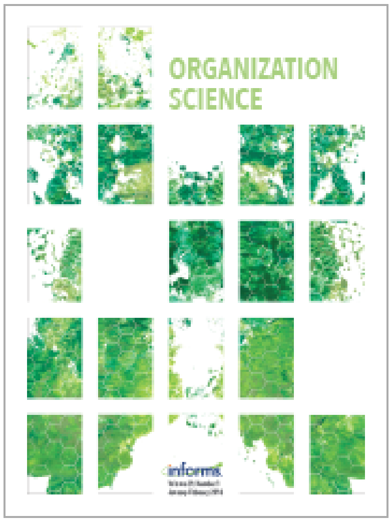

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Collective Attention and Collective Intelligence: The Role of Hierarchy and Team Gender Composition

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Abstract. Collective intelligence (CI) captures a team's ability to work together across a wide range of tasks and can vary significantly between teams. Extant work demonstrates that the level of collective attention a team develops has an important influence on its level of CI. An important question, then, is what enhances collective attention? Prior work demonstrates an association with team composition; here, we additionally examine the influence of team hierarchy and its interaction with team gender composition. To do so, we conduct an experiment with 584 individuals working in 146 teams in which we randomly assign each team to work in a stable, unstable, or unspecified hierarchical team structure and vary team gender composition. We examine how team structure leads to different behavioral manifestations of collective attention as evidenced in team speaking patterns. We find that a stable hierarchical structure increases more cooperative, synchronous speaking patterns but that unstable hierarchical structure and a lack of specified hierarchical structure both increase competitive, interruptive speaking patterns. Moreover, the effect of cooperative versus competitive speaking patterns on collective intelligence is moderated by the teams' gender composition; majority female teams exhibit higher CI when their speaking patterns are more cooperative and synchronous, whereas all male teams exhibit higher CI when their speaking involves more competitive interruptions. We discuss the theoretical and practical implications of our findings for enhancing collective intelligence in organizational teams.

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Keywords: collective intelligence • team hierarchy • team composition • gender differences • collective attention

A growing body of research demonstrates that teams exhibit a characteristic level of collective intelligence (CI), which is a team's ability to work together across a wide range of tasks (Woolley et al. 2010, Riedl et al. 2021). Furthermore, teams vary in the level of CI they develop; CI appears to form relatively early in teams' work, and early measures of it successfully predict performance weeks and months later (Engel et al. 2015, Kim et al. 2017, Woolley and Aggarwal 2020). Ongoing research focuses on identifying the factors that lead one team to have higher CI than another. Recent studies suggest that one such factor is the team's level of *collective attention* (Chikersal et al. 2017, Mayo and Woolley 2021, Tomprou et al. 2021) which, along with collective memory and reasoning, is theorized as one of the core cognitive functions underlying the emergence of collective intelligence (Gupta and Woolley 2021). A team's level of collective attention refers to the quality and coordination of members' focus. Recent research demonstrates that the level of collective attention in a team is manifested in various forms of interactional synchrony (Tickle-Degnen and Rosenthal 1990, Bernieri and Rosenthal 1991), which are operationalized as facial expression and/or vocal (prosodic) synchrony in teams working contemporaneously (Chikersal et al. 2017, Tomprou et al. 2021) and temporal "burstiness" in activity in distributed collaborations (Riedl and Woolley 2017, Mayo and Woolley 2021).

A team's level of collective attention is associated with team member characteristics, such as members' social perceptiveness or ability to pick up on subtle cues (Chikersal et al. 2017, Tomprou et al. 2021). However, many teams have little control over their composition, so identifying other leverage points for increasing collective attention could have important practical utility for improving collective intelligence. Team structure is one widely recognized lever for affecting team process (Hackman 1987, Ilgen et al. 2005), and classic work in organizational behavior treats structure as a key mechanism for managing attention in organizations (March and Simon 1958). Yet how team structure and composition jointly affect collective attention and CI is an important question about which little systematic evidence exists. Here we ask the following: do the same team structures and patterns of interaction benefit all teams regardless of member characteristics or only those in which it matches members' preferred style of interaction?

To investigate these questions, we conduct a randomized controlled experiment in which we independently manipulate team structure and composition in face-to-face teams. We examine the effect of team structure on the pattern of collective attention teams develop as observed in their verbal communication patterns. We manipulate team structure via the creation of a status hierarchy, which is shown to have significant implications for team cooperation versus competition (Greer et al. 2018) and which we theorize as operating via effects on collective attention. We also explore whether team composition moderates the effect of cooperative versus competitive patterns of collective attention on collective intelligence. In examining the impact of team composition, we specifically focus on gender as that is the characteristic most consistently associated with differences in response to the cooperative or competitive conditions that team hierarchy can create (Niederle and Vesterlund 2011).

In examining these issues, this study makes three key contributions to the literature. First, we experimentally manipulate team structure and examine how this important team design element alters collective attention as reflected in team interaction patterns, demonstrating a potentially important mechanism underlying the effect of team structure on team emergent states. Second, we introduce a novel automated and unobtrusive methodology for robustly characterizing collective attention in teams via patterns in verbal communication. This new approach enables future researchers to more readily study these rich team process variables in larger samples and in more settings than is practical with traditional methods. Finally, we contribute to the emerging literature on CI by examining the influence of team structure and team composition via new mechanisms that explain why some teams develop higher CI than others. Understanding these mechanisms facilitates the ability of organizations to proactively design teams that can develop high levels of collective intelligence.

Collective Intelligence and Collective Attention

A growing body of work demonstrates that collective intelligence emerges as a product of team collaboration and composition (Riedl et al. 2021) and is a strong predictor of future team performance (Engel et al. 2015, Kim et al. 2017, Woolley and Aggarwal 2020). In developing theory about collective intelligence in human systems, recent work builds on the observation that intelligence in any system—whether biological, technological, or a hybrid—emerges from the integration of memory, attention, and reasoning functions (Gupta and Woolley 2021). In groups, these collective cognitive functions emerge from individual cognition which, via metacognition, combine in the form of transactive memory systems (Wegner 1987, Ren and Argote 2011), transactive attention systems (Gupta and Woolley 2020), and transactive reasoning systems (Fitzsimons and Finkel 2018). Together, these transactive systems emerge and mutually adapt to environmental complexity to give rise to collective intelligence (Gupta and Woolley 2021). Extant work further demonstrates that the level or quality of the collective reasoning, collective memory, and collective attention that develops can each be evaluated via observable and measurable collaborative processes (Gupta and Woolley 2021, Riedl et al. 2021).

Here, we focus on collective attention, which extant work demonstrates is strongly associated with collective intelligence (Chikersal et al. 2017, Mayo and Woolley 2021, Tomprou et al. 2021). Collective attention, also referred to interchangeably by some as group, mutual, or shared attention (Kaplan and Hafner 2006, Shteynberg 2015, Lorenz-Spreen et al. 2019, De Domenico and Altmann 2020), is operationalized in a variety of ways in different parts of the literature. In some research, the amount of collective attention is operationalized as the total number of people paying attention to a particular piece of information or event, such as by viewing an online article or sharing things on social media (Lorenz-Spreen et al. 2019, De Domenico and Altmann 2020). Taking a slightly different perspective, Shteynberg (2015) identifies collective or shared attention as present when individuals are coattending to an object or event with others, resulting in a shared psychological experience with implications for motivation, judgment, and behavior. Yet another perspective, from the developmental psychology literature, conceptualizes shared or mutual attention as occurring when young children attend to their caregivers for cues as to what is important to attend to in their shared context (Butterworth and Jarrett 1991) or how to feel about it, which also helps them learn emotion regulation (Trevarthen and Aitken 2001). Thus, across these literatures, collective attention is conceptualized as the contemporaneous focus of participants in a shared social context on the same target and/or one another, resulting in a shared emotional or psychological experience and influencing a behavioral response. Importantly, extant work does not differentiate the level of collective attention in different interactions in terms of how undivided individuals' attention is or how coordinated they are in timing or content of focus beyond identifying, in some cases, how many individuals are involved (e.g., De Domenico and Altmann 2020).

