What Makes a Strong Team? Using Collective Intelligence to Predict Team Performance in *League of Legends*

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ABSTRACT
Recent research has demonstrated that (a) groups can be characterized by a collective intelligence (CI) factor that measures their ability to perform together on a wide range of different tasks, and (b) this factor can predict groups' performance on other tasks in the future. The current study examines whether these results translate into the world of teams in competitive online video games where self-organized, time-pressured, and intense collaboration occurs purely online. In this study of teams playing the online game *League of Legends*, we find that CI does, indeed, predict the competitive performance of teams controlling for the amount of time played as a team. We also find that CI is positively correlated with the presence of a female team member and with the team members' average social perceptiveness. Finally, unlike in prior studies, tacit coordination in this setting plays a larger role than verbal communication.

Author Keywords
Collective Intelligence; Online Games; Online Collaboration; Virtual Teams; Team Performance

ACM Classification Keywords
H.5.3. Group and Organization Interfaces

INTRODUCTION
While today's teams are becoming more "diverse, dispersed, digital, and dynamic (with frequent changes in membership)," some assert that the fundamentals for effective teamwork have hardly changed [23]. Team-level capability is an important enabling condition for team effectiveness, which has been traditionally conceptualized as some combination of the intelligence or skills of individual members [14,52]. Recent research found that teams exhibited a characteristic level of collective intelligence (CI), manifest in their performance across a wide range of tasks, and that this measure of CI predicted future performance on more complex tasks [17,18,57]. The primary objective of this paper is to examine whether CI, which has been previously demonstrated in more traditional groups, generalizes to an emerging type of team that forms, performs, and interacts online with high levels of structural change. To do this, we study existing teams that play *League of Legends*, the popular Multiplayer Online Battle Arena (MOBA) game, which is characterized by an intense, fast-paced competition between two teams of players.

Examining collective intelligence in teams that show high levels of virtuality—diverse, dispersed, digital, and dynamic [22,23]—such as MOBA teams is important for advancing both the CSCW literature and the literature on teams. First, collective intelligence is, by definition, a team's ability to perform a wide variety of tasks [57], and it can serve as an efficient metric of a team's general capability that transcends specific tasks and contexts. However, although previous research on CI has demonstrated its potential to assess team capability beyond a composition of individual abilities, it has primarily been examined in more traditional environments involving teams that work face-to-face at least part of the time. Many of the common predictors of CI, such as proportion of women, average social perceptiveness and equal conversational turn-taking [56,57], may not easily generalize to contexts characterized by high virtuality such as MOBAs. Given that players in MOBAs perform high-tempo tasks without rich, face-to-face communication [33], it would seem that other means of coordination could be more critical. In such

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environments, there may be a larger role for tacit coordination, or coordination that occurs without explicit verbal communication [1,55]. It is thus an open question whether CI would generalize to teams playing MOBA games, or what its correlates would be. This would have implications for how teams are formed or managed in MOBA games.

Furthermore, findings of such a study could shed new light on how CI operates in other environments that are similar to MOBAs. Despite stark differences in the kinds of tasks and settings, other research suggests that social and collaboration dynamics in online video game teams simulate those of other sorts of virtual teams, increasingly common in the modern business world [7,42]. MOBA games are often characterized by intensity, fast decision making, and competitiveness, which is not unusual in real world organizations. The speed of decision making in business is accelerating, forcing leaders and employees to make and modify decisions quickly in response to rivals' actions [42]. Like MOBA teams, teams that face urgent, volatile, and complex environments, such as emergency response groups, may not easily afford explicit, elaborate communication due to the demand of quick decision making and action [35]. Thus, the knowledge we gain from MOBA teams with regard to what makes a smart team operating under such conditions may provide a glimpse into the emergence and development of CI in highly virtual teams faced with intense, fast competition, outside the online gaming world.

Finally, if CI indeed turns out to be a successful predictor of performance in MOBA contexts, it would suggest some fairly concrete steps game designers could take to enhance player team experience. Composing teams with an eye toward the individual characteristics that matter for CI in this context, or designing the environment to encourage the behaviors that enhance CI, are two examples of ways that these research findings could guide game designers.

Here, we examine collective intelligence in the online video game *League of Legends* (*League*), currently the most popular video game in the world with an active monthly player base of 67 million. Players we examined in this study self-organize into teams and battle against other teams in a simulated fantasy world. Based on in-game data, laboratory results, and self-reports of 248 teams in *League*, we find that CI predicts performance in this context just as it does in traditional team contexts. In addition, team compositional variables such as the presence of women and average social perceptiveness positively correlate with CI in these teams, consistent with previous literature. However, surprisingly, the existence of hierarchy enhances CI in *League* teams, and the norm of equal communication does *not* correlate with CI in these teams, departing from prior findings in traditional environments. This suggests that tacit coordination plays a larger role in these teams than we see in traditional contexts, a finding worth further exploration.

BACKGROUND AND HYPOTHESES

Collective Intelligence

Traditionally, group ability or intelligence has been examined in teams as an aggregate of individual member cognitive ability or skills. But a number of studies and meta-analyses have demonstrated that the correlation between average intelligence and team performance is fairly weak, particularly in field settings [14]. This is likely due to the loss of information resulting from crossing levels of analysis [43]. To improve upon this, researchers recently explored whether intelligence exists at the group level, by adopting the same approach that psychologists have used for over a century in examining intelligence in individuals [57]. In measuring intelligence for individuals, psychologists have repeatedly shown that a single statistical factor emerges from the correlations among individual people's performance on a wide variety of cognitive tasks [13,48]. This factor is often referred to as "g" or "general intelligence." General intelligence is conceptualized as an individual's ability to perform across a wide variety of tasks.

