TEAM SPATIAL COGNITION: HOW TEAMS COMMUNICATE, PROCESS, AND USE SPATIAL INFORMATION

by

John P. Solly
A Thesis
Submitted to the
Graduate Faculty
of
George Mason University
in Partial Fulfillment of
The Requirements for the Degree
of
Master of Science
Geoinformatics and Geospatial Intelligence

Committee:

____________________	Dr. Kevin M. Curtin, Thesis Director
____________________	Dr. T. Matthew Rice, Committee Member
____________________	Dr. D. Alec Barker, Committee Member
____________________	Dr. Anthony Stefanidis, Department Chairperson
____________________	Dr. Donna M. Fox, Associate Dean, Office of Student Affairs & Special Programs, College of Science
____________________	Dr. Peggy Agouris, Dean, College of Science
Date: ________________	Summer Semester 2017 George Mason University Fairfax, VA

Team Spatial Cognition: How Teams Communicate, Process, and Use Spatial Information

A Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science at George Mason University

by

John P. Solly
Bachelor of Arts
University of California Santa Barbara, 2015

Director: Kevin M. Curtin, Associate Professor
Department of Geography and Geoinformation Science

Summer 2017
George Mason University
Fairfax, VA

ACKNOWLEDGEMENTS

I would like to thank my committee which consists of Dr. Alec Barker, Dr. Kevin Curtin, and Dr. Matthew Rice. For the last two years, Dr. Barker has mentored me through the research process. I owe much of my success to his encouragement, down-to-earth advice, and time spent reviewing my work. Dr. Kevin Curtin and Dr. Rice have also been instrumental in my thesis process. Both have freely shared their expertise and advice as my thesis took shape. In addition to my committee, this work would not be possible without the funding and support from The Center for Location Science, The Army Research Institute, and the Geography and Geoinformation Science Department at George Mason University.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

TEAM SPATIAL COGNITION: HOW TEAMS COMMUNICATE, PROCESS, AND USE SPATIAL INFORMATION

John P. Solly, M.S.

George Mason University, 2017

Thesis Director: Dr. Kevin M. Curtin

Team spatial cognition is a set of shared mental processes through which teams communicate, process, and use spatial information. Although there is considerable research on teams, researchers have not focused on how teams use spatial information. This prevents the development of methodologies to better understand how teams make spatial decisions. In this research, team spatial cognition was examined through analysis of movement and communication data collected during team pursuit and evasion experiments. 31 lab experiments were conducted with 266 participants using an interactive map-based computer game. Written communications were mined for key team cognition variables such as leadership and backup behavior. The communications were also mined for spatial cognition variables such as spatial reference frame and distance/direction cues. To determine if there was evidence for team-level spatial cognition, player communications were processed using qualitative data analysis (QDA)

techniques. The results demonstrate that there is evidence for team-level spatial processes such as districtization of space, leadership driven spatial reference frame, and spatial backup behavior. Future research could further explore these shared mental processes by investigating these findings across different types of teams and situations.

CHAPTER ONE: MOTIVATION

Exploration of Team Spatial Cognition was born out of a research project, Understanding Network Socio-Geographic Dynamics, conducted by George Mason University's Center for Location Science (locationscience.gmu.edu) and funded by the U.S. Army Research Institute for the Behavioral and Social Sciences. The goal of the research was to examine the spatial characteristics of team activities, especially the movements and communications of human groups trying to accomplish organizational tasks. The project collected information to build concepts to better understand why, how, and when individuals, teams, and systems of teams make choices about their locations.

Preliminary results showed several patterns including spatial temporal clustering, and boundary seeking behavior Barker (2015). Though there appeared to be measureable spatial patterns in how teams played the game, it was unknown why this was occurring. Namely, it was unknown if these patterns emerged from individual decisions, or if the patterns were born out shared team processes.

The task of this research is to explore how the team unit deals with spatial information. Should there be ample evidence that teams handle spatial information differently than individuals, team spatial cognition would therefore be proposed as an area of study focusing on how teams acquire, process, and communicate spatial information to make decisions in space.

CHAPTER TWO: INTRODUCTION

Team spatial cognition borrows concepts from the studies of spatial cognition and team cognition to characterize how a group processes spatial information. Spatial cognition is a fundamental ability in animals concerned with understanding the relationships between external objects and the body of the observer Ma, Hu, & Wilson, (2012). The 'cognition' part of the term concerns the acquisition, storage, retrieval, manipulation, and use of spatial information by humans, nonhuman animals, and intelligent machines Smelser, Baltes, & others, (2001). Lynch, (1960c) proposed five major elements that individuals use to acquire spatial information about their environment: landmarks, paths, nodes, edges, and districts.

Team cognition shares a similar definition to spatial cognition. Cooke, Salas, Kiekel, & Bell (2004, 4) state that team cognition comprises "the cognitive tasks a team performs to detect and recognize relevant cues, make decisions, solve problems, remember pertinent information, plan, acquire knowledge, and design solutions or products as an integrated unit." The main idea being that team cognition is more than the sum of the cognition of the individuals of which the team is comprised Le Bon, (1897).

One characteristic of team spatial cognition is the presence of team-level spatial processing such as dividing an activity space into districts. This process has been called several terms in spatial cognition research including regions Couclelis, Golledge, Gale, &

Tobler, (1987), and ‘districts Lynch, (1960). In the scope of team spatial cogniton, these districts are used to make spatial decisions among members. A second characteristic is that team members displaying leadership qualities influence the spatial reference frame used by the team. This reference frame is the perspective through which an individual locates objects in their environment Ma et al., (2012). A third characteristic is that teams participate in spatial backup behavior. This behavior is evident by individuals sharing spatial information while assisting each other in tasks.

Communication data from a series of team pursuit and evasion experiments conducted by the Center for Location Science at George Mason University was analyzed to investigate the existence of team spatial cognition. The three previously stated characteristics of team spatial cognition were explored by applying qualitative data analysis techniques to 3,257 unique written communications produced by 31 team pursuit and evasion experiments.

The results provide evidence for team spatial cognition. Teams used unique, team level spatial processes such as districtization, a leadership driven spatial reference frame, and spatial backup behavior. The existence of these team level processes implies that individuals process spatial information differently when a part of a team. For example, team members often regionalized their activity with a quadrant system only known to the team. Statements such as, “I’m in between quadrant 1 and 4. I see a evader at 4 so I’m heading towards 4”, were not uncommon despite no quadrant system suggested to the teams. It was also found that team leadership was correlated with spatial reference frame use. Team members who displayed leadership qualities influenced the spatial reference frame used by other members. Finally, there was evidence that individuals dynamically coordinated spatial decisions to assist each other. An increase in backup behavior was positively correlated with an increase in distance and direction cues. Collectively, these findings are evidence for team spatial cognition.