We build on extant work and conceptualize the *level* of collective attention in a team as the quality and coordination of members' focus. *Quality* refers to the degree to which team members are giving their full, undivided attention to team-related targets. *Coordination* refers to alignment on both the timing of attention and the content, which can include other team members or team-relevant objects or events. Thus, a team exhibiting a high level of collective attention is one on which all members are prioritizing and coordinating their attention to team-related activities and members, resulting in a greater amount of attentional resources available to accomplish team goals. In contrast, a team in which all members are dividing their attention between the team and other unrelated targets or attending to the team at different times is not considered to have a high level of collective attention.

Collective attention is strongly influenced by team composition, specifically by members' level of social perceptiveness (Chikersal et al. 2017, Tomprou et al. 2021). Individuals who are strong in social perceptiveness are able to pick up on a wide range of subtle, nonverbal cues to draw inferences about what others are thinking and feeling (Baron-Cohen et al. 2001), which allows them to anticipate others' behavior and responses. Team members' social perceptiveness is associated with increases in behaviors indicative of high levels of collective attention, such as a high level and even distribution of communication among members (Woolley et al. 2010, Engel et al. 2014) and facial expression and vocal synchrony (Chikersal et al. 2017, Tomprou et al. 2021). However, many teams have little control over their composition, and thus, identifying other potential levers for increasing collective attention is important. Another element of team design that is highly relevant to collective attention is team structure. Team structure includes team member roles, norms, and intermember status relationships (Forsyth 2006). The benefits of structure in organizations are theorized to operate largely through their effects on attention (March and Simon 1958); thus, team structure is likely to shape team collective attention.

One dynamic that existing work demonstrates develops directly from the quality of mutual or collective attention in an interpersonal exchange is interactional synchrony (Tickle-Degnen and Rosenthal 1990). However, whereas interactional synchrony is typically associated with more cooperative, harmonious interaction, other work suggests that is not the only way collective attention manifests in group interaction. For instance, some propose that conversational interruptions, a situation in which team members talk over one another, can also be an indicator of high levels of collective attention and engagement (Kennedy and Camden 1983, Mulac et al. 1998). Therefore, we consider extant work suggesting that each of these patterns—interactional synchrony and interruptions—can be indicators of collective attention as manifested in verbal communication.

Interactional Synchrony and Interruptions as Indicators of Collective Attention

In the context of interpersonal interactions, a broadly accepted definition of synchrony is the degree to which the behaviors in an interaction are nonrandom, patterned, and complementary in function and timing (Bernieri and Rosenthal 1991). Sometimes, the timing can be contemporaneous in nature (i.e., occurring at the same time) as in body movements, such as leg movements (Wiltermuth and Heath 2009), physical gestures (Burgoon et al. 1995, Richardson et al. 2007), body posture sway (Lakens 2010), rocking (Valdesolo et al. 2010), finger tapping (Oullier et al. 2008), and dancing (Kirschner and Tomasello 2010), all of which are shown to positively influence team attitudes, physical coordination, and performance (von Zimmermann and Richardson 2016). In other cases, synchrony occurs in behavior that is complementary in function and timing but not necessarily identical in form (Delaherche et al. 2012). In other words, synchrony can be intermodal, such as when speaking and listening or tossing a ball for another to catch or playing different musical instruments. In this manner, synchrony is distinct from concepts such as mirroring or mimicry (Lakin and Chartrand 2003, Chartrand and Lakin 2013) in which behavior matches in form and is close in timing. Whereas some forms of mimicry involve a small time lag (such as nonverbal mimicry), the timing aspect is central to synchrony in that synchrony requires anticipation of others' behaviors to maintain minimal delays (Schmidt and Richardson 2008).

Synchrony can be seen as a special case of the broader concept of entrainment (Bernieri et al. 1988, Levitan and Hirschberg 2011, Wynn and Borrie 2020), a phenomenon in which two or more objects or actors simultaneously adjust their behavior so as to match the others. Communications researchers studying entrainment focus on both how similar speech characteristics are (i.e., rate, pitch, prosody; Wynn and Borrie 2020) at any given moment of time as well as how they become more similar over the course of a conversation. In organizational research, work on entrainment focuses on pacing and cyclical behavior that results when group members are aligning their activity to calendars, deadlines, and requirements serving to regulate the tempo of work (Kelly 1988, Ancona and Chong 1999, Zellmer-Bruhn et al. 2004). Similar to entrainment, interactional synchrony is concerned with temporal alignment of a focal behavior among participants but, in contrast to entrainment, is not focused on its regularity in tempo or cyclicality (Bernieri et al. 1994).

Interactional synchrony is considered by some as fundamental to normal social discourse (Jasnow et al. 1988), in which interaction partners look to each other for cues for when to talk, how much to talk, and when to remain quiet so as to minimize the likelihood of simultaneous starts (Wilson and Wilson 2005). Doing so requires highly coordinated timing, during which participants attend closely to one another's cues, automatically adapting to each other's communicative behaviors by adjustments in intonation, tempo, frequency, and duration (Giles et al. 1991). We contend that the result is interactional synchrony or alignment in periods of speaking versus quiet, which teams achieve by attending to one another's cues and being responsive to each other's signals (Riedl and Woolley 2017). Importantly, whereas most normal social interactions are characterized by some level of interactional synchrony, there is still variation in the degree to which interactional synchrony develops. We suggest that this variability in the level of interactional synchrony across teams can be interpreted as a signal of their level of collective attention. To illustrate, we expect that teams with high levels of interactional synchrony exhibit patterns in which members engage in focused discussions separated by periods without communication. That is, their speech occurs in temporally coordinated clusters. By contrast, teams with low levels of interactional synchrony may have one member talking or narrating aloud what the member is doing with no response from team members, possibly followed by another who delivers a monologue about the member's ideas while other members say very little throughout. That is, one member's speaking is not temporally clustered with the speaking of the others. We interpret such patterns as evidence of low levels of collective attention as the members who are not responding to the speaker are likely not attending to the speaker, and those who are communicating in a one-sided manner are likewise not attending to their team members' cues, possibly even disrupting their ability to focus on the team's work. Accordingly, we theorize that interactional synchrony in verbal communication is a measurable indicator of a team's level of collective attention.

However, interactional synchrony need not be the only way that collective attention can manifest in a team; some argue that another form is through verbal interruptions. Whereas one interpretation of interruptions is a lack of attention to the cues signaling the transition of turns in conversation (French and Local 1983), others point out that interruptions can serve as a means of voicing support or supplying helpful corrections (La France 1974, Lerner 2002), which only occurs if people are paying attention and engaged in the interaction (Bakker et al. 2011). For this reason, some assert that interruptions are, at least for some individuals, an important sign of engagement (Farley et al. 2010, Pfänder and Couper-Kuhlen 2019).