Recent research examined whether a similar kind of "collective intelligence" exists for *groups* of people [57]. The researchers gave about 200 groups a wide range of different types of tasks, and found that teams that did well on one type of task tended to also do well on all of the other tasks. A factor analysis of the groups' scores revealed a single, dominant, general factor explaining a large proportion of the variance in all of the groups' scores, consistent with the amount of variance typically explained by the first factor in a battery of individual cognitive tasks [9]. They called this first factor "*collective intelligence.*" Collective intelligence was then shown to predict a team's future performance on more complex tasks [57].

Based on these studies, researchers suggest that CI is "a group's capability to perform across a wide range of tasks" that is a function of both bottom-up and top-down features of the group, specifically, team composition and team structure [56]. That is, CI is built upon some combination of individual members' attributes and group structures, processes, and norms. In both face-to-face and online groups, CI has been predicted by a high proportion of women in the group, high level of average member social perceptiveness, moderate level of cognitive diversity, large amounts of communication and equal distribution of communication [1,18,57]. The positive role of average social perceptiveness in CI suggests that groups composed of individuals with the ability to perceive subtle emotional and interpersonal cues are better equipped to develop higher levels of CI. Women score higher on tests of such abilities, on average, explaining in part why having more women in a group raises CI. Groups that communicate more as well as more equally are also more collectively intelligent, highlighting the importance of group interaction patterns that allow groups to take advantage of skills and resources embedded in all team members.

Collective Intelligence and Virtual Teams

Despite the empirical evidence and utility of collective intelligence as an index of group-level competence, collective intelligence is a fairly new concept, and has only been explored in a limited range of settings. Of special interest in this paper is the emerging type of team characterized as being dispersed, digital and dynamic with fluid membership, a type which is increasing in number and importance in today's organizations [23]. We believe that a better understanding of CI in this type of team will contribute to both the collective intelligence and virtual teams literatures, and help in designing social and technological systems for virtual teams that not only take into account teams' CI but improve it.

Virtual teams are groups of individuals that are geographically dispersed and brought together by technologies to work on a particular task [21]. Instead of dichotomizing virtual teams and non-virtual teams, scholars have recently conceptualized virtual teams in terms of a continuum of virtuality, which varies along multiple dimensions such as geographic dispersion, electronic dependence, and structural dynamism [22]. For instance, a team whose members are highly dispersed, never meet face-to-face, and change frequently in membership and roles could be considered a highly virtual team. Such highly virtual teams may face a number of challenges including communication difficulties due to the lack of social and nonverbal cues, and high demands to adapt to structural changes.

The literature on virtual teams and virtuality has largely focused on identifying the conditions or emergent states that lessen the impact of the challenges to virtual team performance such as trust and shared understanding, and designing group processes and technological systems that support effective virtual teamwork [12,21,28,30]. However, little attention has been paid to virtual teams' capacity to work as a team, or the alternative ways in which they coordinate, which could affect teams' ability to maximize process gains from system interventions. The recent findings on CI challenge us to ask whether some virtual teams are better off based on their group composition and structure, best influenced at their inception. Identifying the role of CI in virtual teams and its building blocks is thus important for developing effective team composition and group structures for virtual teams early on.

Virtual Teams in *League of Legends*

To explore whether collective intelligence is important for virtual teams, especially those with high levels of virtuality, we look to multiplayer online games, which have emerged as a virtual laboratory for studying human social behavior [2,5,42,53]. Among many genres of multiplayer online games, the most extensively studied is the Massively Multiplayer Online Games (MMOs), where a large number of players with evolving characters interact together, typically in one persistent virtual world [26,27]. However, aside from studies that found individuals are motivated to play MMOs for teamwork and collaboration, the literature on MMOs with an explicit focus on teamwork is limited [8]. While the context of MMOs requires coordination and group interaction often around so-called "guilds," the group dynamics in guilds make it challenging to define group membership and to clearly measure team-level performance [10].

Our focus on the popular MOBA game, *League of Legends,* allows us to explore CI in a game that is explicitly team-based. In MOBAs, each player controls a single character on one of two teams that battle with each other. Furthermore, the number of characters in a game is well defined; the matches are relatively short (usually around 30 minutes); and each player starts each match at the identical character power level, meaning neither team is inherently more powerful than the other, making teamwork a key factor in winning [19].

In *League*, games are typically played 5v5 (a match between two five-person teams). The game presents two different types of teams. In the first type, the game's matchmaking algorithms compose a team of players whose skills and experience are roughly the same. A team matched this way does not repeatedly play games together and often players are paired with strangers they have never met, and will never see again in subsequent matches. In the second team type, players self-organize into teams by recruiting friends or other players in the game community, often strangers. They may or may not play together as a team over an extended period of time, but can continue to play together if they choose. A player can belong to multiple teams at a time, and start and dissolve teams flexibly. This study focuses on the second team type, which exhibits various levels of stability in team membership.

A team's goal in the game is to destroy the opponent team's base. Teams start the game controlling "towers" spread across multiple areas of the map, and teamwork is required to take down the opponent's towers and ultimately destroy the opponent's base. Players choose one character type, called a champion, from over 120 champions that vary in focus (e.g., offensive vs. defensive vs. support) and skills. The chosen characters determine the strengths and weaknesses of the team, and the overall strategy the team needs to try to win the game.

Study Hypotheses

In competitive team-based games like *League*, a set of five disparate individuals must effectively use fundamental cognitive skills such as working memory, executive attention, problem solving, and decision making as individuals. They must also work together with other members effectively to win the game. Thus, one may expect that CI, which captures both individual members' cognitive abilities and the group's ability to cooperate, predict team performance in *League* no less than in other settings.