The following literature review summarizes the current state of team cognition and spatial cognition research. It provides a foundation for unifying two fields of study as well as contributing team spatial cognition to the body of knowledge in human behavioral geography. The first section, spatial cognition, examines how individuals obtain, process, and communicate spatial information. The second section, individual wayfinding, looks at how individuals make navigation decisions in their environment. The final section, team cognition, explores how groups of individuals understand and act in space as a team unit.

CHAPTER THREE: LITERATURE REVIEW

The foundations of team spatial cognition include literature published in the fields of human behavioral geography and industrial/organizational psychology. Despite team cognition and spatial cognition being different fields, both bodies of knowledge are needed to understand how teams use spatial information when making spatial decisions. Thus, parallels are drawn between the two disciplines to introduce a new field of study, team spatial cognition.

Spatial Cognition

Spatial cognition is a relatively old discipline with its earliest developments occurring in the early 20th century and a resurgence of interest in the 1950s and 1960s Smelser et al., (2001). Tolman (1948) first proposed the idea of a cognitive map which Downs & Stea (2011) formally defined as,

> "….a process composed of a series of psychological transformations by which an individual acquires, codes, stores, recalls, and decodes information about the relative locations and attributes of phenomenon in his everyday spatial environment."

In the 1960s, a new topic of study emerged within the field of environmental psychology called environmental cognition. Environmental cognition incorporated concepts such as Tolman's cognitive maps and concerned itself with the study of human behavior in relation to the natural and built environment Proshansky, (1974). Environmental cognition can be thought of as applied spatial cognition whereby individuals use processes such as cognitive mapping to learn spatial attributes of the natural and built environment. Due to the permanence and extent of urban areas as well as the fact that the study area is in a built environment, the following subsections focus on aspects of spatial cognition regarding the built environment.

The first section is an overview on how spatial information is obtained at the individual level and how this information is used in processes such as cognitive mapping. The second section, orientation, shows how this learned information is used to locate objects and oneself in the environment.

Spatial Learning

Spatial learning is the act of acquiring spatial information Thorndyke & Hayes-Roth, (1982). Humans can obtain spatial information from several sources including written/verbal communications, the environment, and from maps. Current research suggests there is no optimal way to obtain spatial information. For example, there are unique advantages to both map reading and actual navigation Thorndyke & Hayes-Roth, (1982). Two common spatial knowledge types are survey and route knowledge Chrastil & Warren, (2013). Route knowledge (also known as procedural knowledge) is knowledge of turn-by-turn directions from one location to another Golledge & Dougherty, (1995). An example of route knowledge would be knowing how to get to the store by memorizing the order of left and right turns. Survey knowledge, on the other hand, is information regarding where things are located and how navigation networks connect them Ishikawa & Montello, (2006). The advantage of survey knowledge is that routes can be improvised on the fly. If a turn is missed, a new route can be quickly found. Research has shown that map readers learn more survey knowledge while navigators learn more route knowledge Thorndyke & Hayes-Roth, (1982).

These two knowledge types are thought to be incorporated into a concept called a cognitive map. Tolman (1948) first coined the term during his experiments with rats. He proposed that rats used cognitive maps to navigate through a maze to reach a reward. Tolman's work was important because it provided evidence that even simplistic brains stored spatial relationships and navigation was not simply stimulus driven behavior. The concept of a cognitive map persists today with new frameworks based on the concept as recent as February 2017 Chraibi & Haensel, (2017) in ArXiv e-prints. Spatial learning and cognitive maps are important for teams because individuals use and communicate spatial information differently. The implications of poor team spatial cognition are increased miscommunication and poor team performance.

In addition to cognitive mapping, researchers have gone further by providing evidence about the organization of spatial information within an individual's cognitive map. For example, there is evidence that spatial relations can be organized hierarchically. Regions such as neighborhoods and other types of areas were found to be an integral part of wayfinding as these relative relations are thought to economize mental storage space Chase, (1983). Regions are perceived early in the learning of an environment and have been found to play a role in search strategies Wiener, Schnee, & Mallot, (2004). It is argued that districtization underlies many spatial judgements, even those referring to pairs of points Couclelis et al., (1987).

An important question regarding team spatial cognition is whether there are shared, team-level cognitive maps that incorporate survey information such as spatial relationships between districts. If this is true, there is a possibility that the shared use of spatial information also underlies spatial strategies and decisions made at the team level. This would be evident if team communication featured shared use of districts while making spatial decisions.

Orientation

Human orientation describes how individuals locate themselves in an environment after losing their bearing Twyman, Newcombe, & Gould, (2009). Relative and categorical orientation are two such methods Twyman et al., (2009). Relative cues are location hints characteristic of a contrast between the shape or size of two or more objects. For example, a large house next to a small house might suggest to an individual that they are at a certain location in the world. Categorical cues, on the other hand, are a contrast between how objects are organized in the brain regardless of shape and size. A red house next to a green house could be used as contextual location information even though the houses themselves are not physically different in shape or size Twyman et al., (2009). Not only do humans use relative and categorical cues, they also use global and local cues. Global cues are points of reference like the sun that can be used anywhere in the world relative to the horizon, while local cues are more location dependent such as a local salient landmark Lawton, (1996).

A common way to locate an object in space is to pair one of the previous cues (relative or categorical) with a spatial reference frame. A spatial reference frame is the perspective though which one sees an object. These frames may either be relative to the viewer or to some external reference Committeri et al., (2004). An egocentric or deictic spatial reference frame is when an individual sees an object relative to their body. For example, "The man is in front of me." An intrinsic spatial reference frame is when an individual sees an object relative to another object. For example, "I am in front of the National Monument." The receiver of this communication would assume you are at the entrance to the monument. The third reference frame is an allocentric or extrinsic reference frame. Again, one could say, "I am in front of the National Monument." But in this case, they mean that they are south of the monument. A person might extrinsically reference an object this way if they are viewing a north up map or if the reference object does not have well-defined spatial prepositions like front, back, right left. A tree is a good example of an object that is often referenced extrinsically because it lacks a well-defined front, back, left, right Retz-Schmidt, (1988). Maintaining a consistent reference frame is important as there may be a 'transformation circuit' in the brain dedicated to spatial reference frame transformations Committeri et al., (2004). It has been found that the intraparietal sulcus/retrosplenial cortex, parahippocampal cortex, and hippocampus areas of the brain were active during mental transformation tasks between egocentric and allocentric reference systems Committeri et al., (2004). What this suggests is that the brain kicks into gear to make appropriate transformations when a perspective change is made. These transformations have been further described by Kail & Park (1990) as resource-demanding algorithms used to execute mental rotations.

Human orientation plays an important role in teams because each player employs different orientation strategies and spatial reference systems. When one person tells another, “The evader is north of building A”, the receiving individual, located northwest of building A and facing north, might need to perform a mental transformation to realize that the evader is directly to their right. In this case, it might have been more efficient for his teammate to tell him this information through an intrinsic reference frame, “The evader is to your right.”