In an attempt to reconcile conflicting findings about when interruptions could be beneficial versus detrimental in collaborative settings, researchers identify different types of interruptions, distinguishing those that could be supportive from those intended to assert dominance or control (Kennedy and Camden 1983, Murata 1994). These can also be distinguished empirically in that, for potentially supportive interruptions—referred to by some as "keep" interruptions—the original speaker typically keeps the floor after a brief interjection from a listener in contrast to more aggressive "yield" interruptions when a speaker yields the floor to the interrupter (McLaughlin 1984). Whereas some keep interruptions may actually be aggressive but failed attempts to overtake the floor from the speaker, there is broader consensus that yield interruptions are more unambiguously assertive and competitive. Consequently, in evaluating how team structure results in different patterns of collective attention, we focus on the contrast of interactional synchrony and competitive (or yield) interruptions as the cooperative and competitive manifestations of collective attention, respectively.

Team Structure and Collective Attention: The Influence of Hierarchy

One of the most fundamental aspects of team structure is the type of hierarchy that is present (Fiske 2002, Gould 2002, Magee and Galinsky 2008, Gruenfeld and Tiedens 2010). Hierarchy is commonly manifested via the rank ordering of individuals within the team with one or more individuals having more power (i.e., control over valued resources; French and Raven 1959, Keltner et al. 2008), status (Barkow et al. 1975), and influence than others. All of these dimensions can be expressed through the formal structure of a team with a team leader or leaders holding the highest rank in the team.

Hierarchy is theorized to provide functional value in teams (Weber 1947, Anderson et al. 2006, Halevy et al. 2011) by introducing expectations about role-appropriate behaviors and, thus, simplifying social interaction (Tiedens et al. 2007). Rank-related role differentiation helps by specifying who should defer to whom and reducing conflict (Tiedens et al. 2007, de Kwaadsteniet and van Dijk 2010, Zitek and Tiedens

2012). Consistent with this possibility, professional athletes who are members of hierarchically differentiated sports teams are more cooperative with one another, leading to greater team success than those lacking a hierarchy (Halevy et al. 2012). Across a number of fields, a sizable body of work suggests that hierarchy is beneficial by helping team members know who does what, when, and how (Halevy et al. 2011). Thus, the function that hierarchy serves in shaping expectations suggests that it is likely to have implications for collective attention.

The potential benefits of hierarchy are not unqualified, however, with some work showing a negative effect of steeper hierarchies on attitude-related outcomes (i.e., lower satisfaction, motivation, and commitment) and mixed effects on team performance (Anderson and Brown 2010). Although a variety of potential moderating factors are discussed, such as type of task (independent versus interdependent; Halevy et al. 2012, Ronay et al. 2012) or the type of leader (Anderson and Brown 2010), our focus is on the characteristics of the stability of the hierarchy itself.

Hierarchy stability refers to the susceptibility of an existing hierarchy to change. Stable hierarchies are those that are relatively set after being put in place, whereas unstable hierarchies are those in which individual rankings are mutable. When the hierarchy is unstable, team members are more likely to engage in competitive behaviors to increase their status (Charness et al. 2014, Greer et al. 2018) even at the expense of the team's ability to coordinate (Garcia and Tor 2007, Groysberg et al. 2011). Team hierarchy instability increases intrateam conflict, which manifests via verbal interruptions, and harms performance (Greer et al. 2018).

In contrast to the competitive contexts engendered by unstable hierarchies as well as contexts lacking a clear hierarchy (Tiedens et al. 2007), stable hierarchy is likely to lead to a (relatively) cooperative context in which one's own actions and plans are likely to correspond to others' actions and plans (Carpendale and Lewis 2004, Iani et al. 2014). When all team members are focused on the same desired outcome, the ability to cooperate becomes easier because it is easier to anticipate teammates' thoughts and behaviors (e.g., Brownell et al. 2006, Cortes Barragan and Dweck 2014, Jin et al. 2017). Taken together, if stable hierarchies are more likely to foster team members' ability to understand or anticipate the thinking, feeling, and behavior of others, the result should be a more cooperative form of collective attention. Consequently, we predict that teams with a stable hierarchy exhibit higher levels of interactional synchrony compared with teams with an unstable hierarchy or those lacking a hierarchy.

Hypothesis 1a. *The presence of a stable hierarchy in teams leads to higher levels of interactional synchrony than the presence of an unstable hierarchy and the lack of a hierarchy.*

Whereas we anticipate that the more cooperative behavior associated with a stable hierarchy will lead to higher levels of collective attention as indicated by interactional synchrony, there is reason to believe that more competitive contexts can lead to increased attention as well, albeit in a different form. For instance, evidence from neuroimaging research shows that brain regions associated with theory of mind activation are recruited to a greater extent when individuals are in competitive contexts than in cooperative ones (Decety et al. 2004, Lissek et al. 2008; cf. Tsoi et al. 2016, who do not observe a difference). This occurs because, whereas both competitive and cooperative contexts often involve interdependence in which others' actions affect one's outcomes, competition involves greater uncertainty about others' behavior and intentions than does cooperation. This can lead to more difficulty in accurately judging others' mental states (Tomasello et al. 2005), leading individuals to pay more rather than less attention to others' cues.

Furthermore, one common manifestation of status competition in social situations is verbal interruption (Farley et al. 2010). Interrupting others and not allowing them to complete their utterance is a dominance display and a tactic for managing other members' attention. Rather than signaling a lack of attention, interrupters are attending to the social context and behaving in ways designed to manipulate how others view them. As such, a team whose members exhibit a high level of interruptions can also be demonstrating a high level of collective attention, albeit one that is more competitive in form than in the case of interactional synchrony.

Taken together, if unstable hierarchies are more likely to foster team members' uncertainty about the thinking, feeling, and behavior of others or to trigger concerns about relative status within the team, the result should be more competitive manifestations of collective attention. Consequently, we predict that teams with an unstable hierarchy or lack of a hierarchy exhibit higher levels of competitive verbal interruptions compared with teams that have a stable hierarchy.

Hypothesis 1b. *The presence of an unstable hierarchy or the lack of hierarchy in teams leads to higher levels of competitive interruptions than the presence of a stable hierarchy.*

Importantly, whereas we discuss the ways in which extant literature can be interpreted as suggesting that interactional synchrony and competitive interruptions are both manifestations of collective attention, we anticipate that the degree to which they facilitate development of collective intelligence likely depends on how members of the team respond to such behavior. As others point out, competitive situations often result in more verbal interruptions (Zimmerman and West 1975, Farley 2008), which, at least for some, are a sign of interest and engagement (Makri-Tsilipakou 1994, Conti et al. 2001). For individuals who find competitive contexts more engaging, then, a lack of interruptions might be less engaging. In contrast, for individuals who are more motivated by cooperative contexts, a high level of interactional synchrony could be more engaging. Put differently, whether interactional synchrony or competitive interruptions positively impact a team's collective intelligence likely depends on how team members respond to cooperative or competitive team contexts.