Furthermore, recent literature has identified more similarities than differences in the social dynamics of online games and offline worlds [58]. It is also argued that virtual teams' success still depends upon fundamental principles of teamwork [23]. Therefore, we expect that collective intelligence, an index of general team capability, will be as important to the performance of *League* teams as it is to the performance of more traditional teams. Thus, we propose the following hypothesis:

Hypothesis 1: Collective intelligence will predict team performance in *League of Legends*.

It is known that in multiplayer online games including MMOs and MOBAs, teams greatly differ in commitment to the team and duration of team membership [26]. Some teams may last a long time, while others may disband quickly. In *League*, for example, a player can create up to three teams per week, and can leave a team easily at any time. The low cost of initiating and leaving a team may incentivize the creation of temporary, opportunistic teams in a large quantity. On the other hand, due to the relatively high cost of maintaining social and collaborative relationships, members of active teams that have existed for a long time would likely to continue to collaborate with the same team, instead of venturing into a new team. In fact, in a study of EverQuest II, a popular MMO game, over 90% of collaboration ties between players were found to disappear over the 13 weeks during which the data were collected [45]. However, the longer a tie was maintained, the less likely it was to decay. Taken together, findings from previous research suggest that teams in *League* may be categorized into two general types in terms of team stability: temporary and lasting. Based on existing research, we would expect CI to vary in both temporary and lasting teams, as the conditions fostering CI are largely present at team inception and it remains relatively stable over time [56]. However, just as team stability predicts other important processes such as team learning, we would expect that more stable teams would be better at translating CI into team performance [40]. The social architecture of *League* presents us with a unique opportunity to differentiate teams based on their stability fairly precisely, enabling us to examine whether team stability promotes or constrains the benefit of CI to teams.

Hypothesis 2: Lasting teams will exhibit a stronger association between collective intelligence and team performance than temporary teams in *League of Legends.*

In addition, we aim to see whether the way CI is constructed in face-to-face teams maps onto virtual teams that are in fast-paced and competitive environments like *League*. For instance, we would like to know whether the factors that affect group CI discussed above—such as social perceptiveness, proportion of women, and equality of communication—also carry over to the context where *League* is played, characterized by high virtuality, speed, and competition. This would enrich our understanding of the degree to which the dynamics in MOBA games mirror those of the offline world, setting appropriate boundary conditions for using these games as a virtual laboratory of real-world organizational behavior [42].

First, in line with existing research, we expect that social perceptiveness, and relatedly the proportion of women in the team, will be positively associated with CI in *League* teams. In existing studies of teams collaborating online either in the lab [18] or as part of a longer-term student project [17], there is a strong relationship between social perceptiveness and CI. Researchers reason that social perceptiveness in this context helps to facilitate the detection of subtle cues that enhance collaboration in a sparse cue environment. In addition, in situations where fast decision making and agile adaptation are required, members who are observant and skilled at monitoring the environment add more value to the team [35]. Because women, on average, score higher on tests of social perceptiveness, adding more women to teams tends to raise average social perceptiveness and improve CI [18,57]. Interestingly, highly competitive game genres like MOBA games are still predominantly male, despite the increase of female gamers in general [29,41,46]. Gender stereotypes about gaming skills and hostility to women players are well-documented in the gaming community, industry, and research [41,46]. It is possible that in this environment, teams could evolve in a manner that places less emphasis on social skills than on skills directly related to gameplay. However, given the particular benefits of higher levels of social perceptiveness for fostering collaboration, we still expect to find a positive relationship between CI and social perceptiveness, and perhaps even a special benefit for those few teams that do include women.

Hypothesis 3: Social perceptiveness and proportion of women will be positively associated with collective intelligence in *League of Legends* teams.

Finally, we speculate that some of the team properties captured by CI are especially critical for virtual teams' overcoming the challenges unique to virtuality, but they may take a different form in virtual environments. Specifically, the context and dynamics specific to high tempo, competitive, team-based online games may accentuate certain factors that are not as important in traditional face-to-face groups. For instance, during the game, it is important for teams to make decisions about tactics and strategies collectively, and to coordinate team members' actions as efficiently as possible. In doing so, teams use explicitly verbal communication channels such as voice chat and text chat, which are found to enhance social interaction for team members but to also interrupt coordination [24,54]. Recent research on team-based online games has started to emphasize the importance of more implicit communication mechanics [50] or tacit coordination as players "make sense of team members' activities and adjust their behavior accordingly" using awareness information such as pings [33].

Outside the online game context, there is growing recognition of the importance of tacit coordination in groups, or coordination that occurs without explicit discussion of strategy among the actors involved [55]. A growing body of work recognizes tacit coordination as an important factor in many settings where explicit discussion is not prominent, either because of the fast pace of the unfolding situation [4], or because of the large numbers of indirectly connected actors, such as in an economy [51], or because of the need to improvise quickly such as in jazz performance and sports [38,44]. While research on CI has shown that amount and equality of verbal communication is important in traditional groups, we may see that this plays less of a role, and thus tacit coordination plays more of a role, in teams faced with a high level of virtuality and fast, competitive environments.

Research has also noted the lack of equality in decision making and communication in online gaming teams as certain members spearhead the team's strategies and tactics [42]. Studies on EverQuest II found that skilled players or experts in the game are highly sought after by other players for obtaining advice and for forming groups to complete difficult tasks; yet expert players were more likely to communicate with other players of similar levels [26,27]. In addition, skilled players were found to be highly task-oriented, spending more time in completing tasks than in communicating with peers [27]. Taken together, in *League* teams, a high level and equal distribution of verbal communication may not be a key ingredient of collective intelligence. This leads to our third hypothesis:

Hypothesis 4: Collective intelligence will not be associated with equality of contribution to conversation or decision making in *League of Legends* teams.

