a TTR representing their own beliefs as well as a TTR representing their teammate's beliefs. In this way, Study 2 provides insight in to (a) how members perceived the task environment (i.e., the goal system and associated beliefs/perceptions reflecting the structural relations among members, actions, and goals) *and* (b) how they believed their teammate perceived the task environment (i.e., the goal system and associated beliefs/perceptions the teammate was believed to be following). As Figure 11 illustrates, M_1's TTR for itself in Study 2 included M_1's beliefs about the perceived importance M_1 placed on G_1 and G_2; additionally, M_1 in Study 2 also held a TTR for beliefs about the perceived importance they thought their teammate, M_2, placed on G_1 and G_2. Consequently, the TTRs modeled in Study 2 created the potential for agents within a team to "anticipate" the actions of one another and thus potentially adapt their choices regarding which performance-relevant behavior to pursue. Moreover, whether one, both, or neither member held *correct* representations of their teammate's beliefs therefor leading to more or less accurate

expectations was manipulated to allow such expectations to be more or less accurate.

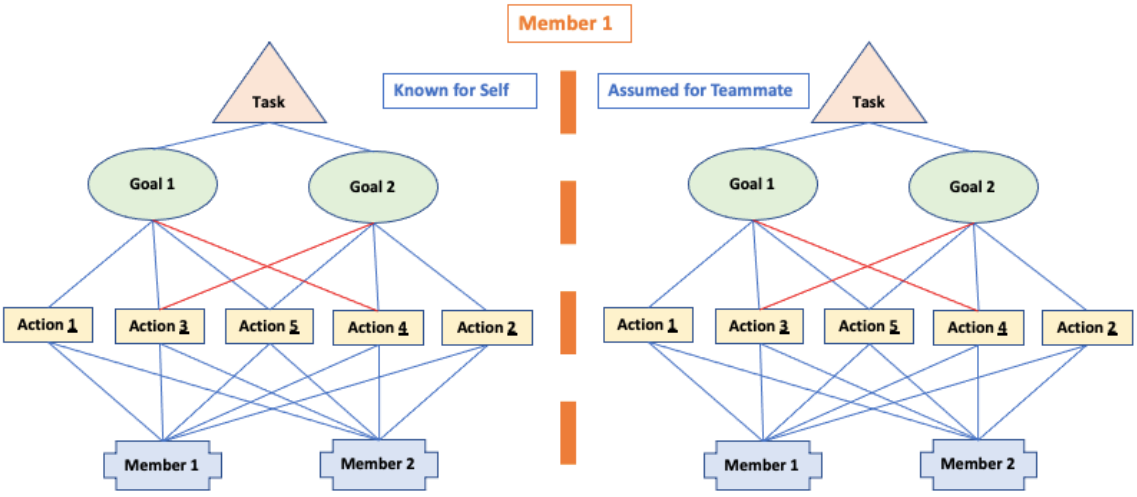

Figure 11. TTR for a simulated agent in Study 2. The TTR in the left-hand pane portrays. Member 1's own values and the right-hand pane portrays the TTR which Member 1 assumes correctly represents Member 2's values. The team task depicted in this figure is identical to that in Figure 2. Blue lines represent positive relationships (i.e., actions that reduce discrepancy in their target action) while red lines represent negative relationships. See Table 3 for action-to-goal, "instrumentality," connection values. Goal-to-task, "importance," connection value is manipulated in Study 2 as described by Table 6.

As in the prior simulation, Study 2 did not model or permit agents to directly coordinate; agents again made action selections independently of and in parallel with one another. However, in contrast with Study 1, agent members did incorporate their assumptions about their teammate's beliefs into their action choices. Thus, the primary purpose of the simulation conducted for Study 2 was to examine how incorporating expectations of others' action choices in an agent's TTR may impact individual and team action choices as well as emergent patterns of team performance. The research question driving Study 2 is thus:

> *RQ2: How does the accuracy of beliefs about teammate's goal preferences in members' TTRs affect individual action choice and team performance?*

Model Specifications

The computational model for Study 2 diverges from that in Study 1 in only one notable way—each agent computed the valences, expectancies, and expected utilities both for itself and for its teammate during goal pursuit. The pseudocode describing this process is presented in Table 5. These calculations only become consequential when members chose which action to perform at a given timestep (e.g., Steps 5-6 in Table 5). Rather than considering only the *EU* of the action the agent would perform, members are proposed to consider the perceived collective *EU* of each possible action combinations that all members on the team could take at that time point. The perceived collective *EU* for an action combination is specifically computed as the sum of the *EU* an agent associates with the action it would take and the *EU* the agent believes its teammate would receive by taking the other action at the current time step (e.g., $EU_{collective} = EU_{action\text{-}self} + EU_{action\text{-}other}$). For example, consider the scenario in which member M_1 is evaluating whether to perform action A_1. To make this determination, M_1 is proposed to consider all the possible combinations of actions that its team could take during that time step if it were to choose action A_1 (e.g., M_1 performs A_1 and M_2 performs A_1; M_1 performs A_1 and M_2 performs A_2; M_1 performs A_1 and M_2 performs A_3; etc.). The perceived collective *EU* for the action combination in which, say, M_1 performs A_1 and M_2 performs A_3 would thus be computed as the *EU* the agent personally associates with action A_1 plus the *EU* it believes its teammate associates with action A_3. For purposes of the present model, each agent is proposed to perform this calculation for all possible action combinations, identify the action combination with the highest perceived collective *EU*, and perform the action associated with that combination. In this way, an agent's beliefs about its teammates goal

priorities has the potential to affect which action the agent chooses to do at each time step.

Of note, the decision rule represented in the present model means that an agent has the potential to perform an action that may not have the highest "personal" *EU*, but nevertheless maximizes the perceived collective *EU* of the team. Furthermore, although each agent's action choice is based partly on what it expects/anticipates the other agent will do, these expectations may be violated—an occurrence which is most likely to happen when the agent holds inaccurate perceptions of its teammate's goal preferences in its TTR. To maintain parsimony in the present model however, agents do not adjust/adapt their perceptions of other agents' TTRs based on whether their teammate engaged in the action that was anticipated.

Table 5
Pseudocode for the interdependent goal pursuit model

Step	**Action**
1	Initialize time clock $t = 0$.
Means Choice	
2	***Each member*** calculates each goal's *valence* as a function of the number of units left to attain of the goal (i.e., *discrepancy between a goal's current state and reference*) and *value to the task for the member's self* (2.1) and *for the member's teammate* (2.2).
3	***Each member*** calculates each action's *expectancy* from time remaining before the deadline, time-to-completion for each action-goal connection (i.e., *instrumentality*), and *time sensitivity* (i.e., the individual's sensitivity to deadlines) *for the member's self* (3.1) and *for the member's teammate* (3.2).
4	***Each member*** calculates each action's *expected utility* by combining its connected goals' *valences* and *expectancies* associated that action's use *for the member's self* (4.1) and *for the member's teammate* (4.2).
5	***Each member*** calculates the value of all possible *action combinations* by summing the *expected utility* calculated for the action the member itself would take and the *expected utility* calculated for the action the member's teammate would take.

6	***Each member*** chooses the *action combination* with the highest summed *expected utility*.
7	***Each member*** performs the action they chose for themselves in the *action combination* selected in Step 6
Goal Network Updates	
8	Based on the means chosen, determine the impact made on each goal's new current state as a function of the selected action's *instrumentality*.
9	Increment time clock $t = t + 1$.
10	If $t <$ *deadline* and at least one task goal's *current state* > 0, repeat Steps 2 – 7.
11	End.

Note. t = current time.

Simulation Design

Table 6 summarizes the model parameters and values used for Study 2. The primary manipulation in Study 2 concerned members' perceptions of each goal's

Table 6
Sim2 Condition Parameters

Condition	M1 Self	M1 Other	M2 Self	M2 Other	Agreement	Correct
1	$G_1 > G_2$	$G_1 > G_2$	$G_1 > G_2$	$G_1 > G_2$	True	2
2	$G_1 > G_2$	$G_1 < G_2$	$G_1 > G_2$	$G_1 > G_2$	True	1
3	$G_1 > G_2$	$G_1 < G_2$	$G_1 > G_2$	$G_1 < G_2$	True	0
4	$G_1 > G_2$	$G_1 < G_2$	$G_1 < G_2$	$G_1 > G_2$	False	2
5	$G_1 > G_2$	$G_1 > G_2$	$G_1 < G_2$	$G_1 > G_2$	False	1
6	$G_1 > G_2$	$G_1 > G_2$	$G_1 < G_2$	$G_1 < G_2$	False	0

Note. G_1 = Goal 1, G_2 = Goal 2. M_1 = Member 1, M_2 = Members 2. The columns labeled "Self" and "Other" indicate an agent's beliefs about which goal was more valued in the TTR it held for itself and its assumed TTR for its teammate (respectively). The column labeled "Agreement" indicates whether both agents on the team valued the same goal in their respective self-TTRs. The column labeled "Correct" indicates the number of agents on the team whose perception of its teammate's goal preferences matched its teammates actual preferences (i.e., whether the goal preferences reflected in the "Other" column for an agent matched the goal preferences in the "Self" column for the other agent). Goal importance within member for "Self" and for "Other" each summed to 100. The importance for Goal 1 was randomly set to a value between (51, 99) or (1, 49). Goal 2 was set equal to the difference between 100 and Goal 1's importance. This was done independently for each agent and independently for their own and for their teammate's values. Only priority (which goal was more important than the other) was manipulated so the actual importance of each goal over the were free to vary across their own TTR and the TTR the teammate is assumed to hold and across runs (teams) within condition. For example, in Condition 1, Member 1 and Members 2 both placed equal value on Goals 1 and 2. In Condition 2, Member 1 valued both goals equally whereas Member 2 valued goal 1 more than goal 2. The "Agreement" column indicates whether agents team agreed on which goals were perceived as most valuable. The "Correctness" column indicates the number of agents on the team whos' values assumed for the teammate match the teammate's actual values.

importance conditioned on the member striving for goal attainment. Six conditions were constructed to represent different configurations of mental representation of goal values within a team. All conditions in the present study represented members as having a singular goal preference (i.e., either $k_1 > k_2$ or $k_1 < k_2$ for each member).[7] As in the prior simulation, conditions were formulated by manipulating the compatibility of

[7] k_i was allowed to randomly vary within these constraints.

team's members' goal preferences in their TTR (i.e., extent to which members agreed about the relative importance of each goal). However, the present study also manipulated the extent to which agents exhibited both actual and perceived compatibility with their teammate's goal preferences. Within each level of perceived agreement/compatibility, one condition simulated members that were both correct about their teammate's goal priorities, one in which only one member was correct, and one in which neither were correct. The resulting six conditions were simulated 500 times for a total of 3000 simulated teams. Parameters, including the number and arrangement of concepts in the goal system, were otherwise identical to those in Study 1 and listed in Table 3.

Measures

The same primary outcome measures recorded in Study 1 were also examined for Study 2. Each of these measures, however, are presented for both members' calculations for *both* themself and their teammate. Additionally, the total number of each action type (i.e., finality) was computed for each simulated team to offer a more nuanced explanation for how agreement impacts performance.

Study 2 Results

The analysis of results from Study 2 begins with a summary of trends in agents' perception of goal valances and action utilities over time to verify the internal validity of the model (i.e., ensuring values unfolded in the general shape expected and that trends aligned across measured values). These examinations also provide opportunities to identify unique/unanticipated patterns that could provide insight into the primary performance outcomes. Following the internal validity checks, the primary performance outcomes are analyzed and interpreted across conditions to determine the impact of

whether members correctly assumed their teammate's goal values beyond the compatibility of their TTRs. Note that for all reported simulations, all Member 1 agents (M_1) and all Member 2 agents (M_2) are functionally identical *within* a given condition (i.e., all M_1s within Condition 1 are parameterized the same). Consequently, it is appropriate to draw inferences and make between-agent comparisons in the aggregate within each Condition (i.e., comparing behaviors/outcomes of M_1 vs. M_2 in each Condition).

Valences

Figures 12 and 13 present changes in valence over time for Conditions exhibiting agreement (Conditions 1, 2, and 3 corresponding to rows of plots in Figure 12) and disagreement (Conditions 4, 5, and 6 corresponding to rows of plots in Figure 13) respectively. As in Figure 3, the y-axis represents valence over time (on the x-axis). The two leftmost columns indicate valences over time according to M_1 based on its own TTR and its assumed teammate's TTR, whereas the two rightmost columns indicate valences over time according to M_2's own TTR and its assumed teammate's TTR.

Overall, trends in dynamic valences unfolded as expected and replicated observations from Study 1. Specifically, teams in the first three Conditions who held compatible TTRs began with a high valence for their preferred G_1 which dropped quickly for both members – valence for G_2 dropped more gradually. Teams in the last three Conditions who held incompatible TTRs began with a high valence for each's preferred goal and both valences declined at similarly gradual rates.

These results demonstrate that the valences an agent associated with each goal were not influenced by their beliefs about which goal their teammate valued. Indeed,

valences in Conditions 1-3 based on members' own TTRs are not only nearly identical across Conditions, but also to those in Study 1, Condition 3 (Figure 3) in which team members also held compatible TTRs with a preference for G_1, yet used no information about their teammate's expected action in selecting their own. Likewise, patterns of valence change in Conditions 4-6 closely resembled each other as well as those in Study 1, Condition 4 with (with identical parameters save the calculation to derive their

expectation for their teammate's action).