Team Gender Composition, Cooperative vs. Competitive Speech Patterns, and CI

Whereas there are many ways that teams can differ in terms of their composition, a growing body of research points to the possibility that the effects of team structure—in particular, the type of hierarchical structure—on team process depends on the gender composition of the team. For example, in the absence of externally imposed conditions, female-dominated teams tend to engage in more equal participation, which is related to higher levels of interactional synchrony (Tomprou et al. 2021). In addition, evidence from a variety of studies shows that women tend to avoid competitive situations, particularly if there is a potential for conflict or need for negotiation (Niederle and Vesterlund 2007, Small et al. 2007) and tend to feel more uncomfortable than men when working in competitive environments and, thus, perform less effectively (Gneezy et al. 2003, Lee et al. 2016). Moreover, women appear to respond particularly negatively to interruptive behavior and dislike being interrupted to a greater degree than do men (Bresnahan and Cai 1996). Taken together, these findings strongly suggest that women, all else equal, prefer more cooperative contexts and perform better in them. If this is true, then we anticipate that it is only when collective attention takes a more cooperative form—interactional synchrony—that the collective intelligence of female-dominated teams in particular is enhanced.

In contrast, competition is argued to be more behaviorally normative for men (Moscovici and Nemeth 1974, Eagly 1987, Schmid-Mast 2001). Whereas competition can reduce the level of intrinsic motivation that women experience, it tends to increase motivation in men (Weinberg and Ragan 1979, Deci et al. 1981). As discussed, one way in which competition manifests is through interruptions. Some studies suggest that men's level of engagement in conversation (as signaled by nonverbal behavior, such as nodding) actually increases when they are being interrupted by a confederate (Farley et al. 2010). Similarly, Gnisci et al. (2012) find that high levels of disagreement interruptions are seen positively because they are taken as a sign of interest and attention by those who are interrupted. In summary, these findings strongly suggest that men, all else equal, prefer more competitive contexts and perform better in them. If this is true, we anticipate that it is only when collective attention takes a more competitive form—competitive interruptions—that the collective intelligence of male-dominated teams in particular are likely to benefit.

Taken together, we expect that team gender composition moderates the effects of both forms of collective attention—interactional synchrony and interruptions—on collective intelligence. Specifically, we anticipate that interactional synchrony is more beneficial in female-dominant teams, whereas interruptions are more beneficial in male-dominant teams.

Hypothesis 2a. *Team gender composition moderates the association between interactional synchrony and CI such that synchrony enhances CI in majority female teams.*

Hypothesis 2b. *Team gender composition moderates the association between interruptions and CI such that interruptions enhance CI in majority male teams.*

Figure 1 depicts the constructs in our conceptual model and our hypotheses as well as our operationalization of them in our experiment, which we describe further in the next section.

Method

Design and Participants

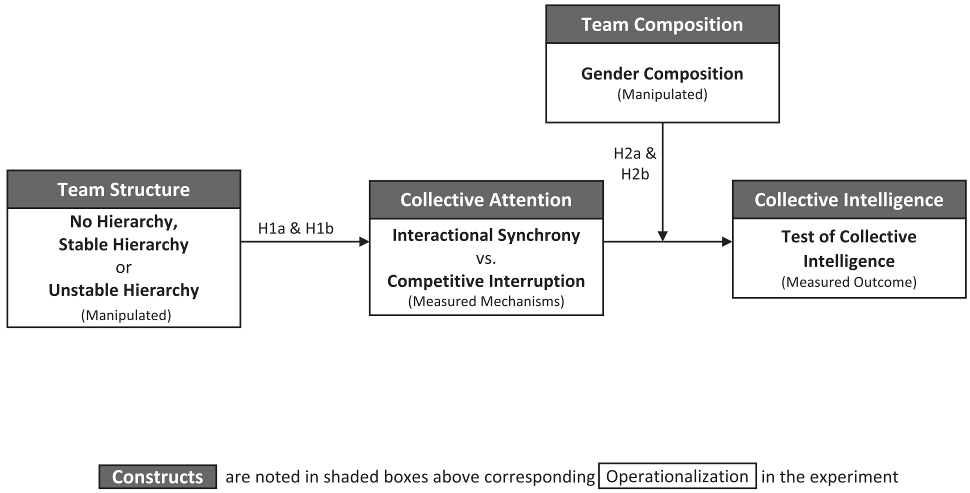
We recruited 600 participants from a university research participant pool in the Mid-Atlantic United States to a two-hour laboratory study on "group behavior." All participants were paid $20 for their participation.

The study followed a 3 × 5 between-groups design with hierarchy (stable, unstable, or no hierarchy) crossed by the team's gender[1] composition (zero, one, two, three, or four women). Participants were randomly assigned to teams of four, and teams were randomly assigned to a hierarchy condition. Four teams were excluded for technical reasons (e.g., failure of audio recording equipment), leaving 584 participants (50.1% men; M_{age} = 25.94, SD_{age} = 8.77, Min_{age} = 19, Max_{age} = 71) in 146 groups.

Tasks and Manipulation

Teams worked together in a private room with members seated around one table, each with the member's own laptop, each connected to the Platform for Online Groups Studies (POGS; pogs.wiki) to enable collaboration. Teams completed a preliminary team decision-making task to get to know each other, following which the stable and unstable hierarchy teams voted for a team leader, which comprised our hierarchy manipulation. To vote, members ranked the other three team members in order of preference; the experimenter privately tallied

Figure 1. Conceptual Model



the rankings and then announced the resulting decision. To manipulate hierarchy stability, teams in the unstable hierarchy condition were told that later they could vote again and choose a different leader. Stable hierarchy teams were told that the person selected would be the leader for the remainder of their session (for a similar manipulation, see Maner and Mead 2010, Case and Maner 2014). Teams in the no hierarchy condition did not vote to select a leader nor did the experimenter assign leadership.

Next, teams completed the Test of Collective Intelligence (TCI; Kim et al. 2017) as described as follows. At the conclusion of their work, team members completed a postexperiment survey, which included our experimental manipulation check and measure of task conflict along with demographic variables (e.g., age, race).

Measures

Collective Intelligence. Teams completed the TCI together to measure team collective intelligence, administered via POGS and timed to take exactly 23 minutes. The TCI captures 176 different measurements across different task types requiring different collaborative processes for completion (McGrath 1984, Larson 2010). To calculate a CI score for each team, we standardized and weighted the team's score on each task using norms and weights derived in a meta-analysis of more than 1,300 teams (Riedl et al. 2021) and calculated the average. The reliability of the TCI in this sample is Cronbach's $\alpha = 0.92$.