Individual Wayfinding

Individual wayfinding concerns how humans navigate in their environment Hund & Padgitt, (2010). The following sections cover how individuals use different wayfinding strategies as well as how they convey wayfinding knowledge to others.

Wayfinding Performance and Strategies

Several authors have sought methods to improve wayfinding performance Goldiez, Ahmad, & Hancock, (2007); Werner & Schindler, (2004). As mentioned above two primary wayfinding strategies are the survey method and the route method Chrastil & Warren, (2013). There are many factors associated with wayfinding success when these strategies are employed. These include age, gender, previous wayfinding experience, familiarity, and wayfinding anxiety Chang, (2013).

In addition to individual differences, the environment also plays a role in wayfinding performance. Werner & Schindler (2004) found several building-specific factors are associated with successful indoor wayfinding experiences. One of those measures is the interconnectivity density index (ICD). Werner's results showed that greater connectedness was correlated with higher wayfinding performance. Other factors they found to influence wayfinding performance within an indoor environment include alignment of the walls/hallways and access to global references such as the sun.

Gender Differences in Wayfinding

Different groups of people tend to employ different wayfinding strategies, and have different levels of success with those strategies. For example, it was found that gender was one of the best predictors of wayfinding accuracy Prestopnik & Roskos–Ewoldsen, (2000).

Though there may be differences with regard to wayfinding ability, both genders have been found to employ the same methods to learn spatial relationships in their environment Galea & Kimura, (1993). Additionally, females outperform males on some measures, including landmark recall. Even after controlling for memory related deficits between genders, females still outperformed men with regard to landmark knowledge Galea & Kimura, (1993). A possible explanation is that, in the past, women stayed close to home and only needed local cues (landmarks) for wayfinding and orientation while men ventured outside of camp, acquiring additional survey knowledge to navigate in their environment Silverman et al., (2000). This is suggested by Silverman's findings that there were gender differences favoring males that occur in a naturalistic setting designed to depict a hunter's navigational tasks.

The genders also differ in how they employ spatial knowledge. Jeanne Sholl, Acacio, Makar, & Leon (2000) found that men tend to utilize survey knowledge (map knowledge) more than route knowledge (also known as procedural knowledge) to navigate their environment. They are also more successful with cardinal directions and use them more often Jeanne Sholl et al., (2000).

Individuals have been shown to conceptualize and use spatial information differently in spatial tasks such as wayfinding. When this is combined with the idea of a group mind Le Bon, (1897) and the role of cognitive maps in wayfinding Wiener et al., (2004), team cognition appears evident.

Route Instructions

Route instructions are a common way humans communicate spatial information. Whenever someone asks for directions to the bathroom or how to get to the freeway, the response is frequently given as a set of route instructions. One of the difficulties with route directions is that they are often given with heterogenous granularity Tenbrink & Winter, (2009). Tenbrink & Winter (2009) found that while giving directions, individuals communicated spatial information with a wide range of spatial and temporal detail.

Not only is there a difference in the level of detail in route instructions, there is also variability in the conciseness of instructions. Daniel & Denis (2004) found that when individuals were told to make the directions, ‘as straightforward as possible’, participants first omitted details not associated with decisions such as passing landmarks not associated with decision points. The last details to be omitted were landmark-decision points Daniel & Denis, (2004). When compared to individuals, groups typically produce more concise directions Daniel & Denis, (2004).

Team members also communicate route instructions to their fellow teammates. Since individuals have been found to provide a wide range of detail in their directions, they may give too much or too little detail. Depending on the individual who receives the directions, this will result in varied wayfinding performance. It would be of interest to discover if being a part of a team leads to each individual giving better or more concise route instructions than if they were on their own. It would also be of interest to discover whether team processes such as leadership affect how route instructions are given in terms of content, accuracy, and spatial reference frame use.

Team Cognition

Team cognition examines how team processes and performance are affected by inter-individual and intra-individual factors Salas, Sims, & Burke, (2005). Le Bon (1897) states that the aggregation of individuals leads to a team where the individuals have vanished and a new entity has been created with characteristics unique and separate to the individuals of which it is comprised. Team cognition is an active area of research as companies, scientists and governments seek to understand how teams form and how they function.

Measuring Team Cognition

Most team cognition researchers agree that teams are an emergent phenomenon consisting of heterogeneous individuals Cooke et al., (2004); Kozlowski & Chao, (2012); Nonose, Kanno, & Furuta, (2012); Salas & Fiore, (2004). Many models have been proposed to describe team cognition and these frameworks have a lot of overlap. Salas et al., (2005) describes five variables that are most common among over 140 team cognition models proposed thus far. These include team orientation, performance monitoring, leadership, backup behavior, and adaptability. Salas also proposed two additional coordinating mechanisms, shared mental models and closed loop communication.

Salas, Fiore, Warner, & Letsky (2010) state that team communication is critical for team cognition. Unlike individuals, person-to-person(s) communication can be thought of as the team 'thinking out loud'   There are many ways to use communication to assess team cognition. One of the automated methods is Latent Semantic Analysis (LSA) Landauer, Foltz, & Laham, (1998). LSA is a tool to represent the contextual-usage meaning of words by statistical computations applied to text. Another method for analyzing textual information is qualitative data analysis (QDA). QDA tends to follow a holistic, post-positivist approach to data analysis which is comprised of coding, sorting, and sifting qualitative data Chowdhury, (2015). Several team cognition researchers have used QDA in their analysis Cañas, Novak, González, & O'connor, (2004); Huang, n.d.; Leinonen, Järvelä, & Häkkinen, (2005).

As an example Huang, (n.d.) used QDA to codify team building phenomena highlighted across different teams and Leinonen et al. (2005) used QDA to assess team collaboration across different team members.

Multi-team Systems

A multi-team system (MTS) is defined as, "two or more teams that interface directly and interdependently…to accomplish a distal goal" Mathieu, Cobb, Marks, Zaccaro, & Marsh, (2004). Team types vary, including cross-functional, single-function, time-limited, enduring, manager-led, and self-led teams. In an MTS, any combination of these team types work together to accomplish goals Edmondson, (1999).

MTSs are more complex than a single team because two or more groups of people must work together. It is, therefore, crucially important that the teams are well coordinated to complete their missions. It has been found that a significant predictor for inter-group conflict is disagreement on how tasks should be completed in the early stages of an MTS Van Den Berg, L. Curseu, & T.H. Meeus, (2014).

Another important factor for multi-team systems is the degree to which teams manage each other Millikin, Hom, & Manz, (2010). If each team is mostly independent, it can lead to lack of cohesion and ineffectiveness. On the other hand, if teams are working too closely, this can lead to groupthink and lack of creativity Millikin et al., (2010).

Other degenerating factors include poor mental model overlap and a lack of backup behavior (coordination) Fleştea et al., (2016). Fleştea et al. (2016) found that weaknesses among search and rescue teams were the result of deficiencies among these two factors.