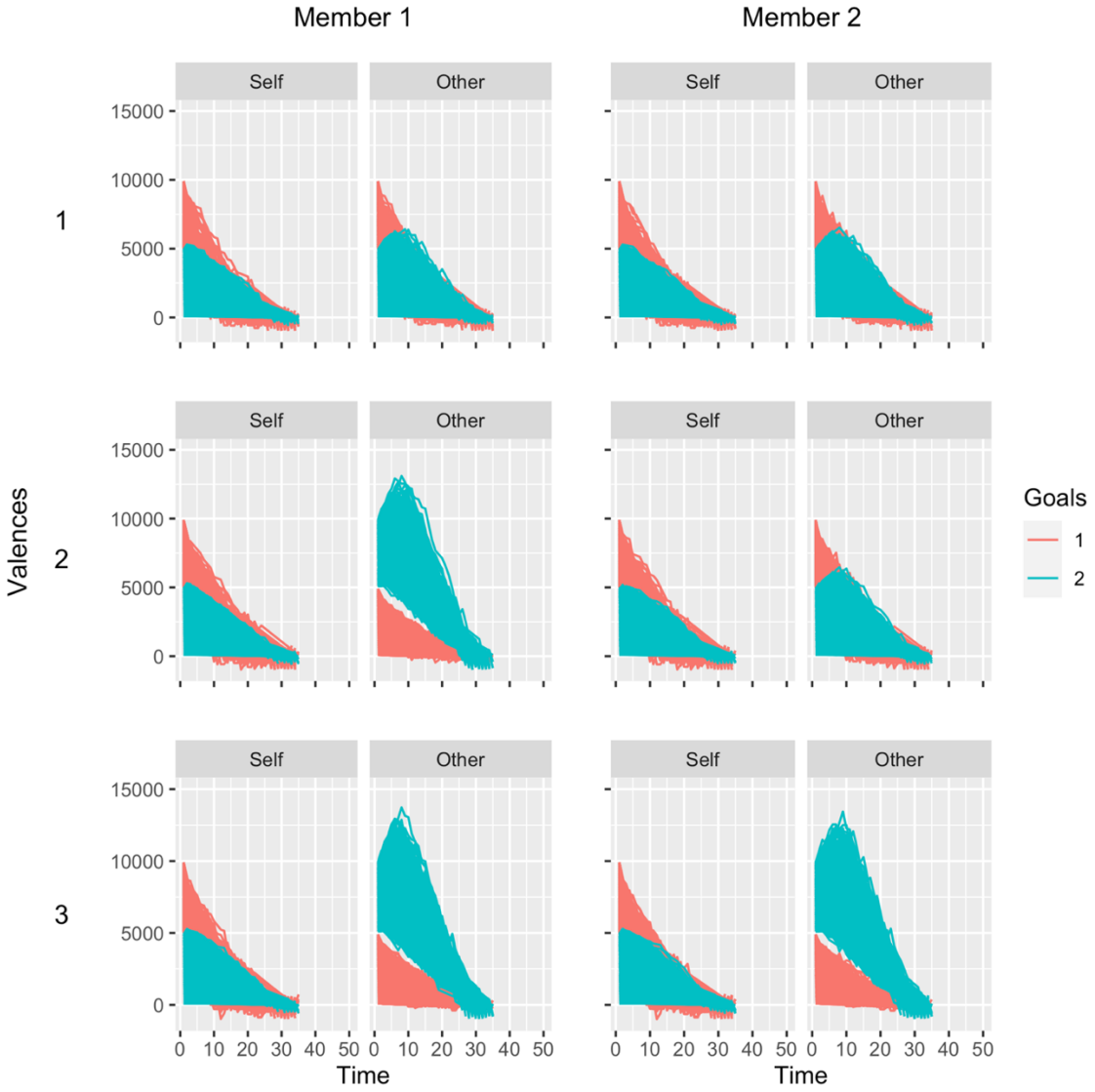

Figure 12. Change in Goal Valences for Members over Time for Conditions Exhibiting Agreement (Study 2: Conditions 1, 2, and 3). Trajectory of change in each goal's valence (y-axis) is plotted over time (x-axis). Each of these 12 plots thus depicts the trajectories of change in each goal's valence (denoted by color) for either member (denoted by columns of plots) using their own TTR or the TTR the other teammate is assumed to hold (labeled accordingly as "Self" or "Other") in all 500 teams within a Condition (denoted by rows of plots). Each member held equivalent goal priorities in all teams within Condition (identical rank-order of goals' importance).

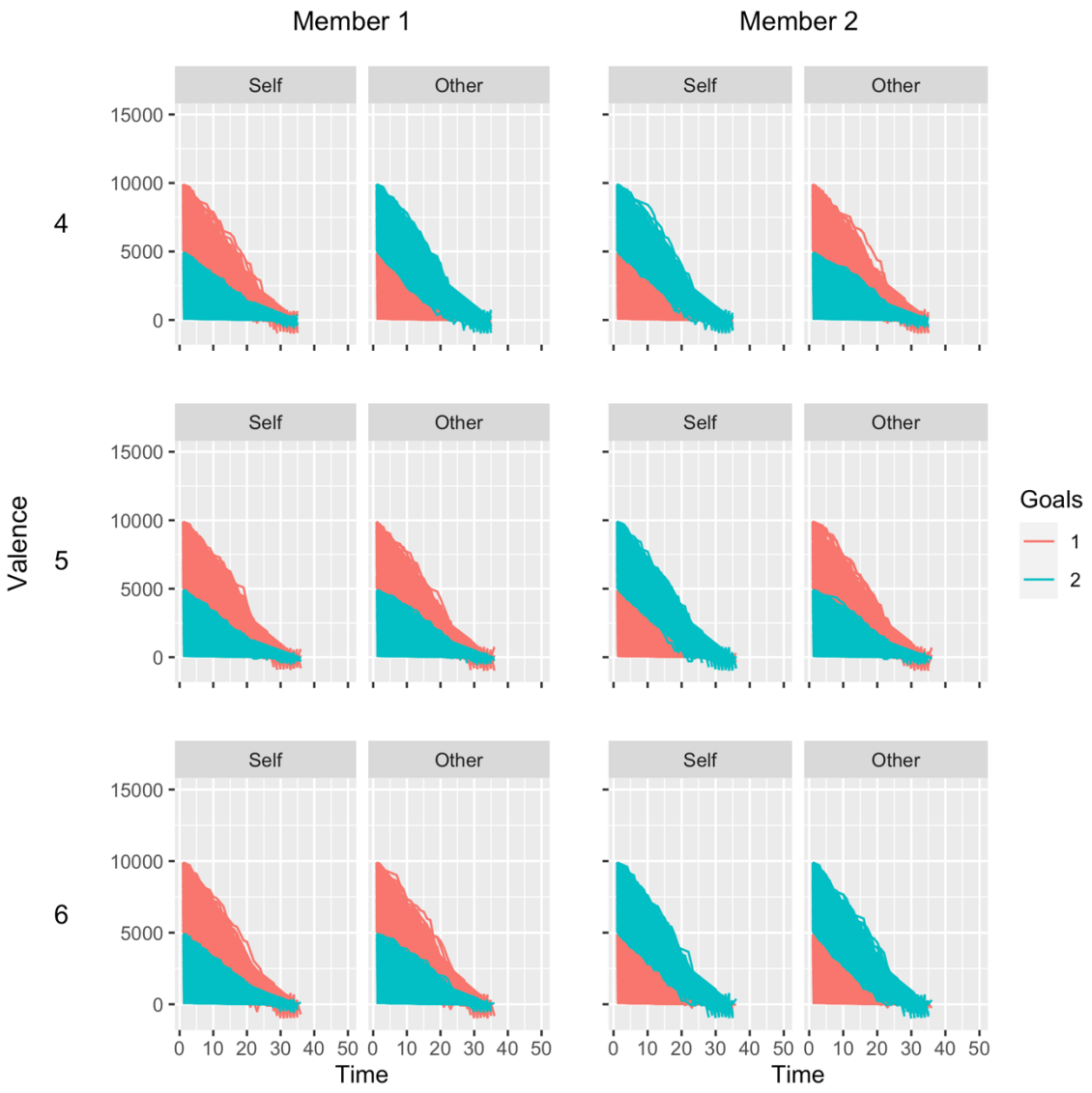

Figure 13. Change in Goal Valences for Members over Time for Conditions Exhibiting Disagreement (Study 2: Conditions 4, 5, and 6). Trajectory of change in each goal's valence (y-axis) is plotted over time (x-axis). Each of these 12 plots thus depicts the trajectories of change in each goal's valence (denoted by color) for either member (denoted by columns of plots) using their own TTR or the TTR the other teammate is assumed to hold (labeled accordingly as "Self" or "Other") in all 500 teams within a Condition (denoted by rows of plots). Each member held equivalent goal priorities in all teams within Condition (identical rank-order of goals' importance).

Expected Utility of Actions

Figures 14 and 15 depict change in expected utility over time for Conditions exhibiting compatible (Conditions 1, 2, and 3 corresponding to rows of plots in Figure 12) and incompatible (Conditions 4, 5, and 6 corresponding to rows of plots in Figure 13)

TTRs. As in Figure 4, the y-axis represents expected utility over time (on the x-axis). The two leftmost columns indicate expected utility over time according to M_1 using its own and its assumed teammate's TTR. The two rightmost columns indicate expected utility over time according to M_2 using its own and its assumed teammate's TTR.

As in Study 1, actions that *reduce* discrepancy for the same goal behave identically (i.e., uni- and counterfinal actions to the same focal goal), making them indistinguishable in these plots. Also replicated from Study 1 is the correspondence of those utilities' trajectories to those of valences for the benefited goal. Results from Study 1 were further replicated whereby EU_5 could begin to increase earlier albeit with more variability for members in teams with compatible TTRs than it for members in teams with incompatible TTRs. The similarity of these patterns across Conditions 1-3 in Study 2 in which teams exhibited agreement and Study 1, Condition 3 (and likewise for Conditions 4-6 in which teams exhibited *disagreement* and Study 1, Condition 4) reveals that members' beliefs about their partners actions, let alone the correctness of those beliefs, had no effect on the expected utility members ascribed actions even when explicitly used in the calculus of action choice.

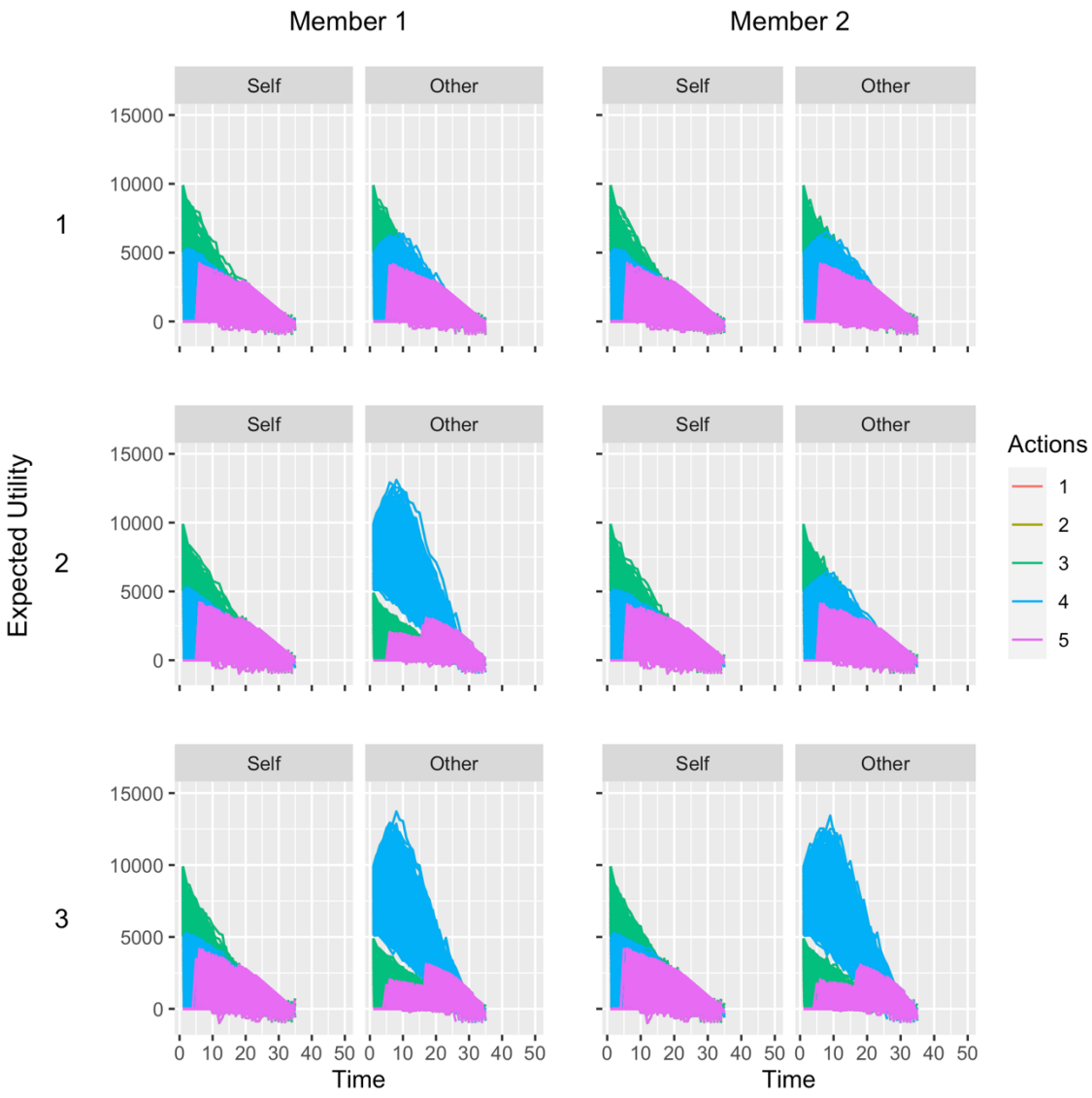

Figure 14. Change in Expected Utilities for Members over Time for Conditions Exhibiting Disagreement (Study 2: Conditions 1, 2, and 3. Trajectory of change in each action's EU (y-axis) is plotted over time (x-axis). Each of these 12 plots thus depicts the trajectories of change in each action's EU (denoted by color) for either member (denoted by columns of plots) using their own TTR or the TTR the other teammate is assumed to hold (labeled accordingly as "Self" or "Other") in all 500 teams within a Condition (denoted by rows of plots). Each member held equivalent goal priorities in all teams within Condition (identical rank-order of goals' importance).