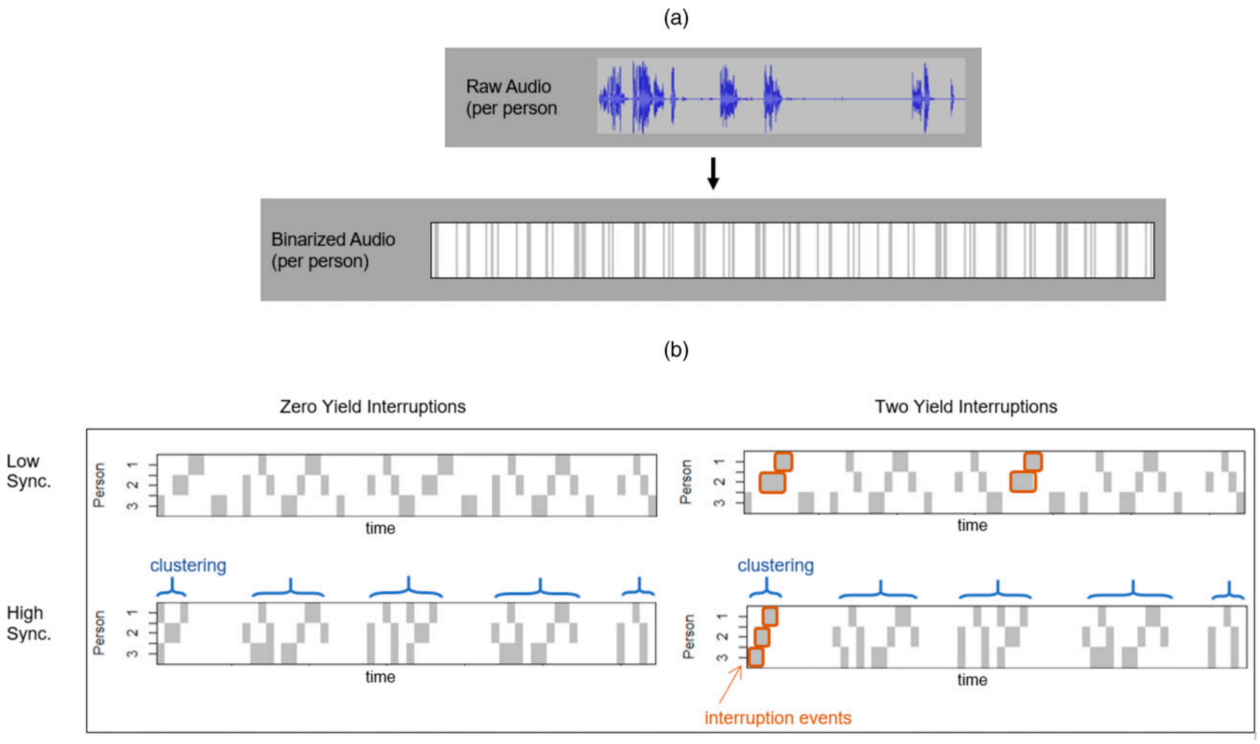
Interactional Synchrony. During the experiment, each participant wore a microphone that recorded individual vocal communication. The audio stream for each person was then binarized into indicators (ones and zeros) of whether a person was talking or not, using a sampling rate of 100 ms because the minimum length of meaningful utterances is 300 ms (Swingle 1984), and the sampling rate should be at least double the shortest signal one wishes to detect (Shannon 1998). This allowed us to capture even short utterances with high precision (see Figure 2 for a schematic illustration).

We analyzed the binarized speaking data for each team using the R package *synchrony* and the function *community.sync* (Gouhier and Guichard 2014). The resulting index ranges from zero to one, capturing the cooccurrence of speaking across all pairwise combinations of members through the duration of the team's work. Whereas zero indicates that the timing of team members' speaking is random and unrelated to one another, values closer to one reflect that all people in the team are clustering their talking together in the same time windows, such as when a group is singing or reciting a prayer.

Competitive Interruptions. Using the same binarized audio data we used for the interactional synchrony measure, we identified every instance in which the speaking onset of a team member occurred at a time when one of the other team members was already speaking. We then identified and counted the instances in which the initial speaker ceases speaking and yields the floor to the interrupter to serve as our measure of competitive interruptions (McLaughlin 1984, Swingle 1984).

Task Conflict. At the end of the experiment, participants completed a four-item measure of task conflict (adapted from Behfar et al. 2008) using a one-to-seven scale to respond to items such as "to what extent did members of your team engage in debate about different opinions or ideas?" This served as a means of triangulating and

Figure 2. (Color online) Audio Data Processing Steps for Calculating Interactional Synchrony and Competitive Interruptions



Notes. (a) Individual-level audio processing. (b) Illustrative example of group audio processing with hypothetical three-person groups exhibiting low vs. high interactional synchrony and zero to two competitive or yield interruptions. For illustrative purposes, speaking amounts are held constant. As interactional synchrony increases, the clustering of speech increases, indicated with bracketing. Low and high interactional synchrony levels depicted here correspond to low and high levels in the study sample. Bold borders indicate speech that is part of a yield interruption. Yield interruptions capture the specific case of overlapping speech wherein one person begins speaking over another person who yields the floor.

validating our behavioral measures of intragroup competition. Team member responses were averaged (α = 0.84) and aggregated at the group level (intraclass correlation coefficient ICC (1) = 0.28, ICC (2) = 0.61, $p < 0.01$, median $r_{wg} = 0.86$).

Observer Ratings of Team Cooperative Work and Team Challenge/Debate. Two independent coders, blind to teams' assigned experimental conditions, reviewed recordings of team interaction and evaluated (on a one-to-five scale) the extent to which (1) teams worked cooperatively and interdependently (versus dividing up and working independently) and (2) team members challenged each other and debated task details and work strategy. One coder rated all 146 recordings, and to check reliability, a second coder rated a randomly selected subset of 45. The intraclass correlation for the two sets of ratings was 0.79 for cooperative work and 0.85 for team challenge/debate. We used the ratings from the one coder who coded all of the recordings for our analyses.

Social Perceptiveness. Social perceptiveness was measured in a survey administered before the team activities using the Reading the Mind in the Eyes (RME) test (Baron-Cohen et al. 2001). Participants completed 18 items,[2] and scores were calculated as the percentage of items answered correctly. The team's mean was then calculated to reflect the team's social perceptiveness.

Control Variables. Because age and race can serve as sources of status and, thus, hierarchy (Ridgeway 2001), we controlled for these variables in our analyses. Team age diversity was calculated as the standard deviation of team member ages, and racial diversity was calculated using Blau's (1977) index.

Results

Descriptive statistics and correlations among study variables are included in Table 1.

Manipulation Checks and Measure Validation

Hierarchy Manipulation Checks. In order to check our leadership and hierarchy stability manipulations, on the posttask survey participants were asked (1) whether their team selected a leader, and (2) if it chose a leader, whether their leader could change. Overall, 98% of stable hierarchy and 99% of unstable hierarchy participants

Table 1. Descriptive Statistics and Correlations

Variable	Mean	Standard deviation	1	2	3	4	5	6	7	8	9	10	11
1. *Collective intelligence*	0.01	1.00											
2. *Interactional synchrony*	0.25	0.03	0.05										
3. *Competitive interruptions*	9.72	8.12	−0.03	−0.56**									
4. *Observations rating cooperation*	1.38	0.73	−0.04	0.34**	−0.24**								
5. *Observations rating challenge/debate*	2.02	0.59	−0.20*	−0.23**	0.25**	−0.33**							
6. *Task conflict*	4.59	0.86	−0.08	−0.13	0.23**	−0.14	0.22*						
7. *Number of women* (centered)	0.01	1.42	−0.07	0.01	0.06	−0.01	0.06	−0.03					
8. *Stable hierarchy* (dummy)	0.33	0.47	−0.05	0.22**	−0.23**	0.05	0.09	0.00	−0.03				
9. *Unstable hierarchy* (dummy)	0.33	0.47	0.02	−0.09	0.12	0.05	0.11	−0.01	0.00	−0.49**			
10. *Equal status* (dummy)	0.34	0.48	0.03	−0.13	0.11	−0.10	−0.20*	0.01	0.04	−0.51**	−0.51**		
11. *Age diversity*	5.86	5.83	−0.40**	−0.04	0.09	0.04	0.12	0.05	0.09	0.03	−0.06	0.03	
12. *Racial diversity*	0.52	0.18	0.08	0.01	−0.04	−0.14	−0.08	−0.02	−0.14	−0.03	0.00	0.04	−0.11

*Correlation is significant at the 0.05 level (two-tailed).
** Correlation is significant at the 0.01 level (two-tailed).

indicated they selected a leader versus 2% of those in the no hierarchy condition, χ^2 (2) = 421.01, $p < 0.001$, and 96% of unstable hierarchy participants indicated they could change their leader versus 4% of stable hierarchy participants, χ^2 (2) = 685.33, $p < 0.001$. These measures support the effectiveness of our manipulations of hierarchy instability.[3]

Speaking Pattern Measurement Validation. We created two independent computational measures of group speaking patterns: interactional synchrony and competitive interruptions. Theoretically speaking, these two measures are orthogonal; it is entirely possible that a team could both synchronize the time periods of its speaking during its work and interrupt each other as they do so, or they could do just one of those or neither. Empirically, the two measures are significantly correlated ($r = -0.56$, $p < 0.05$; see Table 1) but not to the extent that they should be considered indicators of one single dimension, and thus, we analyze them separately.