METHOD

Overview

In order to examine *League* player teams' CI, game performance, and team characteristics and processes, we collected data in three ways. First, all team members individually completed a questionnaire including demographic information as well as data on psychological variables and group cognition, affect, and behavior. Second, collective intelligence was measured using the Test of Collective Intelligence (TCI), an online test battery (described under the *Tasks and Measures* section) [18]. Participating teams completed this test together as a group on an online platform external to the gaming environment. Finally, in-game data for the participating teams, including performance metrics, play history, and other fine-grained play statistics, were provided by Riot Games after the study was completed. The data is non-public and was provided by Riot Games according to their Terms of Use and Privacy Policy. The study was approved by the Institutional Review Board and all participants signed an informed consent form.

Sample

This study focuses on five-person ranked teams in *League* that were active as of December 2014 in the North American realm. The North American realm was selected to minimize measurement error due to different levels of language proficiency, which may affect the validity of the TCI and self-reported measures as they are written in English. To recruit currently active *League* teams, we posted our research advertisement on the game's official community board and reddit.com/r/leagueoflegends. The study was advertised as a research project to study the ability of a team to perform a wide range of collaborative tasks. Players' interest in this research was high, as evidenced by over 300 comments by players and multiple news stories about this advertisement in game-related communities and blogs. Of over 1,100 teams that signed up for the study, a total of 248 teams completed all components of our study (i.e., filling out the online questionnaire individually and completing the hour-long TCI as a team). Players on teams that fully completed the study requirements were each rewarded in-game currencies worth approximately USD15 and given a summary of the team's results on the TCI. The in-game currency is mostly used for cosmetic changes and does not directly influence game performance.

The final sample was 97% male, and the average age was 22 years old, which is close to the demographic makeup found in other research on *League* players [29,37]. All-male teams comprised about 85% of the sample. On average, teams played 60 games together, spending 36 hours since the team's inception.

As with any study relying on voluntary participants there is a chance for selection bias, but the demographic composition of the teams is comparable to that of the general player community. In addition, players who participated in this study do not significantly differ in engagement rates from other five-person ranked teams. This makes it unlikely that our teams deviate significantly from the general team population in this game environment.

Procedure

Upon signup, team leaders received instructions for the study via email, which they were asked to forward to other team members. A ranked team can have up to nine people (including substitute players), and it was up to the team to define who is on the team when the team had more than five people on the roster. Team members were asked to fill out an online survey individually and then complete the TCI as a group.

The TCI was administered via the Platform for Online Group Studies (POGS), which is a browser-based platform for running group studies that involve synchronous multi-player interaction [17]. In POGS, once the session started, participants were given the roster of team members as well as instructions detailing how to navigate the interface, interact with other members, and complete the tasks.

The interface features a collaborative workplace in the center where all members could see the input of others updated synchronously, similar to the way real-time collaborative editing tools like Google Docs work. Using a chat tool in the interface, team members were also allowed to communicate while completing the TCI. We asked the participants to use this text-based chat feature as the sole communication channel while working on the TCI. Tasks were timed and all members synchronously advanced to the next task, once the countdown timer had reached zero.

Tasks and Measures

Test of Collective Intelligence (TCI)

Collective intelligence was measured using the Test of Collective Intelligence (TCI) designed by Woolley et al.[57] and Engel at al. [18]. The original set of tests used by Woolley et al. contains a wide variety of tasks sampled from well-known group task taxonomies by McGrath [36] and Larson [32]. The original test battery was then adapted into the TCI, an online tool that enables researchers to administer the test in a standardized way [17,18].

The TCI used in the current study consisted of 11 tasks, which together capture four general categories of group ability: generating, remembering, choosing, and executing [17]. For example, to assess a group's ability to *generate* ideas, we used three brainstorming tasks where group members had to come up with as many ideas as they could in response to a variety of problems posed. For *remembering*, members had to complete three memory tasks, which required members to collectively remember as much information as possible based on a video, picture, and list of words. A group's ability to *choose* a correct answer was measured using a matrix reasoning task, an unscramble words task and a Sudoku puzzle. Finally, *executing* tasks aimed to measure a group's ability to perform manual and psychomotor tasks. For this category, we used two typing tasks in which groups had to copy as much and as accurately as possible from paragraphs of text and a list of numbers.

A team's CI was then scored following the method used by Woolley et al. [57]. First, each task was scored, and the raw score was standardized. The scores for similar tasks were then grouped together, by taking their mean (e.g. creating one "Brainstorming" score from the three brainstorming tasks), and then were factor analyzed. A team score on the first factor extracted from this factor analysis served as the team's CI score.

In addition to CI, we gathered data on the teams' communication during the TCI using a chat log captured within POGS. Using the chat log, we computed the total amount of chat words by each team for measuring the amount of communication by the team, and the standard deviation in the number of words entered by team members for measuring the distribution of communication.

Self-Report Measures

The online questionnaire, which was administered prior to the TCI, included questions about demographics, social perceptiveness, personality, individual intelligence, and perceptions of team characteristics and processes. First, we asked participants' age and sex. For social perceptiveness, we used the Reading the Mind in the Eyes (RME) test [6], in which participants were asked to guess the mental states of 36 people based on the pictures of their eyes only. Team members' individual scores on the RME test were averaged to measure the team's social perceptiveness.

We also asked participants to assess various characteristics and processes of their team, with regards to collaboration and social interaction in the game. Unless noted otherwise, individual members' responses on the following measures were aggregated to the team level. Research has shown that team learning, a process of detecting and correcting error, is important for team performance [16]. We measured *team learning behavior* using three items adapted from Edmonson's scale [16].

To assess the degree to which teams spend time and effort developing strategies for winning, *strategy-related process* was measured using a three-item scale adapted from the Team Diagnostic Survey (TDS) [52], particularly the subscale that focuses on measuring the quality of team task performance strategies. For example, participants were asked to indicate the degree to which they agreed with the statements like "our team often comes up with innovative strategies, team compositions, and builds that turn out to be successful," and "our team has a great deal of difficulty actually carrying out the plans we make for how we will approach a situation, team fight or team composition."