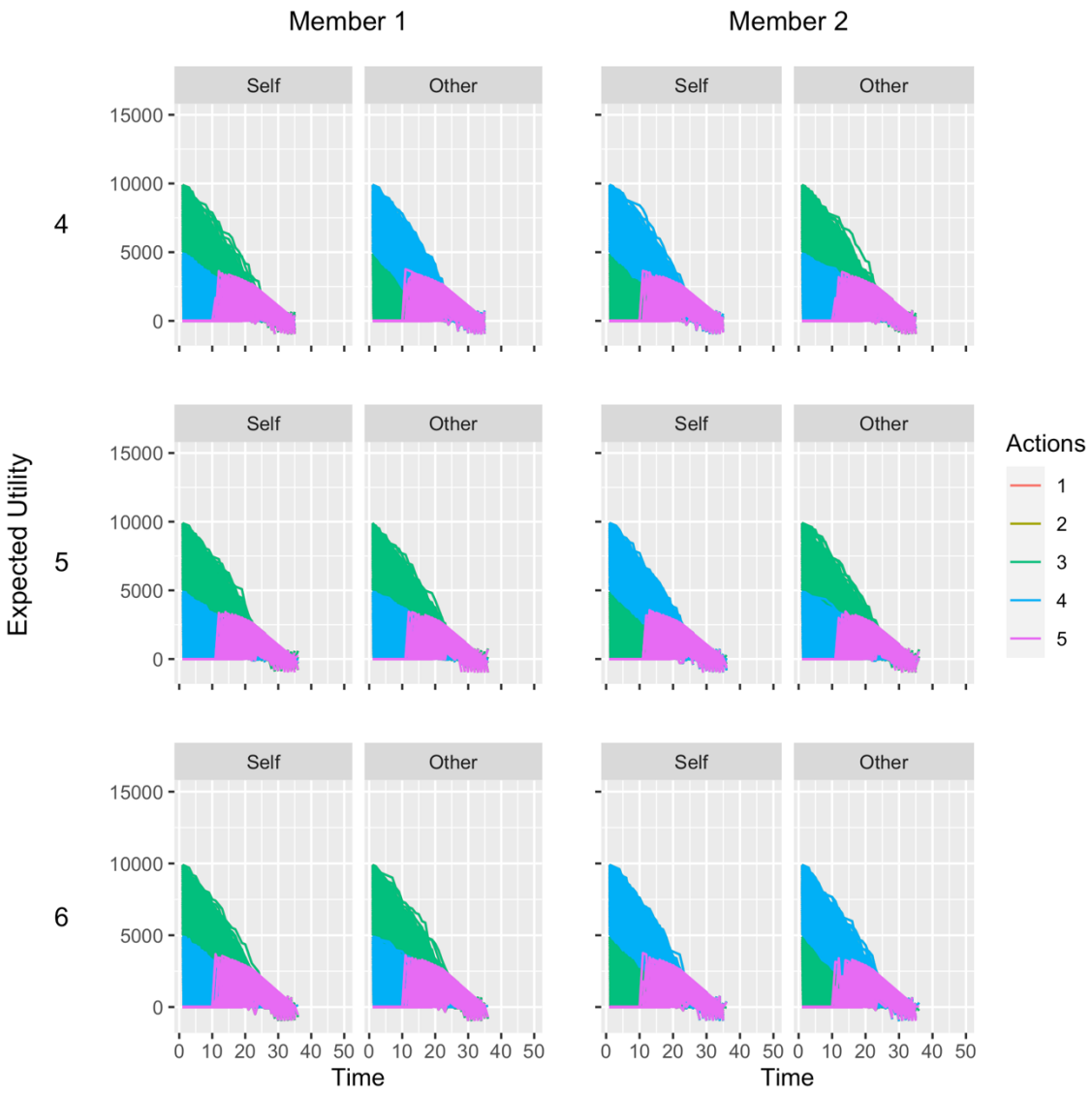

Figure 15. Change in Expected Utilities for Members over Time for Conditions Exhibiting Disagreement (Study 2: Conditions 4, 5, and 6). Trajectory of change in each action's EU (y-axis) is plotted over time (x-axis). Each of these 12 plots thus depicts the trajectories of change in each action's EU (denoted by color) for either member (denoted by columns of plots) using their own TTR or the TTR the other teammate is assumed to hold (labeled accordingly as "Self" or "Other") in all 500 teams within a Condition (denoted by rows of plots). Each member held equivalent goal priorities in all teams within Condition (identical rank-order of goals' importance).

Action Choice

Figures 16 and 17 present the proportion of teams (y-axis) in which members, M_1 and M_2 (respectively by column of plots), selected each action (color) at each timestep (x-axis) within Condition (by row of plots). As observed in Study 1, team

members with compatible TTRs begin by only favoring actions that advance their mutually preferred goal, but slowly become more likely to choose actions advancing the alternative goal (G_2). A small proportion of members from teams with compatible TTRs (and preferences) in both studies also chose the multifinal action relatively early in the simulation. Similarly, the patterns of action choice for members with incompatible TTRs from both simulations are characterized by initially choosing actions that advanced each's own most preferred goal before switching to the multifinal action. These two trends regarding compatibility and action choice patterns persisted whether members tried to predict their teammate's next action (across studies) and whether either or both members correctly assumed their teammate's TTR values. It is unlikely, therefore, that team members' decisions are directly affected by considerations of their teammate's values.

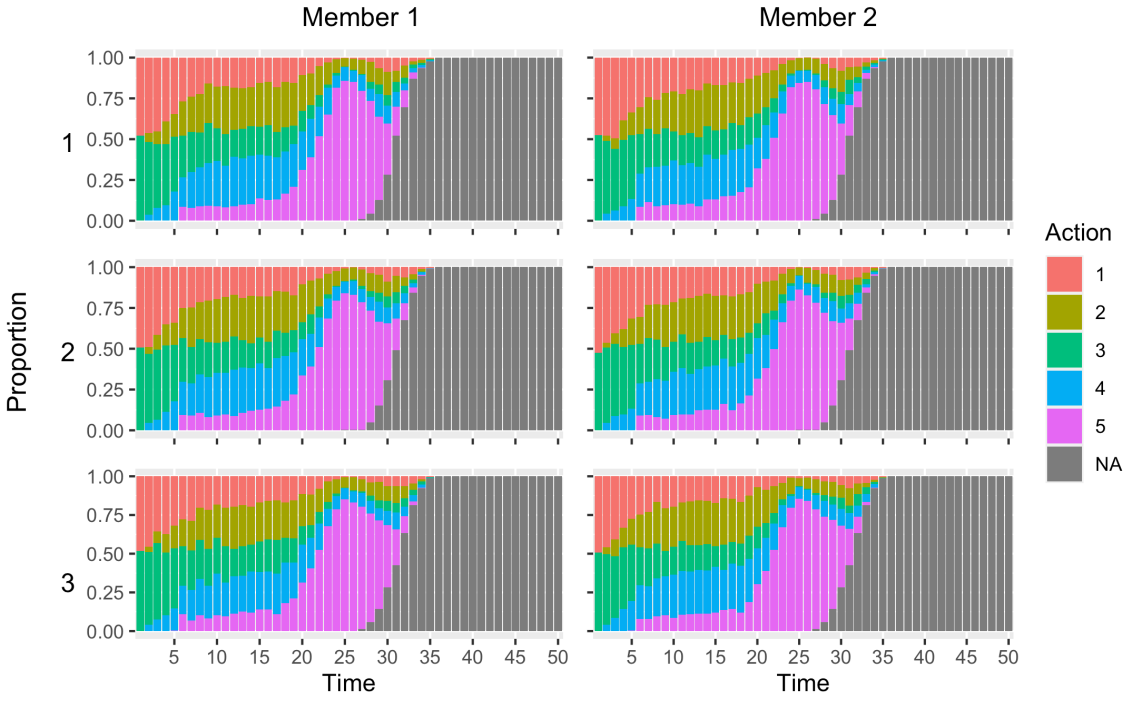

Figure 16. Members' Action Choices over Time for Conditions Exhibiting Agreement (Study 2: Conditions 1, 2, and 3). Proportion of teams (y-axis) in which a team member chose each action (denoted by color) is plotted over time (x-axis). Proportions of actions chosen across time is grouped by member

(denoted by column of plots) within each condition (denoted by rows of plots). For example, Member 1 performed Actions 1 and in roughly equal proportions (~25%) of teams in Condition 1 at timestep 1. Each member held equivalent goal priorities in all teams within condition (identical rank-order of goals' importance).

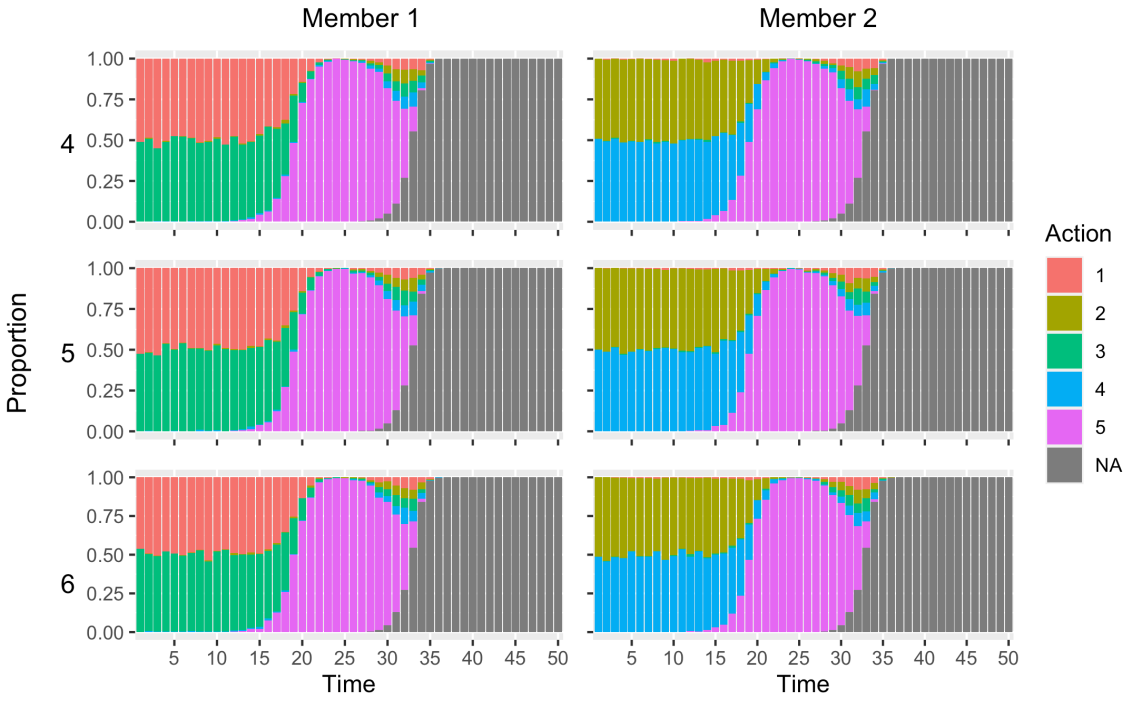

Figure 17. Members' Action Choices over Time for Conditions Exhibiting Disagreement (Study 2: Conditions 4, 5, and 6). Proportion of teams (y-axis) in which a team member chose each action (denoted by color) is plotted over time (x-axis). Proportions of actions chosen across time is grouped by member (denoted by column of plots) within each condition (denoted by rows of plots). For example, Member 1 performed Action 1 and 3 in roughly equal proportions (~50%) of teams in Condition 1 at timesteps (1, 13). Each member held equivalent goal priorities in all teams within condition (identical rank-order of goals' importance).

Goal Progress

Figure 18 depicts the difference in goal progress over time (current state of G_2 *subtracted from* the current state of G_1 at each timestep) by condition. Figure 19 depicts the difference in goal progress over time grouped according to teams' overall rate of completion. Each plot in Figure 19 corresponds to the timestep at which performance was completed and colors demark trajectories of teams within each condition. For example, the chartreuse line in the top-leftmost plot depicts the difference in goal progress over time for a team from Condition 1 which accomplished the task in 24 timesteps (the

quickest/best performance achieved by any team in the current simulations). Performance descends across plots from left to right, ending at the bottom-rightmost plot (slowest/worst performance).