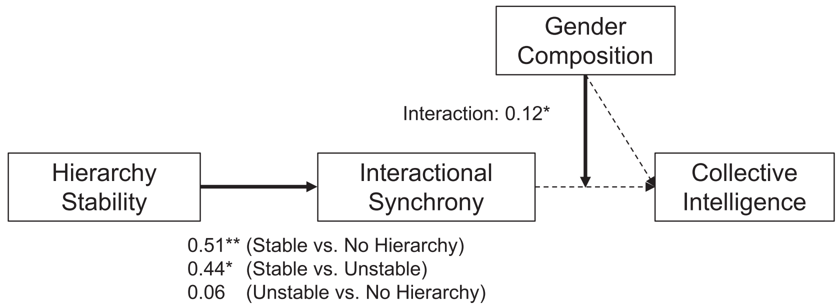
To evaluate the content validity of our computational measures of interactional synchrony and competitive interruptions, we compared them with our observers' qualitative evaluations of cooperative work and team challenge/debate as well as participants' self-report measure of task conflict (see Table 1). There is a significant positive correlation between observer-rated cooperative work and computational measures of interactional synchrony ($r = 0.34$, $p < 0.001$) as well as between observer-rated team challenge/debate and computational measures of competitive interruption ($r = 0.25$, $p = 0.004$). In addition, self-reported task conflict is significantly and positively correlated with observer-rated team challenge/debate ($r = 0.22$, $p = 0.01$) and computational measures of competitive interruption ($r = 0.23$, $p = 0.005$). Taken together, this evidence of convergent and divergent validity supports the conclusion that our computational measures of interactional synchrony and competitive interruptions are capturing dynamics reflecting team cooperation and competition, respectively.

Tests of Hypotheses

To test the hypotheses suggested by our conceptual model (depicted in Figure 1), we employed structural equation modeling (SEM) using maximum-likelihood estimators (Bollen 2005), which we carried out using the *lavaan* package (Rosseel 2012) for SEM implemented for R. SEM is shown to be a more robust method for testing more complex models, including mediation effects, compared with the hierarchical regression approach (Cheung and Lau 2008). We use Bollen–Stine's model-based bootstrapping (drawing 1,000 samples) to determine statistical significance and the adjusted bootstrap percentile method to construct confidence intervals. We dummy-coded our hierarchy stability conditions to include in the SEM analyses, using the no hierarchy condition as a reference category. We used z-scores for continuous variables and zero-centered the gender composition variable to enhance model convergence and for ease in interpreting interactive effects.

Effect of Hierarchy Stability. Figure 3 displays the SEM estimated to test the model of the predicted relationships of our experimental variables with interactional synchrony, which was a good fit to the data (χ^2 (13) = 13.93, $p = 0.645$; comparative fit index (CFI) = 0.99; root mean square error of approximation (RMSEA) = 0.02; standardized root mean squared residual (SRMR) = 0.05; see Figure 3). In Hypothesis 1a, we predict that a stable hierarchy enhances interactional synchrony relative to teams with an unstable or no hierarchy. Our results support our predictions; the stable hierarchy condition led to more interactional synchrony than the unstable hierarchy condition ($B = 0.44$, $p = 0.036$) and

Figure 3. SEM Model Examining Effects of Hierarchy Stability on Interactional Synchrony and CI as Moderated by Gender Composition



*p < 0.05, **p < 0.01. χ^2 (13) = 13.93, p = 0.645, RMSEA = 0.02, CFI = 0.99, SRMR = 0.05.

Conditional effect of cooperative synchrony on CI for different gender compositions:
All Women: 0.32, p = 0.015
3 Women: 0.20, p = 0.024
2 Women: 0.09, p = 0.250
1 Woman: –0.03, p = 0.770
All Men: –0.15, p = 0.322

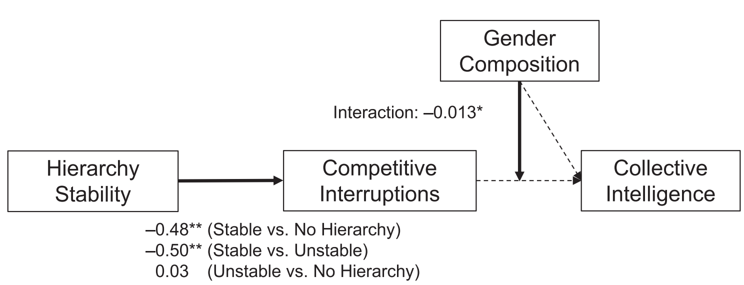
Notes. Dashed lines are not significant. Controlled relationships include age and racial diversity effects on interruptions and collective intelligence, gender composition effect on interruptions, and hierarchy stability effects on collective intelligence. Covariances include unstable and stable hierarchy conditions, gender composition and racial diversity, and age and racial diversity.

the no hierarchy condition (B = 0.51, p = 0.011). We find no significant difference between the unstable and no hierarchy conditions in their effect on interactional synchrony (linear hypotheses for equal coefficients in the SEM model; p = 0.748). Gender composition did not predict interactional synchrony (B = 0.02, p = 0.755).

Figure 4 displays the SEM estimated to test the predicted model of relationships of our experimental variables with competitive interruptions; this model was also a good fit to the data (χ^2 (13) = 9.86, p = 0.827; CFI = 1.00; RMSEA = 0.00; SRMR = 0.04; see Figure 4). As predicted in Hypothesis 1b, the unstable hierarchy condition led to more competitive interruptions than the stable hierarchy condition (B = 0.50, p = 0.009) as did the no hierarchy condition (B = 0.48, p = 0.006). The unstable and no hierarchy conditions did not significantly differ in competitive interruptions (linear hypotheses for equal coefficients in the SEM model; p = 0.918). Gender composition did not predict competitive interruptions (B = 0.03, p = 0.670).