Equality in decision making was measured by asking the participants to rate on a seven-point Likert scale the extent to which decision making power is distributed equally among the team members (a) in general, (b) during the early phase of the game, and (c) during team fights in the game.

In addition, we gathered information about team's communication within and outside the game. Participants were asked how frequently they talk to other members to exchange information about the game (*game-related communication*) and how frequently they talk to other members about their life outside the game (*non game-related communication*). Finally, we asked whether or not players engage in in-game chat, online voice chat, and face-to-face communication with team members.

In-Game Metrics

Various in-game metrics about the participating teams were provided by Riot Games. We had access to these metrics on both team and individual levels. For the team metrics, teams' statistics from 5v5 ranked team queue were considered. For the team members' individual metrics, we used the statistics for their individual play in 5v5 ranked solo queue.

To measure teams' game performance, we considered two metrics at the team level: teams' Match Making Rating (MMR) and their skill tier. These metrics were gathered at two points in time: at time of study and six months after study completion. In *League*, teams of similar skill levels are matched to compete. The matching algorithm used to do this is based on MMR. MMR is similar to the Elo rating system, a method for measuring the relative skill levels of players, originally designed for chess competitions by Arpad Elo. A player's rating reflects his or her relative strength and can be used to calculate the expected probability of winning given the opponent's rating. Thus, two players with equal ratings are expected to have an equal chance of winning. When a player scores an unexpected win, that is, when a low-rated player beats a player that is rated higher, the underdog player takes many points from the high-rated player. For an expected outcome, fewer points are transferred. MMR is only used internally and is not visible to players.

In addition, teams are placed in a ranking system comprised of various tiers (Bronze, Silver, Gold, Platinum, Diamond, Master, Challenger; from lowest to highest), each of which contains five numeric divisions (1 to 5). A team progresses to a higher tier after having consistently beaten opponents in the current tier.

Both MMR and skill tier indicate teams' performance level relative to others. Both are derived from the history of wins and losses and are consequently highly collinear. However, while MMR is used internally by the matchmaking system to find the most suitable opponents, skill tier is an externally visible variable to represent a team's skill level. Of the two, MMR is considered the best indicator of skill since it was designed to predict game performance. Skill tier is correlated with MMR, but is still a useful metric for understanding different levels of game performance intuitively. On the other hand, we excluded from our analysis the metrics that are more prone to be influenced by play style (e.g. average number of kills vs. deaths per game) or do not account correctly for opponent strength (e.g. Win-Loss ratio will approach 50% over time for most players since they are facing opponents of similar MMR).

To measure teams' level of experience with regard to the amount of time they have spent playing ranked games, we gathered data on total game count, total hours played, and game count in the last 90 days, at both individual and team levels. Play time metrics were strongly correlated with one another; the average of bivariate correlation coefficients among three time metrics was .92 for individual play time and .80 for team play time. However, individual play time metrics and team play time metrics were not significantly correlated with each other. Confirming the orthogonality of these two types of play time metrics, factor analysis of three time-related metrics for individual play and three time-related metrics for team play resulted in a two-factor solution, accounting for 91% of the total variance. The two factors were referred to as *individual play time* and *team play time* respectively.

Finally, we obtained metrics on teams' play strategy and social interaction. Metrics that indicate a team's strategies that give a big advantage in the game include the number of games with first dragon kill, baron kill, tower kill, inhibitor kill, and first blood. Metrics that indicate a team's orientation to teamwork include assists, and wards bought and placed, which cost the individual player but benefit the whole team. For metrics that indicate team members' social interaction, we considered total report count, total verbal report count, and total honor count. In *League*, players can be reported for making direct offense, socially offensive commentary, purposefully losing the game, refusing to support their team, and not participating in the match. On the other hand, honor badges can be granted by other players for helpfulness, friendliness, teamwork, and being an honorable opponent.

RESULTS

Collective Intelligence Factor Analysis

Factor analysis of scores on all tasks in the TCI using the principal components method yielded one factor with an initial eigenvalue accounting for 38.38% of the variance whereas the next factor explained 14.77%. These results are consistent with prior research [17,18,57], giving additional support to the conclusion of a single dominant collective intelligence factor in groups, including self-organized teams in *League*.

H1: Collective Intelligence and Game Performance

To examine H1, which states that CI predicts actual game performance for *League* teams, we considered four types of performance metrics: MMR at time of study, MMR after 6 months, highest skill tier at time of study, and skill tier after 6 months. Note that MMR and skill tier are collinear as discussed above, but we present the results from both metrics to corroborate our hypothesis testing.

For the relationship between CI and the two MMRs respectively, we ran OLS hierarchical regressions, first entering individual play time and team play time, and then CI. Individual and team play time variables were included as control variables [46] because play time inevitably affects performance, and we aimed to examine how team CI

	MMR at Time of Study		MMR after 6 Months	
	Step 1	Step 2	Step 1	Step 2
Individual Play Time	.30***	.32***	.27***	.28***
Team Play Time	-.22***	-.22***	-.21**	-.22***
Collective Intelligence		.14*		.15*
R^2	.14	.16	.11	.14
R^2 Change		.02*		.02*

Table 1: Results of regression analyses of the effect of collective intelligence on game performance (MMR at time of study and MMR after 6 months) controlling for individual and team play time. Note: N = 248; standardized coefficients (□) used; * *p* < .05, ** *p* < .01, * *p* < .001.**

could uniquely account for team performance above and beyond players' effort and experience.