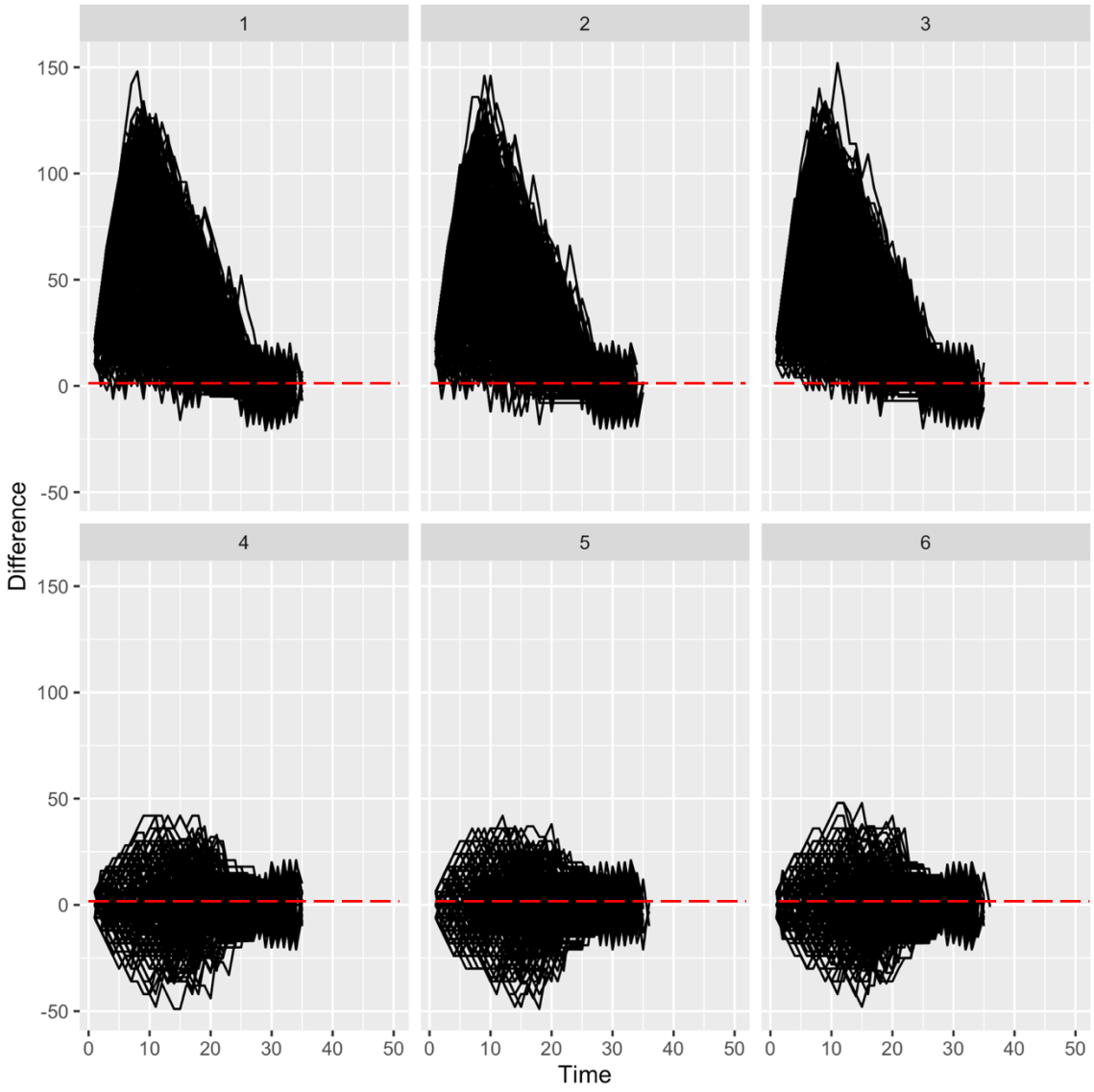

Figure 18. Change in Relative Goal Progress over Time for Simulated Teams (Study 2). Values along the y-axis represent the number of units made towards G_1 minus the number of units made towards G_2. Positive values therefore represent more cumulative progress having been made on G_1 and negative values represent more progress having been made on G_2. Each plot depicts the trajectory of change in relative progress differences over time (x-axis) resulting from both members' actions' instrumentality in every timestep.

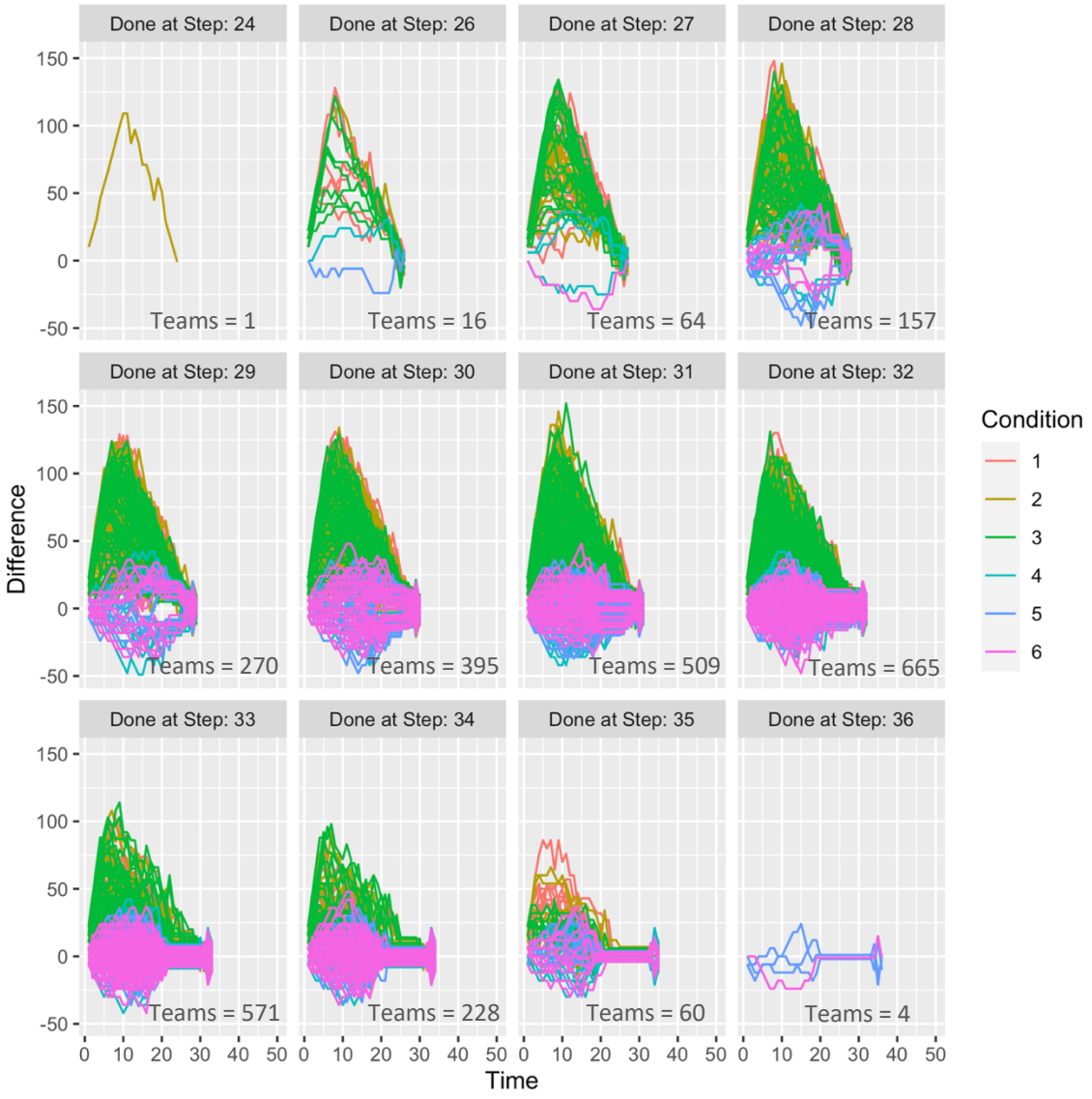

Figure 19. Change in relative goal progress over time for simulated teams based on overall time to task completion (Study 2). Values along the y-axis represent the number of units made towards G_1 minus the number of units made towards G_2. Positive values therefore represent more progress having been made on G_1 and negative values represent more progress having been made on G_2. Each plot represents the trajectory of progress differences for teams that completed the task at each timestep. Trajectories' color denotes the condition to which they belonged. The total number of teams to finish at each timestep is denoted by 'n' in each plot.

Study 2 replicated the same overall pattern of findings in both figures (compared to Figures 6 and 10 respectively) from Study 1 with respect to how compatibility of members' TTR impacted team goal progress. Teams that tended to prioritize completing one task goal over another (resulting in a more "peaked" progress-difference trajectory

with larger deviations from ‘0’) tended to complete the task more quickly than those which advanced both goals at the same rate (resulting in a “shallower” progress-difference trajectory with smaller deviations from ‘0’). Moreover, teams that tended to exhibit a more peaked progress-difference trajectory were those whose members possessed compatible TTRs (i.e., agreement over goal priorities, Conditions 1-3 in Study 2); in contrast, teams that tended to exhibit a shallower progress-difference trajectory were those whose members possessed incompatible TTRs (i.e., disagreement over goal priorities, Conditions 4-6 in Study 2).

Additionally, teams with more peaked trajectories in Figure 19 exhibited comparatively fewer timesteps during which the progress-difference between goals did not change (i.e., remained flat over time). Flat progress-difference trajectories indicate time periods in which both goals in the task environment were being advanced by the same amount; in the present simulation, this is most likely the result of both members choosing the multifinal action. However, because the multifinal action had the lowest overall net instrumentality towards task completion (i.e., made the least amount of goal progress towards completing both task goals), both members choosing this action more frequently was comparatively inefficient and had the potential to result in a slower overall rate of task completion. In the extreme, this trend is exemplified by comparing the trajectory of the team from Condition 1 which finished the task in 24 timesteps (top-leftmost panel of Figure 19) with that of the team from Condition 5 which finished the task in 36 timesteps (bottom-leftmost panel of Figure 19). The goal progress trajectory of the former team is more peaked and remains flat for only a short period of time near the beginning of the task whereas the latter team’s trajectory remained relatively flat for the

duration of task performance. As in Study 1, these patterns indicate that compatibility via agreement on goal preferences leads members to work in lockstep, attending to the same goals at the same time, whereas teams composed of members with incompatible TTRs divide goal pursuit between them resulting in consistent progress on and attention to both goals simultaneously.

There are no discernable differences in trends of goal progress trajectories between Conditions 1, 2, and 3 which all contained teams with compatible TTRs yet differed according to the number of members correct about their teammate's beliefs. A steep increase to a large discrepancy difference before a more gradated decline characterized trajectories for teams' progress in all three mentioned conditions and also closely resembles those in Study 1, Condition 3 (Figure 6 and Figure 10) who were identically parameterized without holding any beliefs about their teammate's goal values. A smaller amplitude, more gradual incline and decline, and often reflection around the y-axis characterized progress-difference trajectories for teams in Conditions 4, 5, 6 and Study 1, Condition 4. These observations support concluding that using predictions of teammates' actions in the selection of one's own action did not notably impact either members' action choices relative to choices made without that information, correct or otherwise.

Task Completion

Figure 20 plots the number of teams (y-axis) which completed the task at each timestep (x-axis) in each condition (each plot) whereby lower values on the x-axis indicate faster completion (higher performance). Accompanying descriptive statistics are displayed in each panel. As in Study 1, teams whose members possessed compatible

TTRs (Conditions 1-3) tended to complete their task goals slightly more quickly on average than teams whose members possessed incompatible TTRs (Conditions 4-6); again, however, teams with compatible TTRs also tended to display greater variance in task completion rates than those with incompatible TTRs. This pattern is more explicit in Figure 20 which depicts the same performance outcomes, but grouped by compatibility (agreement versus disagreement). The roughly equivalent distributions in Figure 21 across the number of members on a team who were correct about their partners values facilitating correct predictions did not impact performance.

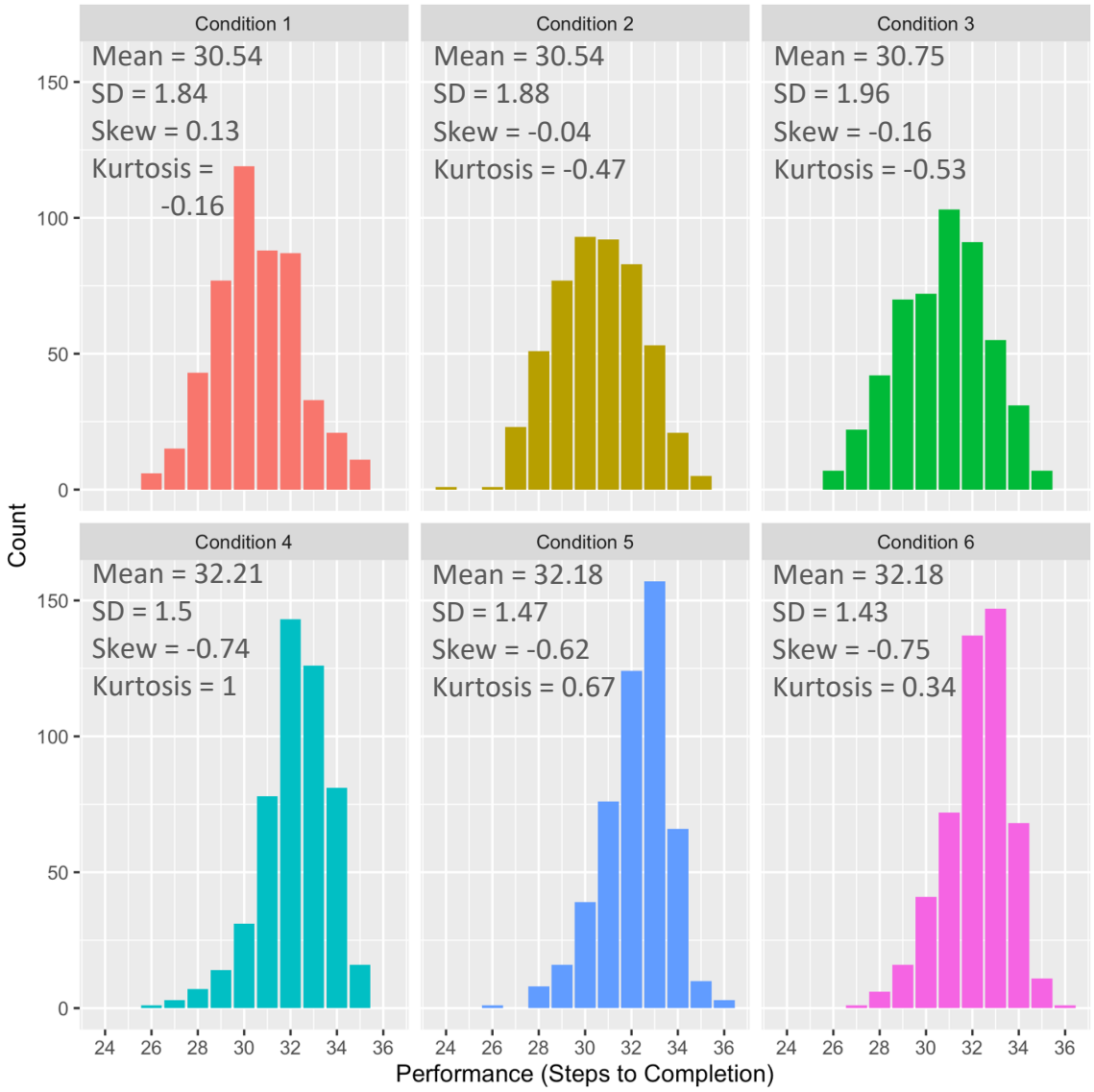

Figure 20. Time to Task Completion for Simulated Teams (Study 2). Six plots represent the distributions of performance outcomes for each condition. Values along the x-axis represent the speed of task completion whereby lower numbers indicate quicker task completion (higher performance). The y-axis indicates how many teams completed their task by each timestep.