As a robustness check, we also examined the role of the team's average social perceptiveness, which is

Figure 4. SEM Model Examining Effects of Hierarchy Stability on Interruptions and CI as Moderated by Gender Composition



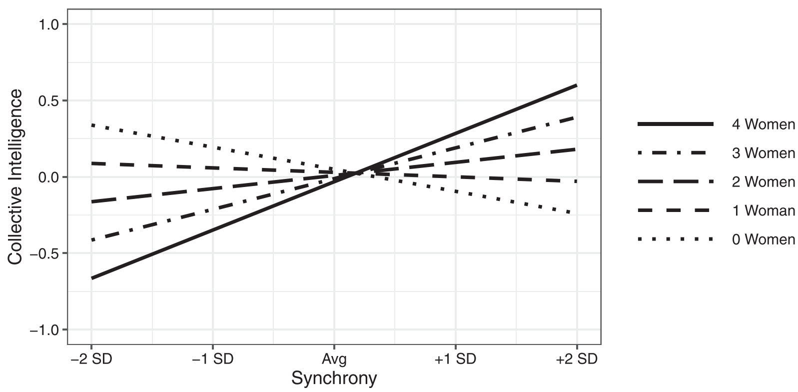
*p < 0.05, **p < 0.01. χ^2 (13) = 9.86, p = 0.827, RMSEA = 0.00, CFI = 1.00, SRMR = 0.04.

Conditional effect of interruptions on CI for different gender compositions:
All Men: 0.28, p = 0.044
1 Woman: 0.15, p = 0.117
2 Women: 0.02, p = 0.811
3 Women: –0.11, p = 0.301
All Women: –0.24, p = 0.120

Dashed lines are not significant. Controlled relationships include: age diversity and racial diversity effects on interruptions and collective intelligence; sex composition effect on interruptions. Included covariances include those between sex composition and social perceptiveness, unstable and stable hierarchy conditions, sex composition and racial diversity, and age diversity and racial diversity.

Notes. Dashed lines are not significant. Controlled relationships include age and racial diversity effects on interruptions and collective intelligence, gender composition effect on interruptions, and hierarchy stability effects on collective intelligence. Covariances include unstable and stable hierarchy conditions, gender composition and racial diversity, and age and racial diversity.

Figure 5. Interaction of Synchrony and Gender Composition on CI



shown to be a significant predictor of team synchrony in prior research (Chikersal et al. 2017). First, we added social perceptiveness to our primary analysis focused on interactional synchrony specifically as an outcome of the team composition variables (i.e., gender) and as a predictor of interactional synchrony. The model was a good fit to the data (χ^2 (17) = 17.10, p = 0.672; CFI = 1.00; RMSEA = 0.01; SRMR = 0.05). Consistent with extant research, we observed that social perceptiveness is a significant predictor of interactional synchrony (B = 0.108, p = 0.039). As in our primary analysis, team gender composition is not directly related to interactional synchrony (B = −0.005, p = 0.935), but it is related to social perceptiveness (B = 0.39, p = 0.028). The indirect effect of gender composition on interactional synchrony via social perceptiveness is marginally significant (B = 0.031, p = 0.088). The effect of stable hierarchy on interactional synchrony remains significant even when controlling for team social perceptiveness and gender composition (versus no hierarchy: B = 0.51, p = 0.010; versus unstable hierarchy: B = 0.41, p = 0.042). By contrast, when predicting competitive interruptions, we find that neither gender composition nor social perceptiveness are significant predictors and teams in the unstable and no hierarchy conditions exhibited significantly more interruptions than stable hierarchy teams even when controlling for team social perceptiveness and gender composition (B = 0.50, p = 0.007; B = 0.48, p = 0.010; respectively).

Taken together, these analyses underscore the strength of the hierarchy manipulation in shaping interactional synchrony and competitive interruptions. Whereas social perceptiveness is a significant predictor of interactional synchrony, the effect of stable hierarchy is substantially larger, and we saw no team composition effects on competitive interruptions. This suggests that team structure is a very important point of leverage for encouraging more cooperative versus competitive manifestations of collective attention.

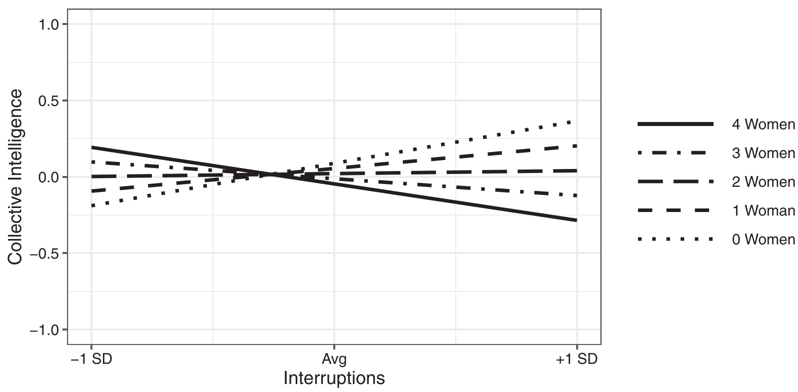
Effects of Interactional Synchrony and Interruptions on CI. Next, we examined the effect of interactional synchrony on CI. The direct effect of interactional synchrony on CI was not significant (B = 0.09, p = 0.249); rather, as predicted by Hypothesis 2a, the relationship was qualified by the gender composition of the team, which moderated the effect of interactional synchrony on CI (B = 0.12, p = 0.048). Upon probing this interaction to examine the simple slopes (see Figure 5), we found that interactional synchrony had a positive effect on CI in teams with majority women (three women: B = 0.20, p = 0.024; four women: B = 0.32; p = 0.015). The effect of interactional synchrony on CI was not significant for other gender compositions. This suggests that interactional synchrony is beneficial in female-dominated teams.[4]

In examining the effect of competitive interruptions on CI, we observe that they also did not have a direct effect: (B = 0.02, p = 0.811); however, as predicted by Hypothesis 2b, the interaction effect of competitive interruptions with gender composition was significant (B = −0.13, p = 0.035). In probing this interaction to examine the simple slopes (see Figure 6), we found that competitive interruptions had a significantly positive effect on CI when the team was all male (B = 0.28, p = 0.044), whereas the effect was not significant for teams with three men (majority male) or other gender compositions.[5]

Discussion

A growing number of studies point to the influence of collective attention on collective intelligence. How, then, can we enhance collective attention? Here, we conduct a randomized controlled experiment to test the causal effect of team structure in shaping collective attention and its interaction with team gender composition to affect collective intelligence. What we find provides a more nuanced picture than previously understood; more cooperative manifestations of collective attention, such

Figure 6. Interaction of Competitive Interruptions and Gender Composition on CI



as interactional synchrony, are facilitated by stable hierarchy and beneficial for CI but *only* in teams that are predominantly female. By contrast, teams with no hierarchy or unstable hierarchies manifest more competitive, interruptive patterns of collective attention, which also enhance CI but *only* in all-male teams. These findings have important theoretical implications for research on team structure, team composition, and collective attention.

First, our finding that the presence and stability of hierarchy can shape different manifestations of collective attention is an important nuance for the functional perspective of hierarchy (Gruenfeld and Tiedens 2010). An underlying conclusion of this work and others is that hierarchy in and of itself is neither good nor bad for team functioning. Our work here serves to reinforce this point and provides greater clarity on two dimensions that impact the effect of hierarchy on team performance: its stability and the gender composition of the team. Moreover, we add to this research stream by showing that the functional benefits of hierarchies derive, at least in part, from their ability to enhance collective attention. In highlighting the impact of hierarchy stability on collective attention, we reinforce the idea suggested in extant work that hierarchical relationships and structures can impact unconscious interpersonal processes (Tiedens et al. 2007) in ways that have implications for team performance. In building on work suggesting that the effects of hierarchy are both implicit and explicit (Caza et al. 2011), our findings demonstrate the value of behavioral measures of intragroup processes that capture interaction patterns that can go unnoticed by team members themselves. For example, in the present work, the effects of team hierarchy stability on the competitive versus cooperative communication patterns in the team are likely occurring outside of participants' explicit awareness or conscious intent in ways that self-report survey measures of group process might miss.