Team cognition has great potential for informing research into multi-team systems as each team functions as a single entity interacting with other teams. It is no longer effective to analyze teams at the individual level as it is not individuals interacting, but groups of teams collaborating to achieve a goal. It is therefore essential that team mental processes are understood and properly described at the team level.

Improving Team Performance

Several factors have been proposed that correlate with team success. One of those factors is role identification behavior MacMillan, Entin, & Serfaty, (2004); Pearsall, Ellis, & Bell, (2010). Role identification behavior is an intentional sharing of skills or task knowledge by a team member. This way, each member ‘knows their place’ and can contribute more effectively. With each member assuming a role, tasks may be distributed to the appropriate members and goals may be reached.

Though role identification is important, interdependence between team members is also a factor. It was found that deliberate manipulation of tasks to require information sharing and collaboration prevented teams from breaking apart de Jong, Curşeu, & Leenders, (2014).

The fact that interdependence between members leads to increased team performance is evidence that the team unit is important. Le Bon (1897) states that the crowd supersedes its individuals. Team spatial cognition asserts that this interdependence and collaboration makes teams more effective because the team unit is greater than the sum of its members.

Team Spatial Cognition

From reviewing team cognition research, it became clear that several of its factors have overlap with or influence spatial cognition. Take the definitions for team cognition and cognitive maps. The definition of team cognition is,

> "the cognitive tasks a team performs to detect and recognize relevant cues, make decisions, solve problems, remember pertinent information, plan, acquire knowledge, and design solutions or products as an integrated unit" Cooke et al., (2004).

This closely parallels the definition for cognitive mapping which is,

> "A process composed of a series of psychological transformations by which an individual acquires, codes, stores, recalls and decodes information about the relative locations and attributes of phenomena in his everyday spatial environment" Downs & Stea, (2011)

The main differences between the two definitions is the focus of team cognition on an 'integrated unit' and the focus of cognitive mapping on the 'spatial environment.' Team spatial cognition combines these ideas to describe how teams take advantage of spatial information as an integrated unit.

Another factor of team spatial cognition is the influence of a leader on how the team communicates spatial information. Salas et al., (2005, 260) states that a role of the team leader is to "…provide acceptable interaction patterns." If it is the team leader's job to establish interaction patterns, then perhaps leaders also determine the spatial communication style used between team members. This would be evident by team members adopting the way in which the leader uses spatial reference frame when communicating route instructions.

A third factor of team spatial cognition is spatial backup behavior. Salas et al., (2005) describes backup behavior as, '…shifting work responsibilities to underutilized team members'. When this re-assignment is done, there is evidence that this flexibility in job assignment leads to effective teams Campion, Medsker, & Higgs, (1993). In terms of backup behavior regarding spatial decision making, this flexibility could be represented by flexibility in how the task should be undertaken. For a wayfinding task, this could be flexibility in the direction taken or the distance traveled.

In conclusion, spatial cognition and team cognition have extensive bodies of knowledge, but the two disciplines have been largely separated. The power of team spatial cognition emerges through the team unit's superior ability to analyze and use spatial information at the team level. By providing evidence for team spatial cognition through team level use of districts, spatial reference frames, and spatial backup behavior, it will be shown that spatial cognition can and should be analyzed at the group level when studying teams.

CHAPTER FOUR: DATA

The data used in this research come from 31 tabletop pursuit and evasion experiments with 266 participants on the George Mason Campus in Fairfax, Virginia. These experiments produced 10,332 communications between players and 6,952 unique locations. Each experiment consists of two teams, pursuers and evaders. The pursuing team's goal is to find and capture evaders while the evading team seeks to avoid capture. If all evaders are captured prior to the end of the game the pursuers win. If any evader is uncaptured at the end of the game the evaders win.

Participants were gathered from an online recruitment system called SONA systems. The Psychology Department at George Mason University offers undergraduate students course credit for their participation in research projects. Table 1 shows each experiment along with the number of players participating on both the evading and pursuing teams.

There was some variation in team size with the largest game being 5 vs 6 and the smallest being 3 vs 2 with an average team size of 8.74 players. Table 1 shows, for each experiment, the number of participating players.

Table 1. Participation for the first 31 experiments

Experiment	Total Players	Evaders	Pursuers	Total Number of Messages
1	9	5	4	236
2	10	5	5	316
3	10	5	5	383
4	6	3	3	419
5	10	5	5	95
6	7	4	3	595
7	9	5	4	331
8	10	5	5	269
9	9	5	4	413
10	10	5	5	218
11	7	4	3	578
12	9	5	4	377
13	10	5	5	381
14	8	4	4	377
15	10	5	5	285
16	5	3	2	82
17	9	5	4	135
18	10	5	5	198
19	10	5	5	463
20	10	5	5	360
21	10	5	5	91
22	7	4	3	435
23	9	5	4	238
24	8	4	4	673
25	9	5	4	347
26	10	5	5	485
27	6	3	3	64
28	9	5	4	413
29	6	3	3	602
30	8	4	4	253
31	11	6	5	181

In addition to player communications, demographic information about each participant (age, ethnicity, etc.) was captured as well. The following table is a sample of some of the questions participants answered.

Table 2. Sample demographic information collected from each participant.

Player Name	What is your age?	What is your gender?	What is your Race?	Do you live on or off-campus?
Evader 1	20	Female	Black	on-campus
Evader 2	24	Female	Asian	on-campus
Evader 3	21	Male	Asian	on-campus
Evader 4	19	Male	White	on-campus
Evader 5	18	Male	Asian	off-campus
Pursuer 1	20	Female	White	on-campus
Pursuer 2	19	Female	Asian	on-campus
Pursuer 3	19	Female	White	on-campus

In addition to demographic information, a post-exercise questionnaire was also issued to participants. These questions were aimed to assess how players reasoned about the decisions made during the game. Some of these questions included "What was your team's strategy to win?" and "Did you individually perform any specific tasks related to your team's strategy." The layout of the experiment is depicted in the following figure:

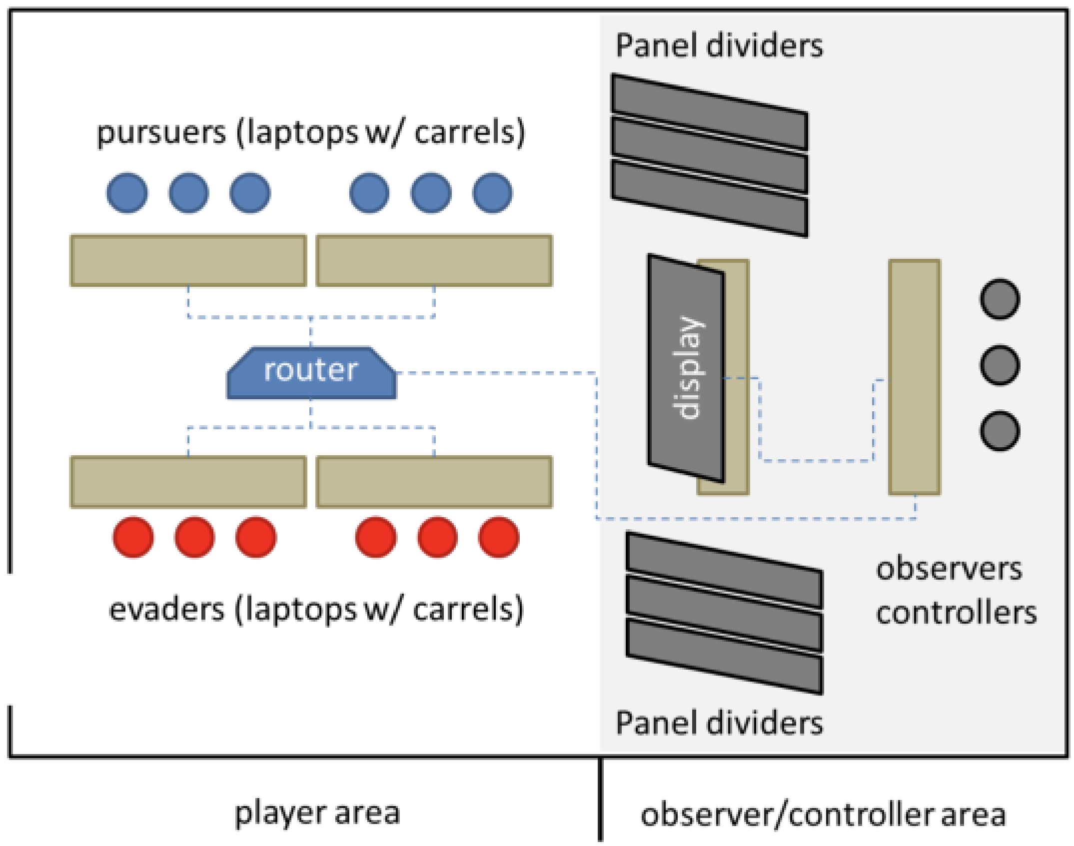

Figure 1. Experiment layout

Once the experiment began, participants were shown an informational video and then individually seated at computer based on a random assignment of pursuer or evader. Between each station a cardboard divider was placed to prevent participants from viewing one another's screens. The experiment runs for two hours or until all evaders have been captured. If, after two hours, at least one evader remains, the evading team wins.

Figure 2. Evader computer stations.

During the experiment, the players are presented with the interface in figure 3. On the left side of the screen, players can see messages sent from fellow players as well as use the interface to send messages to their fellow players. On the right side of the screen is the George Mason University campus where players are able to move around and receive information via the map.

Figure 3. A pursuit and evasion experiment. Blue squares represent pursuing players, red squares represent evading players

The game is turn based, whereby each turn players have the opportunity to move and/or communicate. The distance a player can travel per turn is limited to 230ft which represents the average distance a person can walk in a minute based on research performed by Barker (2015). Figure 4 shows the movement of players during a turn. The length of each line represents the distance a player moved during a turn. Pursuers are represented as blue dots and evaders are red dots.

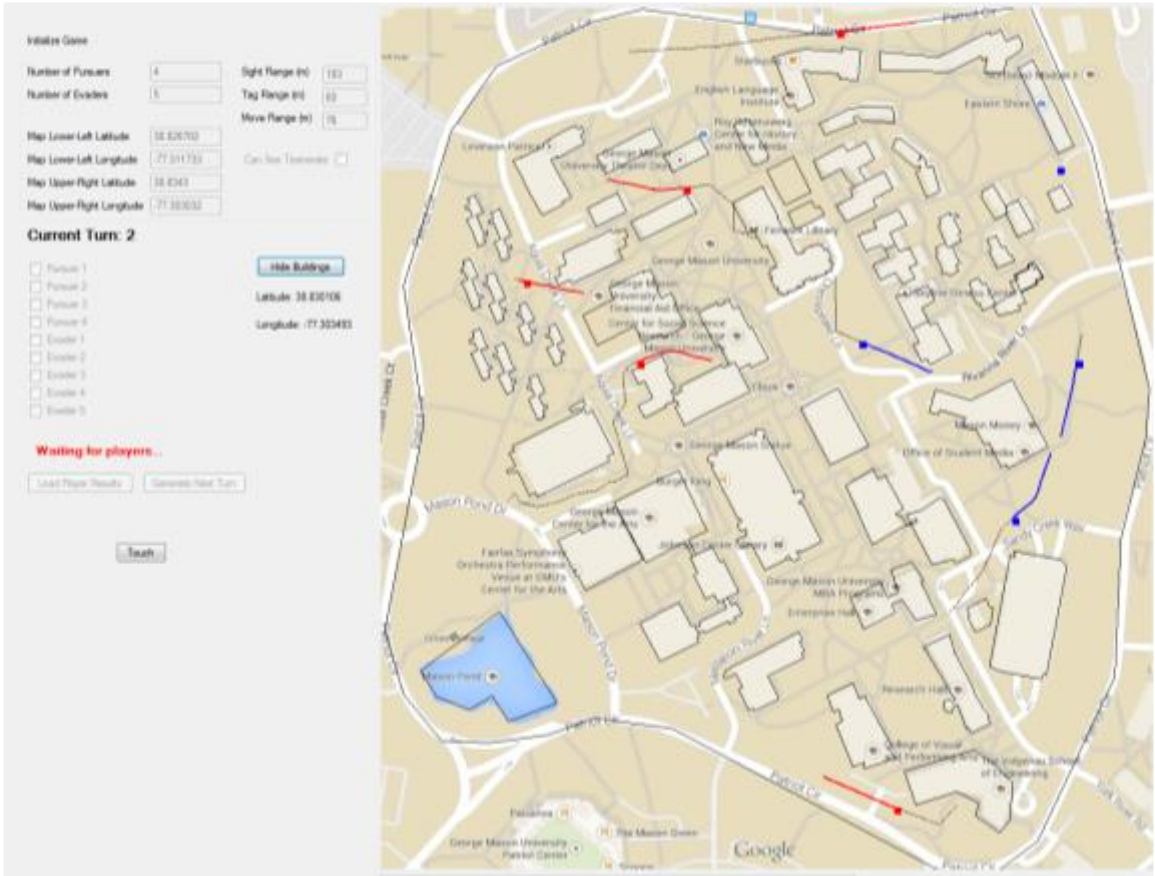

Figure 4. Movement of players during a game. Pursuers are blue and evaders are red.

Figure 5 shows all 6,952 locations of all 266 participants during experiments. Players were limited to the sidewalks on the George Mason Campus and could not enter buildings or other obstructions such as Mason Pond.