As shown in Table 1, CI had a significant, positive effect on both MMR at the time of the study and MMR 6 months later, after controlling for individual play time and team play time. That is, assuming that players have spent equivalent amounts of time playing *League* as an individual and as a team, teams with higher CI will have a better chance of winning, and this effect appears to persist for at least six months. One interesting finding to note is that team play time had a negative relationship with team MMR after controlling for individual play time. That is, simply playing a lot as a team not only does not help the actual team performance but hurts it. On the other hand, teams that demonstrated high levels of CI were more likely to play the game well.

Next, the relationship between CI and skill tier, as another indicator of team performance, was examined. Due to the small sample size, teams that are in the top four tiers (platinum, diamond, master, challenger) were grouped to create a new variable called "Platinum and above." An ordered logit regression was conducted with CI as the predictor variable, highest skill tier at time of study as the outcome variable, and individual play time as the control. The results showed that CI significantly predicted highest skill tier at time of study, b = .29, Wald $\chi^2(1)$ = 6. 03, p = .01. Specifically, as CI increases, the change in the odds of moving from a tier to one tier higher is 1.34 (or 57% increase). Figure 1 illustrates this relationship.

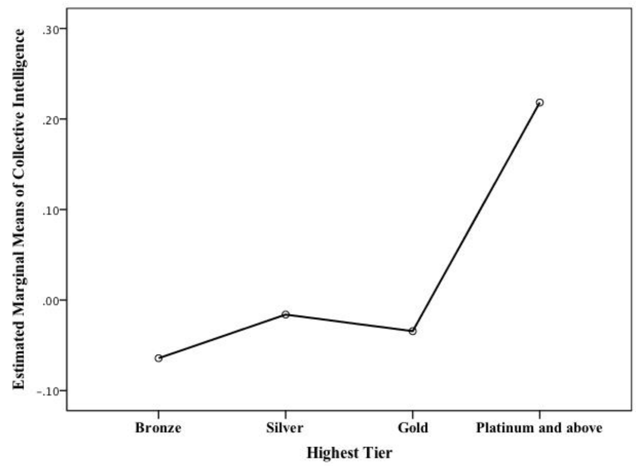

Figure 1: Collective intelligence by highest skill tier reached at time of study

H2: Temporary vs. Lasting Teams

Recognizing that teams in *League* vary in stability, we hypothesized that lasting teams would exhibit a stronger association between CI and team performance than temporary teams. The unique ecosystem around ranked teams in *League* may affect motivations for teams to continue playing together. Since *League* offers a fairly significant incentive for players to achieve the Gold tier, teams may form to pursue this goal and disband after accomplishing it. In addition, teams with tier rank below their expectations may habitually stop playing in the current team, form a new team with the same players, and keep playing until they can place directly into a desirable tier.

Yet, there are a sizable number of teams in our sample that have played for an extended period of time up to almost a year with the same team (see Figure 2). The median number of days during which teams were active was 182. Our data confirm that ranked teams in *League* differ in stability, ranging from temporary groups opportunistically gathered to achieve a specific goal to teams that stayed put for a longer duration, continuously working together to improve their team performance.

Here we define temporary teams as those who disbanded within 90 days after study completion, and lasting teams as those who continued to play together with the same team until at least 6 months after study completion, the point of time at which we obtained team MMR data again. Ninety days is a reasonable time frame to distinguish temporary teams from lasting teams. In a previous study that observed EverQuest II players' social networks, over 90% of relationships discontinued over the course of 13 weeks, showing the largely transient nature of social and collaboration ties in MMOs [45]. On the other hand, the longer a tie survived, the more likely it continued to stay in the future.

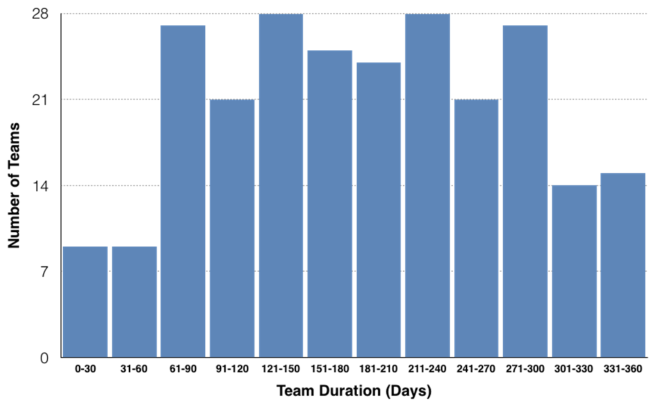

Figure 2: Frequency distribution of teams by team duration (days)

In our data, there were 192 teams that were considered lasting (i.e., active at least 6 months after study completion) and 56 teams that were considered temporary (i.e., inactive within 90 days after study completion). The lasting teams were, on average, active for 205 days total while temporary teams were active for 123 days total ($t(114.162) = 7.459$, $p < .000$), although by definition no longer than 90 days after completing the TCI. However, the two types of teams did not significantly differ in MMR, skill tier, and CI.

We ran separate regression models for the lasting and temporary teams. Table 2 shows the results of two analyses where MMR after 6 months was regressed on CI separately for temporary teams and lasting teams, controlling for individual and team play time. Results show that for temporary teams, CI did not make a significant impact on teams' future MMR. However, for teams that have stayed active for 6 months after the study, CI, measured earlier, significantly predicted MMR in the future. These results suggest that lasting teams in *League*, though not more collectively intelligent than temporary teams on average, were more likely to benefit from CI in improving actual game performance.