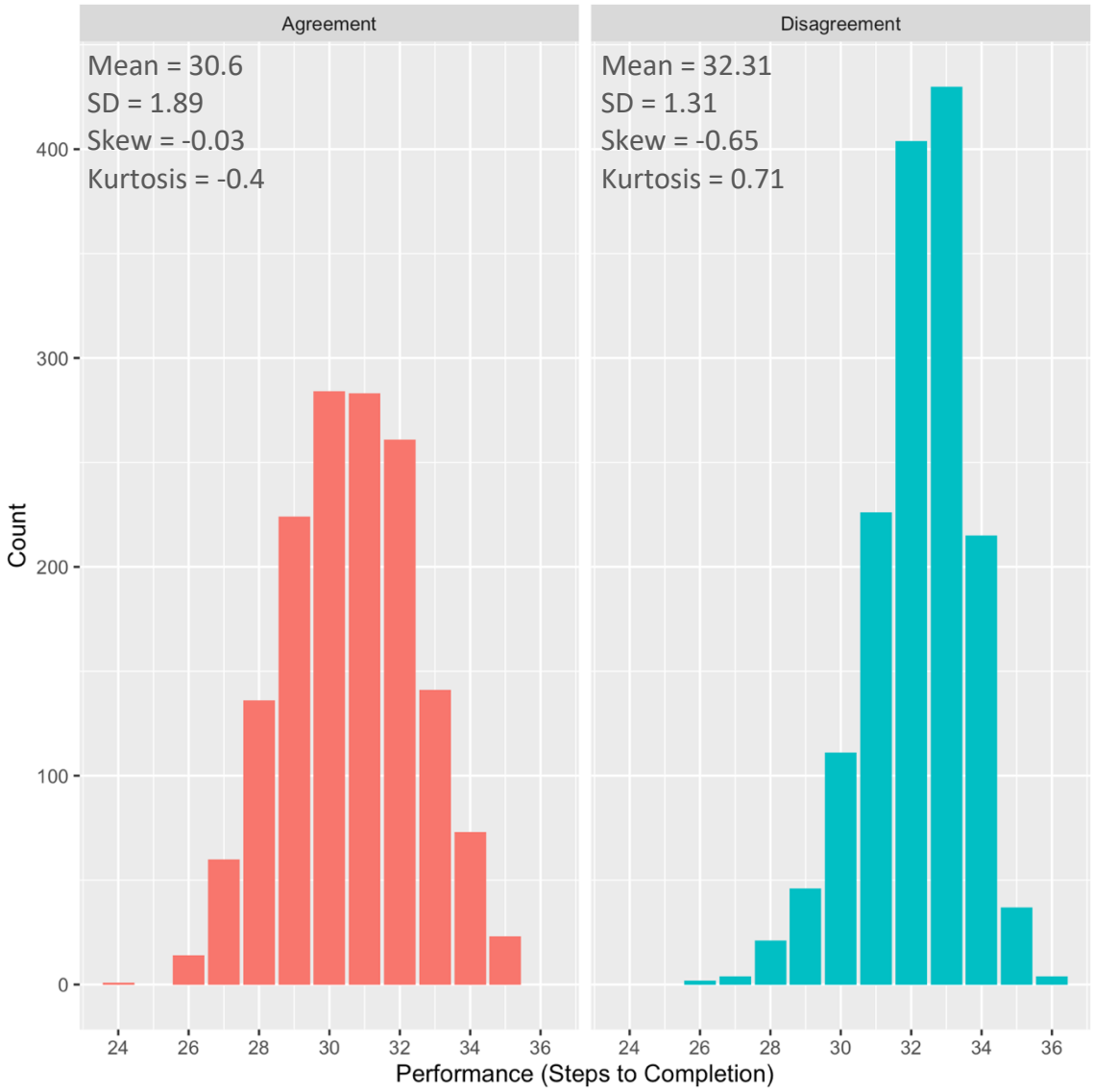

Figure 20. Time to Task Completion for Simulated Teams with Compatible (Agreement) Versus Incompatible (Disagreement) TTRs (Study 2). Values along the x-axis represent the speed of task completion whereby lower numbers indicate quicker task completion (higher performance). The y-axis indicates how many teams completed their task by each timestep.

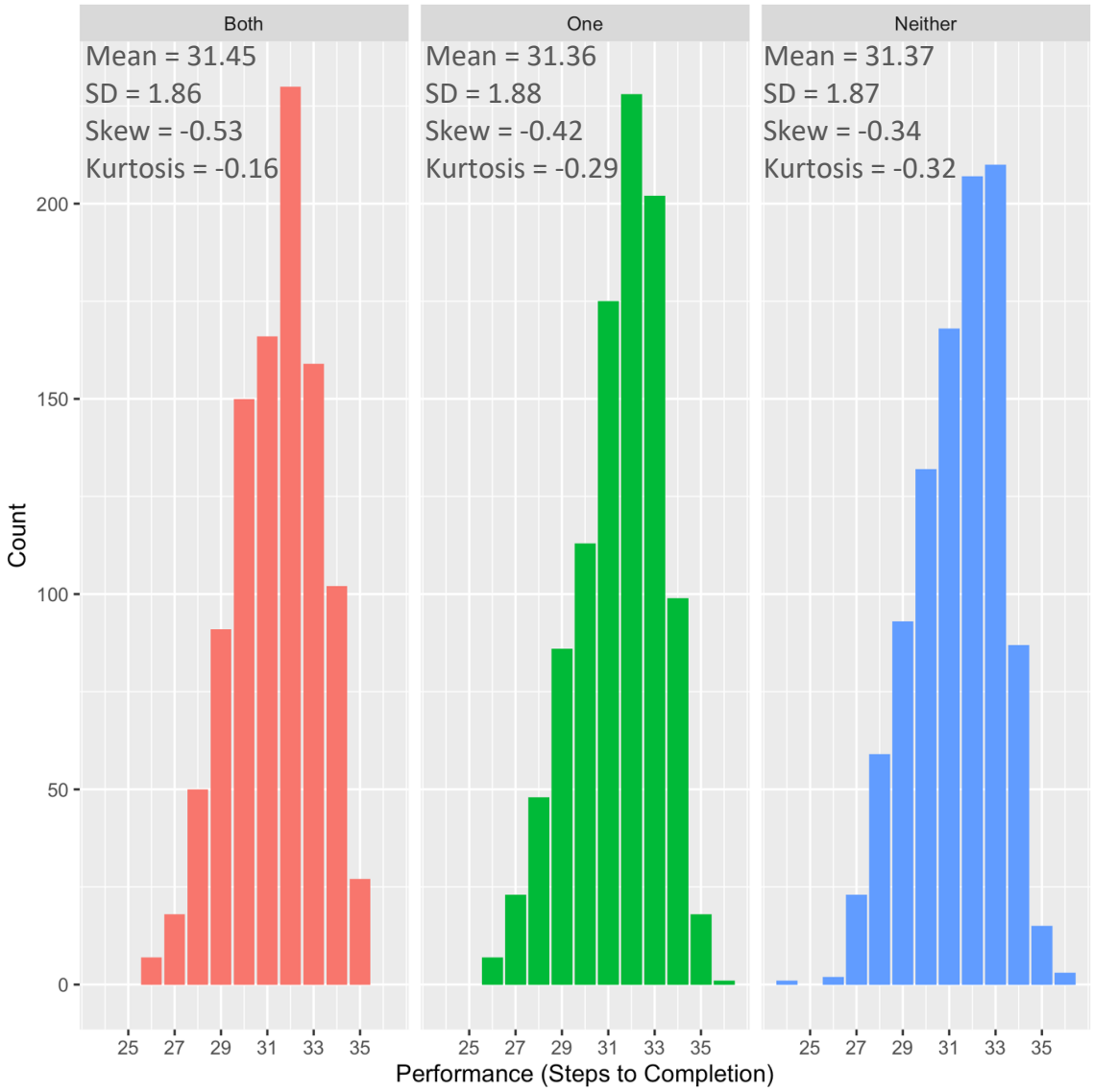

Figure 21. Time to Task Completion for Simulated Teams Based on Number of members in a Team with Correct Beliefs about the Teammate's Goal Preferences (Study 2). Values along the x-axis represent the speed of task completion whereby lower numbers indicate quicker task completion (higher performance). The y-axis indicates how many teams completed their task by each timestep.

Study 2 Discussion

Study 2 was conducted to assess whether patterns of team members' action choices changed when the calculus for those choices included correct or incorrect predictions for teammates' actions. Patterns of action choice and goal pursuit associated with compatible TTRs in Study 1 were replicated in Study 2. Specifically, members with compatible TTRs frequently attended to the same goal at the same time leading to

asymmetrical goal pursuit. Likewise, members with incompatible TTRs frequently attended to different goals at the same time leading to more symmetrical goal pursuit. The pattern inspired by compatible TTRs did tend to result in better performance, although performance outcomes were more variable than when TTRs were incompatible.

However, patterns associated with compatible and incompatible TTRs manifested similarly across the number of members correct about the other members' beliefs – there was no discernable effect of correct or incorrect representation of members' teammate's TTR. Indeed, all metrics for Conditions 1-3 in Study 2 were indistinguishable from those of Condition 3 in Study 1 which had the same parameters but without the assumed TTR for the other member. Likewise, all metrics for Conditions 4-6 in Study 2 were indistinguishable from those of Condition 4.

No effect of others' expected actions manifested in this model likely due to the implementation of the model rather than a theoretical misspecification. In the present model, actions were assigned values independently but then chosen together – expected utilities of actions by the self and other teammate were calculated independently then summed. In this way, actions retained their values no matter with which other action they were paired. An effect may have manifested had the model combined members' actions within a timestep *before* assigning values to actions which guide choices. Future work should seek to specify the precise way values are assigned to actions *after* accounting for other simultaneous actions rather than disregarding the mechanism of coordination (explaining the relationship between compatible team cognition and team performance).

General Discussion

The two studies conducted and described elucidate the utility of the TTR framework (with its unique features compared to previous theories of team cognition) and, moreover, of compatibility as defined and operationalized by this framework. By including both team *and* task concepts, TTRs depict important information about how individual members fit into specific task contexts represented. TTRs' structure, oriented around effectiveness, clarifies the nature of associations between represented concepts which afford a definition of compatibility as a structural property of team cognition. Specifically, concepts may be ranked according to their effectiveness in completing a team task. Similarities in these rankings determine the degree to which individuals agree with each other on task-relevant values and thus their evaluation of their teammates' decisions and ability to synergize. The TTR framework also proposes that compatibility should benefit team performance through guiding members' course of action. This process was simulated in an agent-based model which incorporated these tenets. Specifically, team task performance was simulated in an agent-based model adapted from previous models of goal pursuit (i.e., Vancouver et al., 2010; Samuelson, 2019) which informed the rules by which agents performed their task, although under novel conditions (i.e., multi-agent interdependence, divergent subjective goal representation, counterfinality).

Study 1 demonstrated how agreement on goal priorities in agents' TTRs could facilitate performance through emergent patterns of goal pursuit. Agents who agree on the priority of one goal over another tended to be 'generalists,' performing actions which advanced progress towards the goal they prefer until that goal is sufficiently reduced at which point one or both team members begin performing actions directed towards the

less-preferred goal. This pattern of individuals' action choices and emergent pattern of team goal pursuit tended to result in higher performance (i.e., fewer steps to completion), but greater variance, than for teams exhibiting disagreement who tended to be 'specialists' and so advance both goals simultaneously as a team. The strength or magnitude of preference, however, contributed to additional variability in pursuit patterns and performance outcomes (i.e., within condition in both studies). Compatibility as agreement on goal priorities therefore affords predictions which can now be tested deductively (presented in Table 9), but those future tests would do well to measure the degree of difference between goals' importance beyond their rank order.

Notably, these effects of compatibility are accomplished without any consideration of the other member or their choices or explicit attempts to coordinate. Instead, members' own beliefs were affected by others' actions only through considering their teammate's contribution to goal progress *through* total goal progress. The results from Study 1 thus suggest that simple outcome interdependence was enough to change individual members' and their team's emergent patterns of taskwork.