Figure 5. 6,952 Player locations during pursuit and evasion experiments using a George Mason campus map

Each player's view is limited to 60 meters surrounding them. Additionally, buildings obstruct their view. Through player-to-player communication, evaders and pursuers receive information on where their teammates are located and what their teammates can see. This information is communicated during each turn. At the beginning of each turn, each player is presented with a chat window where they can type a message and send it to other players. At the beginning of the following turn, the player's teammates see the message and can use that information to influence their spatial decisions. The messages for each game were exported to a csv. file. Table 1 is a sample of how this file is structured. The table header includes turn number, sending player, receiving player, and the message which was sent.

Table 3. Example qualitative data. Each message represents the communication sent from a sending player to a receiving player

Turn	Sending Player	Receiving Player	Message
6	Pursuer 4	Pursuer 1	heading toward sandy Creek
6	Pursuer 3	Pursuer 2	i see 2 by mason pond parking deck
6	Pursuer 5	Pursuer 4	im by JC ill check around there

The total number of messages was 10,332 over 31 games with 3,257 unique messages. Players were able to send the same message to several players, so the larger message count reflects this duplication. The average amount of communications per game for evaders was 135 while the average amount of communications for pursuers was 198. One of the primary reasons pursuers have more communications is that when an evader is captured, they can no longer communicate.

This message data is essential for understanding team cognition as (Salas et al., 2010) states that team communication is essential for team cognition. Additionally, there are several researchers who have used communication data to analyze team cognition (Artman & Garbis, (1998); Cooke, Gorman, Kiekel, Foltz, & Martin, (2005); Cooke et al., (2005); Preston A. Kiekel, Cooke, Foltz, Gorman, & Martin, (2002); Preston A. Kiekel et al., (2002); Preston Alan Kiekel, (2002); Nonose, Kanno, & Furuta, (2013); Soós & Juhász, (2010); Zimmermann, (1994). The benefit of analyzing team communication in this experiment is magnified by the fact that the text based messages were the only method participants had to communicate with each other.

CHAPTER FIVE: METHODS

There are generally two ways to collect underlying intention behind a spatial decision. An individual either states their intention while deciding, or he/she reports their reasoning afterward based on memory Montello, Richardson, Hegarty, & Provenza, (1999). Team cognition is actually easier to measure than individual cognition because some members of the team ‘think aloud’ through player-to-player communication Cooke et al., (2004). This is why the qualitative data used in this analysis consists of the messages sent during the experiment.

Qualitative data analysis (QDA) was used to process player communications. QDA is a constructivist style of data collection and data analysis which is comprised of coding, sorting, and sifting of qualitative data Chowdhury (2015). The reason QDA is a constructivist approach is because it seeks to capture the meaning behind data rather than describing the data itself. Originally, QDA was done with pen and paper, but in the 1980s, the first computer aided qualitative software began to be used Richards (2002). The four phases of QDA are (1) defining the analysis, (2) classifying data, (3) making connections between data, and (4) conveying the message(s) Baptiste (2001).

The first phase of the analysis is deciding how to capture the data. This phase is explained in the data section as it primarily concerns how the data is collected rather than how it is analyzed. The second phase includes labeling and grouping tagged data Baptiste

(2001). A label such as ‘leadership’ might be used to group all communications featuring leadership qualities into a single category. Two major questions to ask oneself are whether there is sufficient differentiation between labels and whether the data itself should influence how the labels are created. Baptiste (2001) states these questions as follows,

> (1) Are my definitions (of categories) sufficiently developed to clearly distinguish between categories; to aid in the proper assignment of tagged units; and to assist in adequately fulfilling the purpose of the study?
>
> (2) Do I familiarize myself with all the collected data (transcripts, fieldnotes, etc.,) by reading and re-reading them before I begin formal tagging, or do I jump straight into tagging?

To combat these challenges, tags were created based on spatial cognition and team cognition literature. This ensures the tags are originating from existing literature instead of being created out of the collected communications. To apply these tags to the player communications, games were coded with a formal dictionary of authoritative definitions. For each code, it was tagged once per communication as Cañas et al. (2004) did when measuring team cognition using QDA techniques. Examples from the experiments were appended to a dictionary so that each term contained both a formal definition and examples from the collected data. If a researcher would like to repeat this study, the definitions and examples for each tag are provided in a dictionary that is included in the appendix.

Phase 3 is when tagged data is analyzed to produce new insights. Two important questions from Baptiste's (2001) analytic handbook are,

(1) What existing theories have I used to help me construct and support these relationships?

(2) How does my story or theory confirm (and/or) challenge existing theory?

The relationships that characterize and describe team spatial cognition are based in the team cognition and spatial cognition literature. For example, the first aspect of team spatial cognition concerns the shared use of districts. The concept of districts is found throughout spatial cognition literature. A particularly salient paper to spatial cognition researchers comes from Lynch's *Image of the City* where districts are featured as one of five elements individuals use to learn spatial relationships in their environment. The 'shared' use of districts comes from the concept of shared mental models which permeates team cognition literature, and was formally defined in Salas et al., (2005).

The second aspect of team spatial cognition concerns a leader influencing the spatial reference frame used by the team. This would be evident by team members adopting the dominant spatial reference frame used by the team leader. In this research, a leadership driven spatial reference frame use was defined as a positive correlation between leadership use of a spatial reference frame and use by team members. If players' use of spatial reference frames matched the leader, this would be evidence that the leader reference frame use is related to team use of a reference frame.

The third characteristic of team spatial cognition is spatial backup behavior. Backup behavior is found throughout the team cognition literature and is also a part of the Big Five as defined by Salas et al. (2005). The 'spatial' aspect of backup behavior is depicted with the presence of distance and direction cues within a backup behavior communication. If there is a relationship between backup behavior communications and distance/direction cues, this would indicate the importance of spatial information when teammates are assisting other players.

To carry out this analysis, QSR International's NVivo 11.4 qualitative data analysis Software was used *NVivo qualitative data analysis Software*, (2017). Nvivo provides a programmatic way of applying a QDA technique. Communications were coded using definitions contained in a pre-established dictionary of tags derived from the literature. Spatial cognition tags were sourced from the research of prominent authors such as Montello, Lynch, Golledge, Tolman. These tags include districts, spatial reference frame, and distance/direction cues. For team cognition tags, the Big Five and its two coordinating mechanisms were taken from Salas et al., (2005).