H3: Women, Social Perceptiveness, and CI

In H3, we hypothesized that similar to previous research on CI in face-to-face and online lab groups, social perceptiveness and proportion of women would be positively associated with CI in *League*. As expected, CI had a significant and positive correlation with the number of women in the teams ($r = .18$, $p = .005$), and social perceptiveness as measured by the group members' average score on the Reading the Mind in the Eyes test ($r = .14$, $p = .03$). However, the proportion of women and social perceptiveness were not correlated with each other. Previous research explained that the positive relationship between the proportion of women and CI was largely due to higher social perceptiveness in women on average [57]. In our data, on the other hand, an OLS regression with the proportion of women and social perceptiveness as predictor

	Temporary Teams (n = 56)		Lasting Teams (n = 192)	
	Step 1	Step 2	Step 1	Step 2
Individual Play Time	$.41^{**}$	$.41^{**}$	$.26^{***}$	$.28^{***}$
Team Play Time	.08	.08	$-.21^{**}$	$-.21^{**}$
Collective Intelligence		.03		$.17^{*}$
R^2	$.17^{**}$	$.17^{**}$	$.12^{***}$	$.15^{***}$
R^2 Change		.00		$.03^{*}$

Table 2: Two regression models for the effect of collective intelligence on game performance (MMR after 6 months) for temporary teams and lasting teams. Note: standardized coefficients (b) used; * $p < .05$, ** $p < .01$, *** $p < .001$.

variables showed that the proportion of women and social perceptiveness uniquely contributed to CI ($\beta_{women} = .16$, $p = .012$; $\beta_{social\ perceptiveness} = .16$, $p = .012$). In addition, we tested a simple mediation model using PROCESS macro on SPSS [25]. Both the Sobel's Z test and the bootstrapping approach showed that there was no significant indirect effect of the proportion of women on CI via social perceptiveness (Sobel's $Z = 1.10$, $p = .27$; 95% bias-corrected 10000 bootstrap confidence interval ranged from -.0068 to .1003).

It is important to note that only 37 teams out of 248 teams included a female member, and there was only one female member in these teams. Thus, we do not know whether the effect of women would continue to increase as the number of women increases. Relatedly, the lack of correlation between the proportion of women and social perceptiveness is likely due to a restriction of range in number of female members, but it discounts the hypothesis that the effect of women in groups on CI was mediated by social perceptiveness in this sample.

H4: Communication Processes and CI

We hypothesized in H4 that contrary to the previous research [57], equal communication and decision making would not positively predict CI in teams in *League* due to the game's nature that requires fast decision making and prompt adaptation to changes real time. Results showed that equal distribution of communication during the TCI, as measured by standard deviation of chat lines and standard deviation of chat word count, was not significantly correlated with CI in these teams.

In addition, we ran a regression with self-reported communication-related variables as the predictor variables and CI as the outcome variable. We found that teams' perceived equality in decision making had a negative relationship with CI, $b = -.23$, $p = .002$. That is, the more hierarchy in decision making, the higher the CI. In addition, frequency of communication specific to the game predicted CI negatively ($b = -.23$, $p = .06$). In addition, whether they communicate via in-game text chat, online voice chat, or face-to-face did not make any difference in CI. Finally, CI was negatively correlated with team's strategy-related process and team learning behavior respectively, ($r_{strategy} = -.13$, $p = .046$; $r_{learning} = -.15$, $p = .017$).

The negative relationships between CI and these group process variables that are usually beneficial for performance in traditional groups are somewhat surprising. However, they do suggest that teams operating with a high level of virtuality are likely to adopt more tacit coordination methods. Furthermore, it is plausible that it is teams that are experiencing difficulties that would see a need to have extensive discussions or engage in what we think of as team learning behaviors; teams working more smoothly together may be engaging in more tacit coordination, and see less of a need for these more explicit processes [27].

Finally, in addition to the predictors of CI that have been demonstrated in previous research, we examined how team members' behavioral tendencies exhibited within the game, as measured by in-game metrics, were related to team CI. Metrics that indicate aggressive strategies had no significant relationship with CI. However, average wards placed, implying members' teamwork orientation, had a positive correlation with CI ($r = .18$, $p = .005$). Teams' average count of reports received (for toxic behavior) was negatively correlated with CI ($r = -.13$, $p = .04$), indicating that the more members a team has who have been reported for toxic behavior, the less collectively intelligent the team is. However, the average count of honors was also negatively related with CI, $r = -.17$, $p = .007$. These findings may appear contradictory; however, given the strong correlation between count of reports and count of honors ($r = .62$, $p = < .001$), we suspect that the results are partly driven by "honor begging" [59], a phenomenon where some players engage in begging or trading of honors with other players. Alternatively, the findings may suggest that teams composed of individuals manifesting extreme behaviors, whether positive or negative, may not work smoothly as a team, which is consistent with some existing research on real world teams [49].

DISCUSSION

The primary goal of this research was to examine whether CI is predictive of performance in highly virtual teams, and what individual and group factors are associated with teams' CI in these settings. We answered these questions in the context of fast-paced, competitive online video games, using unique data sets comprising in-game metrics, laboratory results, and self-reports of 248 teams in the popular online game *League of Legends.* Our results suggest that CI does, in fact, predict the team's future performance in the game. In addition, as in face-to-face settings, teams' average social perceptiveness and proportion of female members were significant and positive predictors of CI. As is often the case in other real world settings, experience playing the game is the strongest predictor of performance, while more generalized metrics of ability, such as CI, are more modest. While the effect sizes are modest, the power of CI for predicting team performance is similar in magnitude to the relationship between scores on widely used standardized tests and individual performance in longer-term, multi-faceted situations [39].

We also found that teams in *League* vary in stability, which moderated the relationship between CI and team performance. The ranking system and incentive structure in *League* seems to pave the way for opportunistic teams that form primarily to obtain external incentives and disband quickly, which we call temporary teams. However, other teams stayed intact for an extended period of time and continued to play together with the same team. Interestingly, our analyses revealed that the benefit of CI for game performance applied to these lasting teams that are continuously active and committed, but not to the temporary teams. Future research should examine why lasting teams in *League* were better able to reap the benefit of CI to actual performance than temporary teams. Learning is one potential mechanism as stable teams engage in more learning behavior, which may allow them to benefit more than others from collective intelligence [3,16,40]. In addition, as shown in previous research, team stability may have facilitated the development of team cognition such as transacive memory system, which enhances performance [34].