Furthermore, our findings contribute to the communications literature by clarifying the role of structure, particularly unstable hierarchy, in increasing the incidence of competitive interruptions. Furthermore, our study clarifies the conditions under which interruptions are harmful versus helpful to the quality of collaboration by demonstrating the impact of team gender composition. In doing so, our work reinforces and builds on findings showing that men and women differ in their interpretations of interruptive speech (Bresnahan and Cai 1996) with implications for performance. These results also bolster prior work demonstrating that competition benefits the performance of men, but not women, when working individually (Gneezy et al. 2003) as well as in teams (Baer et al. 2013). In doing so, our findings also contribute to answering the question of how gender composition affects team performance (Walker et al. 1996, Chatman and O'Reilly 2004, Woolley et al. 2010, Apesteguia et al. 2012, Hoogendoorn et al. 2013). In extant work, the relationship between gender composition and team performance is not straightforward; some find that female-dominated teams have worse performance as compared with other team compositions (Apesteguia et al. 2012), whereas others find the opposite (Woolley et al. 2010, Riedl et al. 2021). This study adds an important insight by showing that the effect of gender composition on team performance depends greatly on the compatibility between a team's composition and the team process encouraged by its structure.

Finally, these results suggest an important caveat to the previously identified link between more cooperative forms of coordination and CI, such as synchrony (Chikersal et al. 2017) or more equal conversational turn taking (Woolley et al. 2010, Engel et al. 2014, Tomprou et al. 2021). Again, prior work shows that female-dominated teams tend to have more cooperative and egalitarian norms such that even male members of female-dominated teams engage in cooperative behavior; the reverse is true of male-dominated teams, in which all members, including women, tend to engage in more competitive behaviors (Chatman and O'Reilly 2004). Our findings suggest that, when team members adapt their pattern of communication to match what is normative for team members, this may be a functional adaptation that facilitates effective collaboration. Notably, these results indicate that effective communication in one team does not necessarily look like effective communication in another team; "smart" coordination may take different forms depending on who is on the team.

Aside from its theoretical contributions, our study also has methodological implications for research on constructs, such as collective attention. Here, we develop unobtrusive measures of verbal communication patterns, and through triangulation with self-report and qualitative observational measures, we demonstrate the construct validity of our computational measures of interactional synchrony and competitive interruptions in teams. We hope the development of such measures enables these and other important group process variables to be studied in a broader range of settings with larger samples enabling more robust analyses. Here, we find that these measures uncover some important and largely misunderstood mechanisms; had we simply examined the impact of the team composition and structure on outcomes, we would have drawn some erroneous conclusions. Our approach, therefore, highlights the important benefits of capturing and analyzing detailed process data, which we hope has been made more tractable for researchers through the application of our presented methodology.

We would be remiss if we did not acknowledge some of the limitations of the present work. First, the degree to which these findings, which are based on short-term, laboratory-based teams, generalize to longer term collaborations in other settings is an aspect that requires further examination in future work. No single study can address all aspects of internal validity and generalizability; here, our use of random assignment and experimental manipulation enables the establishment of causality, which provides a stronger basis on which to examine these dynamics in organizational settings, in which randomized controlled experiments of composition and structure are typically not possible. It is interesting to observe the strong effects elicited by the internal context created by group structure and composition even in these ad hoc groups; if coupled with an external context, such as a competitive organizational culture, one can only imagine how much stronger these effects could become. We hope that future research is able to examine similar situations in organizations in which both internal and external context can be considered (Maloney et al. 2016) and contribute additional insights and nuances.

Despite these limitations, there are several practical implications of the work. First, consistent with other recent reviews of the literature (Greer et al. 2018), we find that the effect of hierarchy in teams is nuanced. Organizations that induce competition among team members via their performance review and promotion processes, for instance, are likely to undermine the ability of their teams to collaborate effectively unless they are able to instill general norms and expectations around more competitive interaction styles. The same is likely true for organizations that fail to institute a hierarchy and allow employees to collaborate as peers as our findings demonstrate that no hierarchy teams behaved very similarly to unstable hierarchy teams. Second, in terms of gender composition, our findings show that the conditions conducive to effective collaboration in predominantly female teams are different than those conducive to collaboration in all-male teams. This suggests that organizations that are predominantly male or female are likely to cultivate collaboration climates that are inhospitable to the minority gender. It also raises the question as to how to foster collaboration in teams that are gender-balanced. Future work might explore the use of interventions that either help individuals who are of the minority gender understand and operate within different styles of interaction or help teams more explicitly set norms and expectations about how to work together.

In conclusion, the findings of the current study add to a growing body of evidence that a team's level of collective attention provides an important basis for collective intelligence to develop. Organizational leaders would do well to enhance the likelihood that their teams develop high CI. An open question has been whether CI can be encouraged systematically; the evidence presented here suggests that the composition of the team and how it is structured are two important foundations for collective attention and collective intelligence.

Acknowledgments

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Endnotes

[1] Our categorization of gender is based on participant drivers' licenses used for study registration. We use the term "gender" rather than "sex" to be consistent with the American Psychological Association's guidelines on the use of bias-free language: https://apastyle.apa.org/style-grammar-guidelines/bias-free-language/gender.

[2] The original RME scale is 36 items. We used a shortened 18-item version, which we validated by having participants in 57 of the groups (228 individuals, 38% of the sample) complete the full 36-item version of the RME scale. We calculated scores for these participants based on 18 items as well as the full 36 item test; the correlation between the two versions was $r = 0.94$, $p < 0.001$.

[3] Of the 96 teams that selected leaders, 37 were female. The effect of having a female leader was not significant for interactional synchrony ($r = -0.025$, $p = 0.805$), competitive interruptions ($r = 0.109$, $p = 0.291$), or collective intelligence ($r = 0.039$, $p = 0.710$), and we, therefore, do not include this as a variable in our analysis.

[4] As mentioned in the methods section, we controlled for both racial and age diversity in our analyses. We did not find any significant effects of racial diversity on interactional synchrony,

competitive interruptions, or CI. Age diversity also did not significantly affect interactional synchrony or competitive interruptions. However, age diversity was negatively related to CI in both the model analyzing interactional synchrony ($B = -0.39$, $p < 0.001$) and the model analyzing competitive interruptions ($B = -0.41$, $p < 0.001$).

[5] As a robustness check, we explored whether our results for interactional synchrony hold when controlling for competitive interruptions and vice versa, and we observed that they did. There was no substantive change in our pattern of results in terms of both the effect of team structure in the development of interactional synchrony or competitive interruptions or the interaction of each with gender composition in affecting CI. As a second robustness check, we also explored whether our results hold if, instead of using the competitive yield interruptions, we conducted our analysis using keep interruptions. In our data, there are more than four times as many keep interruptions as yield interruptions. However, in estimating an SEM using keep interruptions, we observe patterns that are very similar to the results with the competitive yield interruptions: the unstable hierarchy condition led to more keep interruptions than the stable hierarchy condition ($B = 0.36$, $p = 0.046$) as did the no hierarchy condition ($B = 0.35$, $p = 0.058$), and the interaction effect of interruptions and gender composition on CI is consistent in direction though only marginally significant ($B = -0.12$, $p = -.060$) likely because of the difficulty of separating supportive keep interruptions from those that are actually failed yield interruptions.

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