Study 2 examined how TTR compatibility informs performance processes and outcomes by requiring agent-members account for their teammate's next action in their own action choice. Study 2 replicated effects of compatibility and incompatibility from Study 1, however, allowing members to predict their teammate's actions and use those predictions to inform their own action choices did *not* noticeably change the outcomes of members' own action choices in the aggregate regardless of whether prediction information was based on a correct or incorrect understanding of their teammate's beliefs. This apparent lack of effect, however, is more likely the result of model

implementation than theoretical development. Specifically, how members calculated the values of their team's output (own action combined with their teammate's action) in each timestep were mathematically independent which prevented members from changing their own action in response to their teammate's. Additional work is needed to specify how actions' values might be combined to reflect realistic interdependent decision-making.

Together, these two studies indicate that even under the most modest interdependence, individual interdependent actors' patterns of action cannot be fully explained without considering the consequences of teammates' actions. By incorporating language and concepts from theories of motivation and shared goals, TTRs capture the concepts necessary to describe motivation and action in pursuit of shared (i.e., team) tasks. Appreciating sharedness as compatibility, facilitated by the TTR framework, draws attention to the mechanisms through which mental representations guide their holders to better or worse outcomes: through choices rendering mutually experienced consequences. Future directions for increasing external validity and other illustrative capabilities of the present model are discussed in the following section.

Implications

Compatibility as operationalized by the TTR framework and demonstrated here through the process of interdependent goal pursuit extends research on team cognition in three notable ways. First, following Cronin, Weingart and colleagues' (e.g., Cronin & Weingart 2007, Weingart et al., 2008; 2010) emphasis on goals in compatible cognition, TTR's content, structure and the process through which compatibility exerted influence on performance outcomes was derived directly from theories of motivated cognition and

goal pursuit. These theories' tenets helped inform a framework for representing team tasks (TTRs) which considered goals as organized networks of diverse knowledge (different categories of concepts) which gave rise to higher-order values such as goal priorities, and also to more complex beliefs such as of *who* should do *what when*.

Second, the present work maintained a steadfast process-orientation in discussing and testing compatibility, which was also largely facilitated by an appreciation of goals. As intimated above, TTRs represented knowledge (about members, actions, and goals) directly informed how team performance was to unfold which, given system interdependence, naturally included the effect of TTRs' compatibility or potentially other descriptors of team knowledge distribution. Theories of goal pursuit not only became the clear choice for expressing *how* compatible TTRs informed team performance outcomes, but also demonstrated the importance in recognizing privately held values (i.e., of goals, actions, and potentially members) are dynamic as initial beliefs are updated in response to task progress (at the minimum). As demonstrated in the simulated model, performance is the result of *discreet* behavioral choices from which dynamic and fluid trends in performance emerge as the *same decision criteria* are applied to *dynamic values*. Goal pursuit was the only process modeled in order to keep simulations simple so (a) the effect of compatibility through action choices in goal pursuit alone is clear and (b) results can serve as a baseline as future research increases interdependence and adds mechanisms of effect. Indeed, future research should consider modeling or observing compatibility as it reciprocally informs other crucial team processes such as communication, conflict, and sense-making.

Third, while compatibility is expressly a characteristic of cognition *across* individuals, i.e., a "team-level" construct, it emphasizes the importance of considering individuals above and beyond their shared team identity. Characterizing team cognition as a single pool of knowledge held in common ignores the unshared knowledge individuals invoke in their performance decisions. Likewise, characterizing team cognition as a single pool of all knowledge held by anyone obscures the knowledge individuals invoke in deciding on actions such as 'requesting information' that dictate how pragmatically effective a transactive memory system is. It is critical team cognition research appreciate the utility in describing cognition as a property of teams without overshadowing its expression through individuals' agency directly informed by private mental representations.

Future Directions

The studies discussed are relatively unique in their application of goal/motivation theories to elaborate the effects of team cognition. As such, these studies suggest several future directions for modeling interdependent goal pursuit as well as team cognition. As team cognition has been shown here to impact team performance through decisions during interdependent goal pursuit, implications for the latter are as critical as implications for the former to realize a deeper understanding of team cognition and its consequences.

Team Cognition

Regarding compatibility, future work should strive to define TTR compatibility to capture more than agreement on goal priorities. Observations in both studies indicate that the strength of preferences explains variance in performance trajectories and outcomes

beyond rank-order by dictating *how much* discrepancy relative to other goals agents tolerate before attending to task goals with larger discrepancy. Additionally or alternatively, team cognition research might measure compatibility through similar values of *combinations* of concepts, e.g., how good for accomplishing the task is M_1's performing A_2 given its impact on G_3. Compatibility should also be expanded beyond considerations of agreement. Agreement itself is predisposed by common understanding of the problem or situation teams face. Whether or not all concepts *and* connections between exist between team members' TTR and how interdependent decisions result is likely another fruitful source of inquiry.

Finally, teams do engage in multiple team processes beyond interdependent taskwork. Future research on the mechanisms through which compatibility guides team performance would do well to include information exchange as well as interpersonal communication processes such as conflict management. In doing so, theory of team cognition may explain compatibility's influence on performance outcomes through members' desire or willingness to consider teammates when planning action, process of forming beliefs about aspects of their task environment and teammates' values and habits through communication *as well as* observational learning, and how these processes might influence individuals' decisions among actions in team performance (and vice versa). The mechanism by which interdependent actors chose actions in Study 2, i.e., deriving expectations/predictions for their teams' joint output should also be revisited in future models and would benefit from considering other such team processes. Although as earlier sections proposed, one model-directed solution might be to combine actions before calculating expected utility of the combination as a single action.

Modeling TTRs

The conducted studies were the second (after Samuelson, 2019) to specify multiple means (actions) for satisfying a single goal and thus also to investigate consequences of actions' potential to satisfy multiple goals (i.e., multifinality). Several phenomena warrant a closer look at the mechanism of action choice in the present model and thus the role of instrumentality. Agents in the present model only consider instrumentality through expectancy – of which instrumentality is only a small piece. The difference between, for example, +5 and +7 instrumentality (the positive instrumentalities of uni- and counterfinal actions respectively) was insufficient to elicit different expectancies at any point during the simulation despite agents being very sensitive to time.[8] Relatedly, all uni- and counterfinal actions which serve the same goal are almost certain to eventually be valued equally and so randomly selected. Once all uni- and counterfinal actions which benefit the same goal can accomplish the goal if used exclusively (i.e., when all expectancies = 1) instrumentality ceases to influence action choice. Agents thus essentially were not motivated to complete the task as quick as possible. This desire to use more instrumental actions even once the goal can be reached should at least be considered as another parameter if not part of expectancy itself. However, once a multifinal action can accomplish more than one of its constituent goals (expectancy for an actions' instrumentalities for more than one goal are equal to '1'), it *will* be more valuable than any uni- or counterfinal action in the system as it derives more value than any one goal can offer *regardless of its instrumentality*.

[8] The difference in instrumentality of +2 out of 100 units of progress (2%) as insufficient to elicit different expectancies may serve as a useful benchmark for future models of which expectancy is a key component.

Finally, modeled agents cannot "appreciate" negative instrumentality. One immediate suggestion for this particular limitation is to simply bound expectancy by [-1, 1] rather than [0, 1] to signify negative instrumentality's reducing the chance of completing decremented goals.

In sum, theory around *actions'* expectancy might benefit from considering either a) calculating actions' expectancy by their progress (perhaps weighted by importance) on the goal system as a whole rather than combining expectancies calculated separately across actions' instrumentalities, b) including a more detailed action planning process as 'whether a goal can be accomplished by any single action if used exclusively' obscures real likelihood that people often plan sequences of diverse actions, or c) limiting expectancy to a property of goals or excluding expectancy from specific situations such as the one here modeled in which the outcome of actions and thus task completion is known or easily calculable.

Conclusion

In conclusion, compatibility via agreement on goal priorities was demonstrated to impact team performance through individual team members' action choices during goal pursuit. Communication was "prohibited" among members in that their only information about their teammate's actions came retroactively (Study 1) or were derived from their own beliefs (Study 2). Synchrony, however, was allowed to and did emerge in accordance with agreement. Compatibility was therefore supported as an important mechanism for predicting synchrony and subsequent performance. Whether or not it explains more about this mechanism than "sharedness" or "similarity" is yet to be seen. The mental calculus simulated in the present model borrowed from theories of goal

pursuit and yielded a useful framework for construing work performance at both the individual and team level with particular utility in illustrating the complex system and the resulting emergent patterns of belief and behavior. Together, the framework of theories of goal representation and pursuit provide footing for future empirical work on important structural aspects of team task representations, of their interdependence, and the resultant, emergent pattern of thought and action which results.

Appendix A

Computational Model ‘R’ Code: Study 1 Input Parameters

```
library(snowfall); library(rlecuyer); library(parallel)
library(plyr); library(dplyr); library(arrayhelpers); library(ggplot2); library(reshape2);
library(psych); library(effectsize); library(nlmeU)
library(sandwich); library(clubSandwich); library(lmtest); library(gee); library(lme4);
library(misty); library(MASS); library(markovchain)
library(gridExtra)

numberOfRuns <- 500
time.length <- 50

#Condition 1: (=/=)
conds1 <- lapply(1:numberOfRuns, function(x){

  time.sensitivity <- 1 #Set how much time-remaining will affect expectancy judgements

  goal.distances <- c(100,100) #Set initial discrepancy for each goals (keep # of goals
consistent)
  goal.deadlines <- c(50,50) #Set maximum time-steps allowed for pursuit of each goals
(keep # of goals consistent)

  action.to.goal <- rbind( #Set action instrumentalities for each goal; # of arguments =
rows = number of actions; arguments' length = cols = number of goals
    c(5,0),
    c(0,5),
    c(7,-4),
    c(-4,7),
    c(1,1))

  memberID <- 1:2 #A vector from 1 to '# of individuals'

  member.goal.values <- matrix(rep(50,4), nrow = 2, ncol = 2)


return(list(time.sensitivity,goal.distances,goal.deadlines,action.to.goal,memberID,membe
r.goal.values))})

#Condition 2: (=/>)
conds2 <- lapply(1:numberOfRuns, function(x){

  time.sensitivity <- 1 #Set how much time-remaining will affect expectancy judgements
```

```
  goal.distances <- c(100,100) #Set initial discrepancy for each goals (keep # of goals
consistent)
  goal.deadlines <- c(50,50) #Set maximum time-steps allowed for pursuit of each goals
(keep # of goals consistent)

  action.to.goal <- rbind( #Set action instrumentalities for each goal; # of arguments =
rows = number of actions; arguments' length = cols = number of goals
    c(5,0),
    c(0,5),
    c(7,-4),
    c(-4,7),
    c(1,1))

  memberID <- 1:2 #A vector from 1 to '# of individuals'

  a <- as.numeric(sample(51:99,1))
  b <- 100 - a

  member.goal.values <- matrix(c(50, a, 50, b), nrow = 2, ncol = 2)


return(list(time.sensitivity,goal.distances,goal.deadlines,action.to.goal,memberID,membe
r.goal.values))})

#Condition 3: (>/>)
conds3 <- lapply(1:numberOfRuns, function(x){

  time.sensitivity <- 1 #Set how much time-remaining will affect expectancy judgements

  goal.distances <- c(100,100) #Set initial discrepancy for each goals (keep # of goals
consistent)
  goal.deadlines <- c(50,50) #Set maximum time-steps allowed for pursuit of each goals
(keep # of goals consistent)

  action.to.goal <- rbind( #Set action instrumentalities for each goal; # of arguments =
rows = number of actions; arguments' length = cols = number of goals
    c(5,0),
    c(0,5),
    c(7,-4),
    c(-4,7),
    c(1,1))

  memberID <- 1:2 #A vector from 1 to '# of individuals'

  a <- as.numeric(sample(51:99,1))
  b <- 100 - a
```

```
  c <- as.numeric(sample(51:99,1))
  d <- 100 - c

  member.goal.values <- matrix(c(a, c, b, d), nrow = 2, ncol = 2)


return(list(time.sensitivity,goal.distances,goal.deadlines,action.to.goal,memberID,membe
r.goal.values))})

#Condition 4: (>/<)
conds4 <- lapply(1:numberOfRuns, function(x){

  time.sensitivity <- 1 #Set how much time-remaining will affect expectancy judgements

  goal.distances <- c(100,100) #Set initial discrepancy for each goals (keep # of goals
consistent)
  goal.deadlines <- c(50,50) #Set maximum time-steps allowed for pursuit of each goals
(keep # of goals consistent)

  action.to.goal <- rbind( #Set action instrumentalities for each goal; # of arguments =
rows = number of actions; arguments' length = cols = number of goals
    c(5,0),
    c(0,5),
    c(7,-4),
    c(-4,7),
    c(1,1))

  memberID <- 1:2 #A vector from 1 to '# of individuals'

  a <- as.numeric(sample(51:99,1))
  b <- 100 - a
  c <- as.numeric(sample(1:49,1))
  d <- 100 - c

  member.goal.values <- matrix(c(a, c, b, d), nrow = 2, ncol = 2)


return(list(time.sensitivity,goal.distances,goal.deadlines,action.to.goal,memberID,membe
r.goal.values))})
```