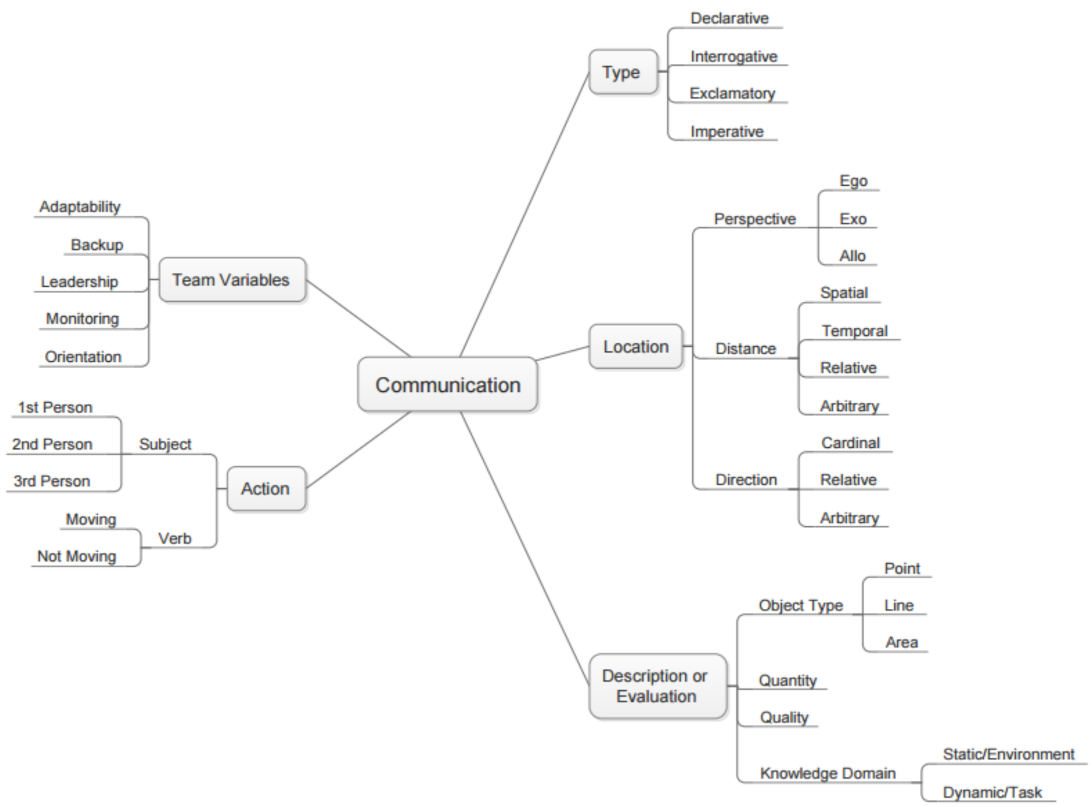

Figure 6. Formal dictionary of labels based on team cognition and spatial cognition literature.

The right side of Figure 6 represents spatial cognition. These elements include spatial reference frame (perspective), and distance/direction as specified in Committeri et al., (2004); Downs & Stea, (2011); Montello et al., (1999). On the left side of the figure, are the Big Five as proposed by Salas et al., (2005). Although not explicitly used in this analysis, the branches of ‘Action’ and ‘Type’ collect additional information from the communication data. The ‘Type’ branch was created based on the four primary moods of the English language (Gibbs, 1984). The action branch captures all of the actions contained within player-to-player messages. The majority of verbs contained in the communications concerned moving or not moving, but other verbs were tagged and played into the larger category of ‘Verb.’

A coding dictionary was also produced (see appendix) which includes each variable, what it represents, and examples of how it would be coded within player-to-player communications. Equipped with this dictionary, the QDA process was started. Below is an example of QDA in progress.

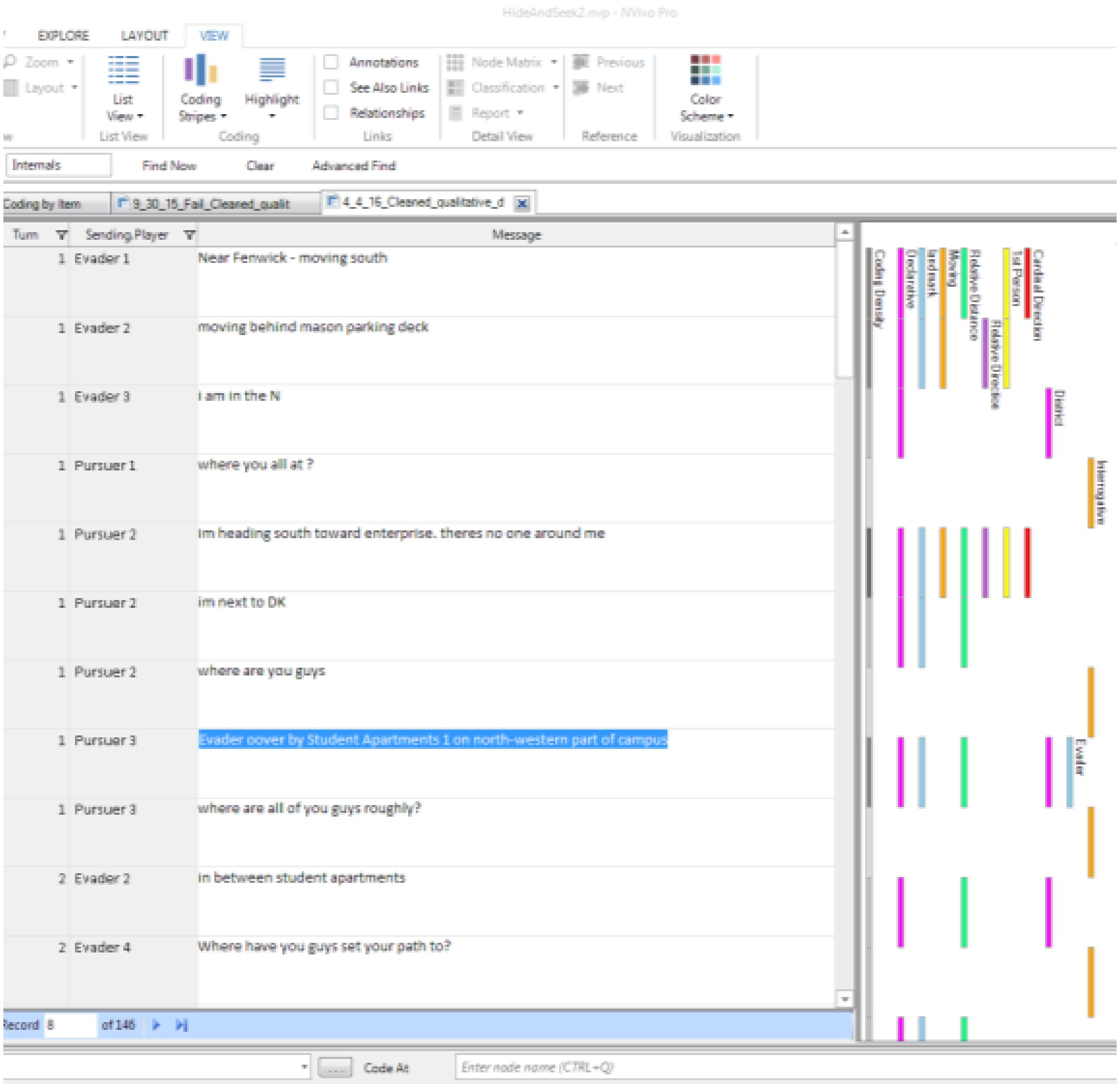

Figure 7. QDA using Nvivo. The message is in the left panel, the codes tagged in the right panel.