The lack of relationship between CI and the amount and equality of communication, both observed during the TCI and self-reported, was an interesting departure from prior studies. It suggests that in these highly virtual, fast-paced environments, tacit coordination plays an even larger role than may have been appreciated. This would provide even more benefit for teams that remain intact and have members with a higher level of skill in reading the subtle cues inherent in tacit coordination.

In addition, we saw a bigger role for hierarchy and *inequality* in decision-making participation than observed previously. This may be a result of the fact that these environments are very fast-moving, and there is, thus, less opportunity to engage in explicit communication and incorporate everyone's views in making game time decisions. Our findings echo a growing recognition of more automated, tacit coordination in gameplay [50], while complementing previous research that emphasizes the role of communication in enhancing players' social relationships such as trust and interaction [37,54].

Among other areas, our research contributes to the literature on virtual teams. Virtual teams are typically distinguished from traditional teams by their heavy reliance on technologies for team communication, frequently leading to a lack of nonverbal and socioemotional cues. However, many virtual collaboration systems incorporate ways to visually display rich contextual information, such as awareness displays [12,15]. In online video games, for example, a team's gameplay is represented in shared visual environments, and each action by a player becomes a cue that other team members can attend to, make sense of, and act on [33]. The CSCW literature has long noted the important role visual information plays in supporting virtual collaboration by serving as an important resource for situation awareness and conversational grounding [20,31]. Our findings about the importance of tacit communication suggest that enriching these visual, nonverbal cues further may be even more important for enhancing team play than building in systems for better verbal communication.

Our research also makes unique contributions to games research. First, findings of this research confirm that online multiplayer games, particularly MOBAs, serve as a valid laboratory for observing and examining social and collaboration dynamics that mirror those observed offline. In addition, our research offers a triangulated approach to studying social and group behavior in online multiplayer games, thanks to the rich data we collected. Previous research on virtual gaming worlds has relied on in-game metrics that mirror real-world counterparts while non-game data was often obtained from players' self-reports. In research reported here, however, along with self-reports and in-game data, we used a more objective behavioral measure of collective intelligence, the TCI. This approach to measuring team capability helps us to understand team dynamics in online teams that are independent of the rules and incentive systems specific to a particular game, as well as to generalize the findings to settings outside the game.

The findings of this study also have implications for designers of online systems, particularly games. That CI predicts performance highlights the importance of teamwork and cooperation in winning games and moving up to a higher tier of game performance. This is consistent with the efforts of the developers of *League* to reduce so-called toxic behavior including non-cooperation, which is found to decrease player retention rates [47]. For example, players who engage in negative behavior receive reports from their peers and players who engage in positive behavior get honor badges.

In addition to this reputation system, designers of the game may consider directly communicating to players about the benefits to game performance of playing cooperatively and working well together with teammates. They may also find ways to incentivize teams to stay together for longer periods of time. As much as it is easy to initiate and leave a team in online multiplayer games, it is costly to maintain one given the limited capacity one has for keeping relational ties [45]. Given the benefit of team stability to team processes favorable for performance in *League*, designers may consider implementing places and tools that support effective communication and easier coordination among team members in order to reduce the cost of organizing and coordinating for teams [11].

Our study findings regarding the predictors of CI can also be used for team composition, whether it is done by the system, self-organized by players or done deliberately in the context of professional eSports teams. For example, players' gender and behavioral indicators related to social perceptiveness can be incorporated into the matching algorithm. Designers may also consider introducing systems that can enhance social perceptiveness or related skills by enriching the range of nonverbal cues available to team members, such as facial expression, intensity of attention and affect, or maybe even physiological signals of arousal or anxiety. We also encourage designers to note the positive role of tacit coordination and hierarchy in decision making in relation to CI in this context and perhaps encourage teams to create roles and structures to benefit from those practices.

This study is not without limitations. First, participation required a high level of commitment from participants, including willingness of team members to find an hour-long period of non-game time to participate in the TCI and to complete the individual questionnaire. Thus, teams that volunteered and completed both components of the study may not represent all ranked teams in *League*, let alone a general gamer population. However, note that the primary purpose of our study was not to describe the population of teams in *League* in general, but to learn what makes a "smart" team in highly virtual, fast-paced, competitive environments where many emerging types of teams face, including teams in *League*. Second, the interpretation of the positive relationship between the proportion of female members and CI is limited by the sample that is highly male dominant. Teams that had a female member comprised only a small portion of our sample (approximately 15%) and none of them had more than one female member. Thus, our findings suggest that the presence of a female member positively predicts CI. For more robust evidence on the role of women in CI for online game teams, future research may consider oversampling teams that have female members. Finally, we note the weak to moderate relationship of CI and team performance, particularly compared to previous research with face-to-face lab groups [57]. It is important to note that games consist of highly specialized tasks, which require game-specific expertise beyond basic cognitive abilities. In addition, the performance metrics we used capture a lot of this information in the form of teams' chance of winning based on its cumulative play record, and in large part are explained by the members' play skills and experience levels. Thus, observing that CI helps predict teams' future performance above and beyond these very strong predictors suggests it is still important component for successful teamwork, even in this very specialized setting.

CONCLUSION

As social interaction increasingly moves from "real life" to the online world, we have the opportunity and some may even say the responsibility to find ways to enrich the interactions and relationships participants develop. The findings of this study suggest some very concrete elements that can be incorporated into online games to enrich participants' collaborative team experiences, and perhaps thereby enhance their abilities as contributors to collectively intelligent teams.

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