Appendix B

Computational Model 'R' Code: Study 1 Model Simulation

```
Simulation <- function(time.sensitivity, goal.distances, goal.deadlines, action.to.goal,
memberID, member.goal.values){

  ## Initialize Logs
  goal.valences <- array(data = NA, dim = c(max(goal.deadlines),
                                    max(memberID),
                                    length(goal.distances))) # time x person x goal

  action.expectancies <- array(data = NA, dim = c(max(goal.deadlines),
                                        ncol(action.to.goal),
                                        nrow(action.to.goal),
                                        max(memberID))) # time x goal x action x person

  action.utilities <- array(data = NA, dim = c(max(goal.deadlines),
                                     max(memberID),
                                     nrow(action.to.goal))) # time x person x action

  focal.actions <- array(data = NA, dim = c(max(goal.deadlines),
                                    max(memberID))) # time x person's action

  current.states <- array(data = NA, dim = c(max(goal.deadlines),
                                     ncol(action.to.goal))) # time x goal

  ##Initial Conditions
  time.clock <- 1 #start time clock
  current.states[time.clock,] <- rep(0,ncol(action.to.goal))  #start goal progress at 0 for
each run
  discrepancies <- goal.distances - current.states[time.clock,]  #prep object


  ## Main Loop
  while (time.clock <= max(goal.deadlines) & (discrepancies[1] > 0 | discrepancies[2] >
0) ) { #loop across time steps

    if (time.clock != 1){
      current.states[time.clock,] <- current.states[time.clock-1,]}

    #####STEP 1: Calculate Valences (from goal value and  discrepancy)              time x
person x goal
    for (i in 1:length(discrepancies)){
      goal.valences[time.clock,,i] <- member.goal.values[,i]*discrepancies[i]
    }
```

```
   #####STEP 2: Calculate Expectancies (from time remaining and action
instrumentalities)             time x goal x action x person

   # time.sensitivity <- 1  #used for testing (make sure values were correct without having
to makeadditional calculations)
   for (i in 1:nrow(action.to.goal)){    # loop through values by: nested for-loop (rows,
then columns)
     for (j in 1:length(action.to.goal[i,])){
      if (action.to.goal[i,j] <= 0){
        action.expectancies[time.clock,j,i,] = 0
      } else {
        action.expectancies[time.clock,j,i,] <- round(1/(1+exp((-
1)*time.sensitivity*((goal.deadlines[j] - time.clock)-
(discrepancies[j]*(1/action.to.goal[i,j])))))),3)}}}

   # IF expectancies vary across people, add loop for person dimension

   #####STEP 3: Calculate Utilities
   thru <- array(data = NA, dim = c(ncol(action.to.goal), #prep temporary object
                                    nrow(action.to.goal),
                                    max(memberID)))

   for (i in 1:max(memberID)){ #Calculate action utility per goal for each person;    goal
x action x person
     thru[,,i]<- action.expectancies[time.clock,,,i]*goal.valences[time.clock,i,]}

   for (i in 1:max(memberID)){ #Sum expectancies within goals to get action utilities for
each person
     action.utilities[time.clock,i,] <- apply(thru[,,i], 2, sum)}


   #####STEP 4: Choose Action
   for (i in 1:max(memberID)){
     if (length(which(action.utilities[time.clock,i,] == max(action.utilities[time.clock,i,])))
>1){
       focal.actions[time.clock,i] <- sample(which(action.utilities[time.clock,i,] ==
max(action.utilities[time.clock,i,])),1)}
     else{
       focal.actions[time.clock,i] <- which(action.utilities[time.clock,i,] ==
max(action.utilities[time.clock,i,]))
     }
   }

   #####STEP 5: Update goal progress
```

```
   for (i in focal.actions[time.clock,]) { #increment goal progress, i.e. 'current.states,' by
the instrumentality of each action on each goal
     current.states[time.clock,] <- current.states[time.clock,] + action.to.goal[i,]
   }

   #####STEP 6: Iterate time step
   discrepancies <- goal.distances - current.states[time.clock,] #update discrepancies

   time.clock <- time.clock +1 #iterate time clock

  }

  performance <- nrow(na.omit(current.states))

  results <- list("member.goal.values" = member.goal.values,
                  "goal.valences" = goal.valences,
                  "action.expectancies" = action.expectancies,
                  "action.utilities" = action.utilities,
                  "focal.actions" = focal.actions,
                  "current.states" = current.states,
                  "performance" = performance)
  return(results)
}

## Allows R to run in parallel
sfInit(parallel = T, cpus = detectCores()-1, type = "SOCK")

## Export needed data to worker machine
sfExportAll()

## Start random number generator
sfClusterSetupRNGstream() # Set seed so that results can be replicated

## Run simulation
startTime<-Sys.time()

#################
## Simulation ##
#################
conds1.dat <- sfLapply(conds1, function(x)
Simulation(x[[1]],x[[2]],x[[3]],x[[4]],x[[5]],x[[6]]))
# write.csv(conds1.dat,"sim1Cond1Dat")
conds2.dat <- sfLapply(conds2, function(x)
Simulation(x[[1]],x[[2]],x[[3]],x[[4]],x[[5]],x[[6]]))
# write.csv(conds2.dat,"sim1Cond2Dat")
```

```
conds3.dat <- sfLapply(conds3, function(x)
Simulation(x[[1]],x[[2]],x[[3]],x[[4]],x[[5]],x[[6]]))
# write.csv(conds3.dat,"sim1Cond3Dat")
conds4.dat <- sfLapply(conds4, function(x)
Simulation(x[[1]],x[[2]],x[[3]],x[[4]],x[[5]],x[[6]]))
# write.csv(conds4.dat,"sim1Cond4Dat")

runTime <- Sys.time() - startTime
runTime

## Stop cluster
sfStop()
```

Appendix C

Computational Model ‘R’ Code: Study 2 Input Parameters

```
library(snowfall); library(rlecuyer); library(parallel)
library(plyr); library(dplyr); library(arrayhelpers); library(ggplot2); library(reshape2);
library(psych); library(effectsize); library(nlmeU)
library(sandwich); library(clubSandwich); library(lmtest); library(gee); library(lme4);
library(misty); library(MASS); library(markovchain);
library(gridExtra)

numberOfRuns <- 500
time.length <- 50
#terminology: matching preferences (instead of agreement)
#Condition 1: Agreement (+,-) with Complete-Accuracy (2 matches)
#####
sim2Conds1 <- lapply(1:numberOfRuns, function(x){

  time.sensitivity <- 100 #Set how much time-remaining will affect expectancy
judgements

  goal.distances <- c(100,100) #Set initial discrepancy for each goals (keep # of goals
consistent)
  goal.deadlines <- c(50,50) #Set maximum time-steps allowed for pursuit of each goals
(keep # of goals consistent)

  action.to.goal <- rbind( #Set action instrumentalities for each goal; # of arguments =
rows = number of actions; arguments' length = cols = number of goals
    c(5,0),
    c(0,5),
    c(7,-4),
    c(-4,7),
    c(1,1))

  memberID <- 1:2 #A vector from 1 to '# of individuals'

  a <- as.numeric(sample(51:99,1)) #m1.m1g1
  b <- 100 - a #m1.m1g2
  c <- as.numeric(sample(51:99,1)) #m1.m2g1
  d <- 100 - c #m1.m2g2

  e <- as.numeric(sample(51:99,1)) #m2.m1g1
  f <- 100 - e #m2.m1g2
  g <- as.numeric(sample(51:99,1)) #m2.m2g1
  h <- 100 - g #m2.m2g2
```

```
  ## TTRs: [person, goal]
  ttr1 <- matrix(c(a,b,c,d), nrow = 2, ncol = 2, byrow = T) # member 1's ttr representing
how M1 thinks, and how M1 thinks M2 thinks
  ttr2<- matrix(c(e,f,g,h), nrow = 2, ncol = 2, byrow = T) # member 2's ttr representing
how M2 thinks, and how M2 thinks M1 thinks


return(list(time.sensitivity,goal.distances,goal.deadlines,action.to.goal,memberID,ttr1,ttr2
))})

#Condition 2: Agreement (+,-) with Partial-Accuracy (1 match)
#####
sim2Conds2 <- lapply(1:numberOfRuns, function(x){

  time.sensitivity <- 100 #Set how much time-remaining will affect expectancy
judgements

  goal.distances <- c(100,100) #Set initial discrepancy for each goals (keep # of goals
consistent)
  goal.deadlines <- c(50,50) #Set maximum time-steps allowed for pursuit of each goals
(keep # of goals consistent)

  action.to.goal <- rbind( #Set action instrumentalities for each goal; # of arguments =
rows = number of actions; arguments' length = cols = number of goals
    c(5,0),
    c(0,5),
    c(7,-4),
    c(-4,7),
    c(1,1))

  memberID <- 1:2 #A vector from 1 to '# of individuals'

  a <- as.numeric(sample(51:99,1)) #m1.m1g1
  b <- 100 - a #m1.m1g2
  c <- as.numeric(sample(1:49,1)) #m1.m2g1
  d <- 100 - c #m1.m2g2

  e <- as.numeric(sample(51:99,1)) #m2.m1g1
  f <- 100 - e #m2.m1g2
  g <- as.numeric(sample(51:99,1)) #m2.m2g1
  h <- 100 - g #m2.m2g2

  ## TTRs: [person, goal]
  ttr1 <- matrix(c(a,b,c,d), nrow = 2, ncol = 2, byrow = T) # member 1's ttr representing
how M1 thinks, and how M1 thinks M2 thinks
```

```
  ttr2<- matrix(c(e,f,g,h), nrow = 2, ncol = 2, byrow = T) # member 2's ttr representing
how M2 thinks, and how M2 thinks M1 thinks


return(list(time.sensitivity,goal.distances,goal.deadlines,action.to.goal,memberID,ttr1,ttr2
))})

#Condition 3: Agreement (+,-) with No Accuracy (0 matches)
#####
sim2Conds3 <- lapply(1:numberOfRuns, function(x){

  time.sensitivity <- 100 #Set how much time-remaining will affect expectancy
judgements

  goal.distances <- c(100,100) #Set initial discrepancy for each goals (keep # of goals
consistent)
  goal.deadlines <- c(50,50) #Set maximum time-steps allowed for pursuit of each goals
(keep # of goals consistent)

  action.to.goal <- rbind( #Set action instrumentalities for each goal; # of arguments =
rows = number of actions; arguments' length = cols = number of goals
    c(5,0),
    c(0,5),
    c(7,-4),
    c(-4,7),
    c(1,1))

  memberID <- 1:2 #A vector from 1 to '# of individuals'

  a <- as.numeric(sample(51:99,1)) #m1.m1g1
  b <- 100 - a #m1.m1g2
  c <- as.numeric(sample(1:49,1)) #m1.m2g1
  d <- 100 - c #m1.m2g2

  e <- as.numeric(sample(51:99,1)) #m2.m1g1
  f <- 100 - e #m2.m1g2
  g <- as.numeric(sample(1:49,1)) #m2.m2g1
  h <- 100 - g #m2.m2g2

  ## TTRs: [person, goal]
  ttr1 <- matrix(c(a,b,c,d), nrow = 2, ncol = 2, byrow = T) # member 1's ttr representing
how M1 thinks, and how M1 thinks M2 thinks
  ttr2<- matrix(c(e,f,g,h), nrow = 2, ncol = 2, byrow = T) # member 2's ttr representing
how M2 thinks, and how M2 thinks M1 thinks
```

```
return(list(time.sensitivity,goal.distances,goal.deadlines,action.to.goal,memberID,ttr1,ttr2
))})

#Condition 4: Disagreement (+,- ; -,+) with Complete-Accuracy (2 matches)
#####
sim2Conds4 <- lapply(1:numberOfRuns, function(x){

  time.sensitivity <- 100 #Set how much time-remaining will affect expectancy
judgements

  goal.distances <- c(100,100) #Set initial discrepancy for each goals (keep # of goals
consistent)
  goal.deadlines <- c(50,50) #Set maximum time-steps allowed for pursuit of each goals
(keep # of goals consistent)

  action.to.goal <- rbind( #Set action instrumentalities for each goal; # of arguments =
rows = number of actions; arguments' length = cols = number of goals
    c(5,0),
    c(0,5),
    c(7,-4),
    c(-4,7),
    c(1,1))

  memberID <- 1:2 #A vector from 1 to '# of individuals'

  a <- as.numeric(sample(51:99,1)) #m1.m1g1
  b <- 100 - a #m1.m1g2
  c <- as.numeric(sample(1:49,1)) #m1.m2g1
  d <- 100 - c #m1.m2g2

  e <- as.numeric(sample(1:49,1)) #m2.m1g1
  f <- 100 - e #m2.m1g2
  g <- as.numeric(sample(51:99,1)) #m2.m2g1
  h <- 100 - g #m2.m2g2

  ## TTRs: [person, goal]
  ttr1 <- matrix(c(a,b,c,d), nrow = 2, ncol = 2, byrow = T) # member 1's ttr representing
how M1 thinks, and how M1 thinks M2 thinks
  ttr2<- matrix(c(e,f,g,h), nrow = 2, ncol = 2, byrow = T) # member 2's ttr representing
how M2 thinks, and how M2 thinks M1 thinks


return(list(time.sensitivity,goal.distances,goal.deadlines,action.to.goal,memberID,ttr1,ttr2
))})
```

```
#Condition 5: Disagreement (+,- ; -,+) with Partial-Accuracy (1 match)
#####
sim2Conds5 <- lapply(1:numberOfRuns, function(x){

  time.sensitivity <- 100 #Set how much time-remaining will affect expectancy
judgements

  goal.distances <- c(100,100) #Set initial discrepancy for each goals (keep # of goals
consistent)
  goal.deadlines <- c(50,50) #Set maximum time-steps allowed for pursuit of each goals
(keep # of goals consistent)

  action.to.goal <- rbind( #Set action instrumentalities for each goal; # of arguments =
rows = number of actions; arguments' length = cols = number of goals
    c(5,0),
    c(0,5),
    c(7,-4),
    c(-4,7),
    c(1,1))

  memberID <- 1:2 #A vector from 1 to '# of individuals'

  a <- as.numeric(sample(51:99,1)) #m1.m1g1
  b <- 100 - a #m1.m1g2
  c <- as.numeric(sample(51:99,1)) #m1.m2g1
  d <- 100 - c #m1.m2g2

  e <- as.numeric(sample(1:49,1)) #m2.m1g1
  f <- 100 - e #m2.m1g2
  g <- as.numeric(sample(51:99,1)) #m2.m2g1
  h <- 100 - g #m2.m2g2

  ## TTRs: [person, goal]
  ttr1 <- matrix(c(a,b,c,d), nrow = 2, ncol = 2, byrow = T) # member 1's ttr representing
how M1 thinks, and how M1 thinks M2 thinks
  ttr2<- matrix(c(e,f,g,h), nrow = 2, ncol = 2, byrow = T) # member 2's ttr representing
how M2 thinks, and how M2 thinks M1 thinks


return(list(time.sensitivity,goal.distances,goal.deadlines,action.to.goal,memberID,ttr1,ttr2
))})

#Condition 6: Disagreement (+,- ; -,+) with No Accuracy (0 matches)
#####
sim2Conds6 <- lapply(1:numberOfRuns, function(x){
```

```
  time.sensitivity <- 100 #Set how much time-remaining will affect expectancy
judgements

  goal.distances <- c(100,100) #Set initial discrepancy for each goals (keep # of goals
consistent)
  goal.deadlines <- c(50,50) #Set maximum time-steps allowed for pursuit of each goals
(keep # of goals consistent)

  action.to.goal <- rbind( #Set action instrumentalities for each goal; # of arguments =
rows = number of actions; arguments' length = cols = number of goals
    c(5,0),
    c(0,5),
    c(7,-4),
    c(-4,7),
    c(1,1))

  memberID <- 1:2 #A vector from 1 to '# of individuals'

  a <- as.numeric(sample(51:99,1)) #m1.m1g1
  b <- 100 - a #m1.m1g2
  c <- as.numeric(sample(51:99,1)) #m1.m2g1
  d <- 100 - c #m1.m2g2

  e <- as.numeric(sample(1:49,1)) #m2.m1g1
  f <- 100 - e #m2.m1g2
  g <- as.numeric(sample(1:49,1)) #m2.m2g1
  h <- 100 - g #m2.m2g2

  ## TTRs: [person, goal]
  ttr1 <- matrix(c(a,b,c,d), nrow = 2, ncol = 2, byrow = T) # member 1's ttr representing
how M1 thinks, and how M1 thinks M2 thinks
  ttr2<- matrix(c(e,f,g,h), nrow = 2, ncol = 2, byrow = T) # member 2's ttr representing
how M2 thinks, and how M2 thinks M1 thinks


return(list(time.sensitivity,goal.distances,goal.deadlines,action.to.goal,memberID,ttr1,ttr2
))})
```

Appendix D

Computational Model 'R' Code: Study 2 Model Simulation

```
Simulation <- function(time.sensitivity, goal.distances, goal.deadlines, action.to.goal,
memberID, ttr1, ttr2){

 ## Initialize Logs
 goal.valences.m1 <- array(data = NA, dim = c(max(goal.deadlines),
                                  max(memberID),
                                  length(goal.distances))) # time x person x goal

 goal.valences.m2 <- array(data = NA, dim = c(max(goal.deadlines),
                                  max(memberID),
                                  length(goal.distances))) # time x person x goal

 action.expectancies <- array(data = NA, dim = c(max(goal.deadlines),
                                    ncol(action.to.goal),
                                    nrow(action.to.goal),
                                    max(memberID))) # time x goal x action x person

 action.utilities.m1 <- array(data = NA, dim = c(max(goal.deadlines),
                                    max(memberID),
                                    nrow(action.to.goal))) # time x person x action

 action.utilities.m2 <- array(data = NA, dim = c(max(goal.deadlines),
                                    max(memberID),
                                    nrow(action.to.goal))) # time x person x action

 action.combos.m1 <- array(data = NA, dim = c(max(goal.deadlines),
                                  max(memberID))) # time x person

 action.combos.m2 <- array(data = NA, dim = c(max(goal.deadlines),
                                  max(memberID))) # time x person

 EUs <- array(data = NA, dim = c(max(goal.deadlines),
                         max(memberID),
                         max(memberID)))      # time x person x person

 focal.actions <- array(data = NA, dim = c(max(goal.deadlines),
                                 max(memberID))) # time x person's action

 OUs <- array(data = NA, dim = c(max(goal.deadlines),
                         max(memberID),
                         max(memberID)))      # time x person x person
```

```
  current.states <- array(data = NA, dim = c(max(goal.deadlines),
                                  ncol(action.to.goal))) # time x goal

  ##Initial Conditions
  time.clock <- 1 #start time clock
  current.states[time.clock,] <- rep(0,ncol(action.to.goal))  #start goal progress at 0 for
each run
  discrepancies <- goal.distances - current.states[time.clock,]  #prep object


  ## Main Loop
  while (time.clock <= max(goal.deadlines) & (discrepancies[1] > 0 | discrepancies[2] >
0) ) { #loop across time steps

    if (time.clock != 1){
      current.states[time.clock,] <- current.states[time.clock-1,]}

    #####STEP 1: Calculate Valences (from goal value and  discrepancy)             time x
person x goal
    ## Member 1
    for (i in 1:length(discrepancies)){
      goal.valences.m1[time.clock,,i] <- ttr1[,i]*discrepancies[i]
    }

    ## Member 2
    for (i in 1:length(discrepancies)){
      goal.valences.m2[time.clock,,i] <- ttr2[,i]*discrepancies[i]
    }


    #####STEP 2: Calculate Expectancies (from time remaining and action
instrumentalities)             time x goal x action x person

    # time.sensitivity <- 1  #used for testing (make sure values were correct without having
to makeadditional calculations)
    for (i in 1:nrow(action.to.goal)){    # loop through values by: nested for-loop (rows,
then columns)
      for (j in 1:length(action.to.goal[i,])){
        if (action.to.goal[i,j] <= 0){
          action.expectancies[time.clock,j,i,] = 0
        } else {
          action.expectancies[time.clock,j,i,] <- round(1/(1+exp((-
1)*time.sensitivity*((goal.deadlines[j] - time.clock)-
(discrepancies[j]*(1/action.to.goal[i,j])))))),3)}}}
    # IF expectancies vary across people, add loop for person dimension
```

```
   #####STEP 3: Calculate Utilities
   ## Member 1
   thru1 <- array(data = NA, dim = c(ncol(action.to.goal), #prep temporary object
                                nrow(action.to.goal),
                                max(memberID)))

   for (i in 1:max(memberID)){ #Calculate action utility per goal for each person;    goal
x action x person
     thru1[,,i]<- action.expectancies[time.clock,,,i]*goal.valences.m1[time.clock,i,]}

   for (i in 1:max(memberID)){ #Sum expectancies within goals to get action utilities for
each person
     action.utilities.m1[time.clock,i,] <- apply(thru1[,,i], 2, sum)}

   ## Member 2
   thru2 <- array(data = NA, dim = c(ncol(action.to.goal), #prep temporary object
                                nrow(action.to.goal),
                                max(memberID)))

   for (i in 1:max(memberID)){ #Calculate action utility per goal for each person;    goal
x action x person
     thru2[,,i]<- action.expectancies[time.clock,,,i]*goal.valences.m2[time.clock,i,]}

   for (i in 1:max(memberID)){ #Sum expectancies within goals to get action utilities for
each person
     action.utilities.m2[time.clock,i,] <- apply(thru2[,,i], 2, sum)}


   #####STEP 4: Choose Combination
   ## Member 1
   combos.m1 <- array(data = NA, dim = c(nrow(action.to.goal),nrow(action.to.goal)))
#create temporary object

   for (i in 1:length(action.utilities.m1[time.clock,1,])) { #fill temporary object with
combination values (from own and perceived other's combined EU)
     for (j in 1:length(action.utilities.m1[time.clock,2,])) {
       combos.m1[i,j] <-
action.utilities.m1[time.clock,1,i]+action.utilities.m1[time.clock,2,j]
     }
   }
   ########################################### just assign maxes
######################################## *check it
   maxs1 <- which(combos.m1[,] == max(combos.m1[,]), arr.ind = T) #matrix of most
valuable combinations at the given time step
   the.max1 <- maxs1[sample(x = nrow(maxs1), size = 1), ] #one value, randomly
selected from the matrix of most valuable combinations at the given time step
```

```
   if (length(which(combos.m1[,] == max(combos.m1[,]))) >1){ #choose combination
(smaple if more than one max, use the max if only one)
     action.combos.m1[time.clock,] <- maxs1[sample(x = nrow(maxs1), size = 1),
]}else{action.combos.m1[time.clock,] <- the.max1}

   ## Member 2
   combos.m2 <- array(data = NA, dim = c(nrow(action.to.goal),nrow(action.to.goal)))
#fill temporary object

   for (i in 1:length(action.utilities.m2[time.clock,1,])) { #fill temporary object with
combination values (from own and perceived other's combined EU)
     for (j in 1:length(action.utilities.m2[time.clock,2,])) {
       combos.m2[i,j] <-
action.utilities.m2[time.clock,1,i]+action.utilities.m2[time.clock,2,j]
     }
   }

   maxs2 <- which(combos.m2[,] == max(combos.m2[,]), arr.ind = T) #matrix of most
valuable combinations at the given time step
   the.max2 <- maxs2[sample(x = nrow(maxs2), size = 1), ] #one value, randomly
selected from the matrix of most valuable combinations at the given time step

   if (length(which(combos.m2[,] == max(combos.m2[,]))) >1){ #choose combination
(smaple if more than one max, use the max if only one)
     action.combos.m2[time.clock,] <- maxs2[sample(x = nrow(maxs2), size = 1),
]}else{action.combos.m2[time.clock,] <- the.max2}

   ## assign both to EUs
   EUs[time.clock,1,] <-
c(action.utilities.m1[time.clock,1,action.combos.m1[time.clock,1]],action.utilities.m1[tim
e.clock,2,action.combos.m1[time.clock,2]])
   EUs[time.clock,2,] <-
c(action.utilities.m2[time.clock,1,action.combos.m2[time.clock,1]],action.utilities.m2[tim
e.clock,2,action.combos.m2[time.clock,2]])

   #####STEP 5: Choose Action
   focal.actions[time.clock,] <-
c(action.combos.m1[time.clock,1],action.combos.m2[time.clock,1]) #each member
chooses a sinlge action to perform

   ## assign both to OUs
   OUs[time.clock,1,] <-
c(action.utilities.m1[time.clock,1,focal.actions[time.clock,1]],action.utilities.m1[time.clo
ck,2,focal.actions[time.clock,2]])
```

```
   OUs[time.clock,2,] <-
c(action.utilities.m2[time.clock,1,focal.actions[time.clock,1]],action.utilities.m2[time.clo
ck,2,focal.actions[time.clock,2]])

   #####STEP 6: Update goal progress
   for (i in focal.actions[time.clock,]) { #increment goal progress, i.e. 'current.states,' by
the instrumentality of each action on each goal
     current.states[time.clock,] <- current.states[time.clock,] + action.to.goal[i,]
   }

   #####STEP 7: Iterate time step
   discrepancies <- goal.distances - current.states[time.clock,] #update discrepancies

   time.clock <- time.clock +1 #iterate time clock

 }

 performance <- nrow(na.omit(current.states))

 results <- list("ttr1" = ttr1,                              # 1
                 "ttr2" = ttr2,                             # 2
                 "goal.valences.m1" = goal.valences.m1,          # 3
                 "goal.valences.m2" = goal.valences.m2,          # 4
                 "action.expectancies" = action.expectancies,     # 5
                 "action.utilities.m1" = action.utilities.m1,     # 6
                 "action.utilities.m2" = action.utilities.m2,     # 7
                 "action.combos.m1" = action.combos.m1,          # 8
                 "action.combos.m2" = action.combos.m2,          # 9
                 "EUs" = EUs,                               # 10
                 "focal.actions" = focal.actions,               # 11
                 "OUs" = OUs,                               # 12
                 "current.states" = current.states,             # 13
                 "performance" = performance)                   # 14
 return(results)
}


#################
## Simulation ##
#################

## Allows R to run in parallel
sfInit(parallel = T, cpus = detectCores()-1, type = "SOCK")

## Export needed data to worker machine
sfExportAll()
```

```
## Start random number generator
sfClusterSetupRNGstream() # Set seed so that results can be replicated

## Run simulation
startTime<-Sys.time()

sim2Conds1.dat <- sfLapply(sim2Conds1, function(x)
Simulation(x[[1]],x[[2]],x[[3]],x[[4]],x[[5]],x[[6]],x[[7]]))
sim2Conds2.dat <- sfLapply(sim2Conds2, function(x)
Simulation(x[[1]],x[[2]],x[[3]],x[[4]],x[[5]],x[[6]],x[[7]]))
sim2Conds3.dat <- sfLapply(sim2Conds3, function(x)
Simulation(x[[1]],x[[2]],x[[3]],x[[4]],x[[5]],x[[6]],x[[7]]))
sim2Conds4.dat <- sfLapply(sim2Conds4, function(x)
Simulation(x[[1]],x[[2]],x[[3]],x[[4]],x[[5]],x[[6]],x[[7]]))
sim2Conds5.dat <- sfLapply(sim2Conds5, function(x)
Simulation(x[[1]],x[[2]],x[[3]],x[[4]],x[[5]],x[[6]],x[[7]]))
sim2Conds6.dat <- sfLapply(sim2Conds6, function(x)
Simulation(x[[1]],x[[2]],x[[3]],x[[4]],x[[5]],x[[6]],x[[7]]))

runTime <- Sys.time() - startTime
runTime

## Stop cluster
sfStop()
```

Citations

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