Given the communication, “I am in quadrant II, to the left of the Johnson Center.” This communication would be tagged with use of districts based on the mentioning of a quadrant. The communication would also be tagged with an extrinsic reference frame as there is no intrinsic ‘left’ of the Johnson Center. Finally, the communication would also be tagged for landmark as the player referenced a building on the map.

The advantage of tagging and grouping player communications is that this allows concepts and ideas in the literature to be applied to qualitative data. Quantitative methods will only answer ‘what’ questions, but when it comes to understanding human spatial behavior, this completely ignores the ‘why’ questions. Through an applied qualitative data analysis approach, spatial communications and decisions are analyzed through the lens of the cognitive processes found in team cognition research.

CHAPTER SIX: RESULTS

This thesis has produced data that shows evidence of team level spatial processing. Over the course of 31 games, players used team-level spatial processes such as districtized playing fields. It should be noted that teams 14 and 17 representing teams participating in experiments 14 and 17 were repeat experiments. Experiments 13 and 16 ended early, so an additional experiment was run. This should be kept in mind as these teams had the experience of participating twice in the experiment. Figures 8 and 9 show shared districts by pursuing and evading teams. Each bar represents the percent of a team's communications that featured districts. This was calculated by taking the total amount of district tags for each member on the team and dividing that number by the total number of messages for the players of the given team $\frac{Total\ District\ Tags}{Total\ Game\ Messages} \times 100$. An example of shared districts would be the following communication coming from Pursuer 1 in experiment six, *"im in between quadrant 1 and 4. I see a evader at 4 so im heading towards 4."* Pursuer 1 indicated that he was between two quadrants (a type of district) while also indicating his relative direction. Another example of a district comes from Pursuer 3 in experiment 15. He/She states, *"I will cover area bottom right corner from enterprise hall over to sandy creek and below."* In this case, the district was more explicit relative distance ("from enterprise hall over to sandy creek") as well as indicating an extrinsic spatial reference frame ("and below"). These are two examples of how participants might share a district. In total, there were 716 instances of shared districts in 3,257 unique messages.

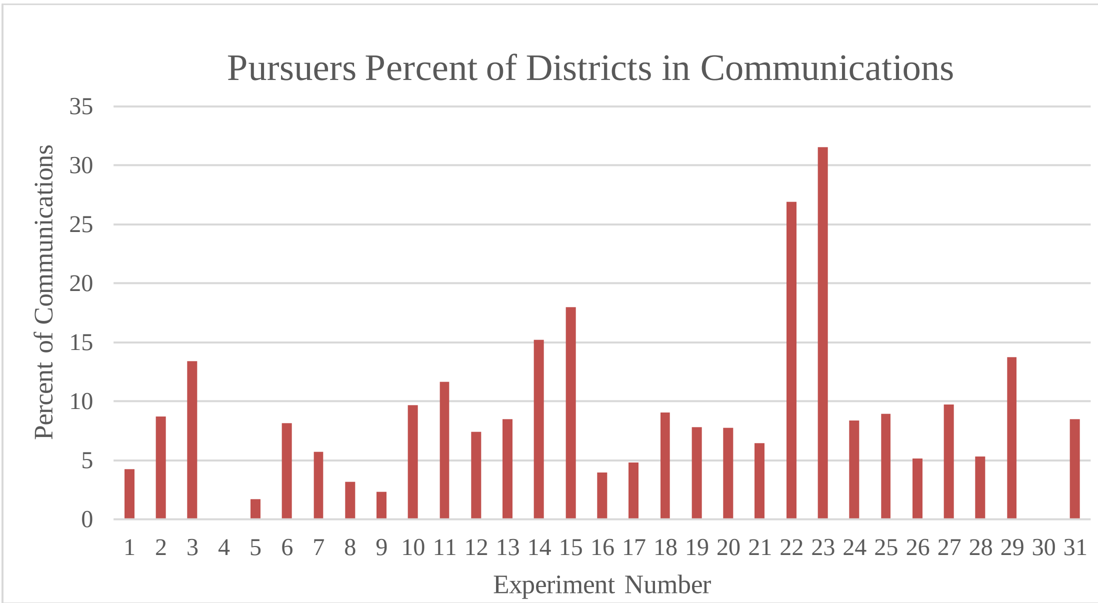

Figure 8. Pursuer messages featuring shared districts.

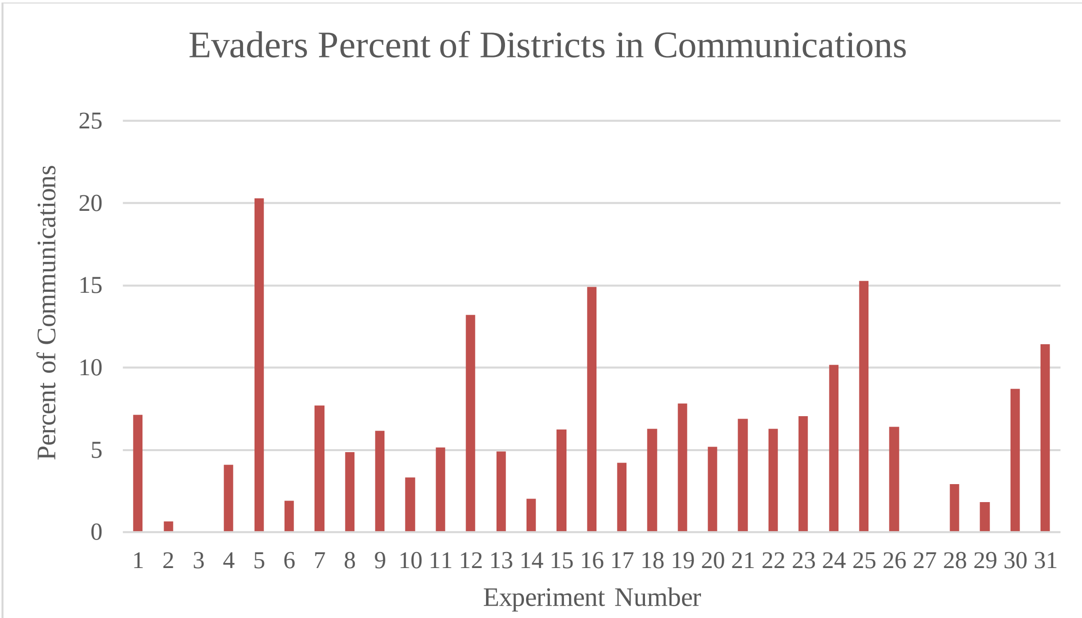

Figure 9. Evader messages featuring shared districts.

Not only did teams use shared districts, but district use was often distributed across the team. Team two, for example, had its district use split evenly between five players. No single player used districts more than any other player. Over 31 pursuing teams, only 11 games consisted of a single player using more than 50% of the team's shared district use. Figure 11 is a pie chart representation of team 29's shared districts. In this game, district use was well split, with each player participating and no single player dominating the conversation.

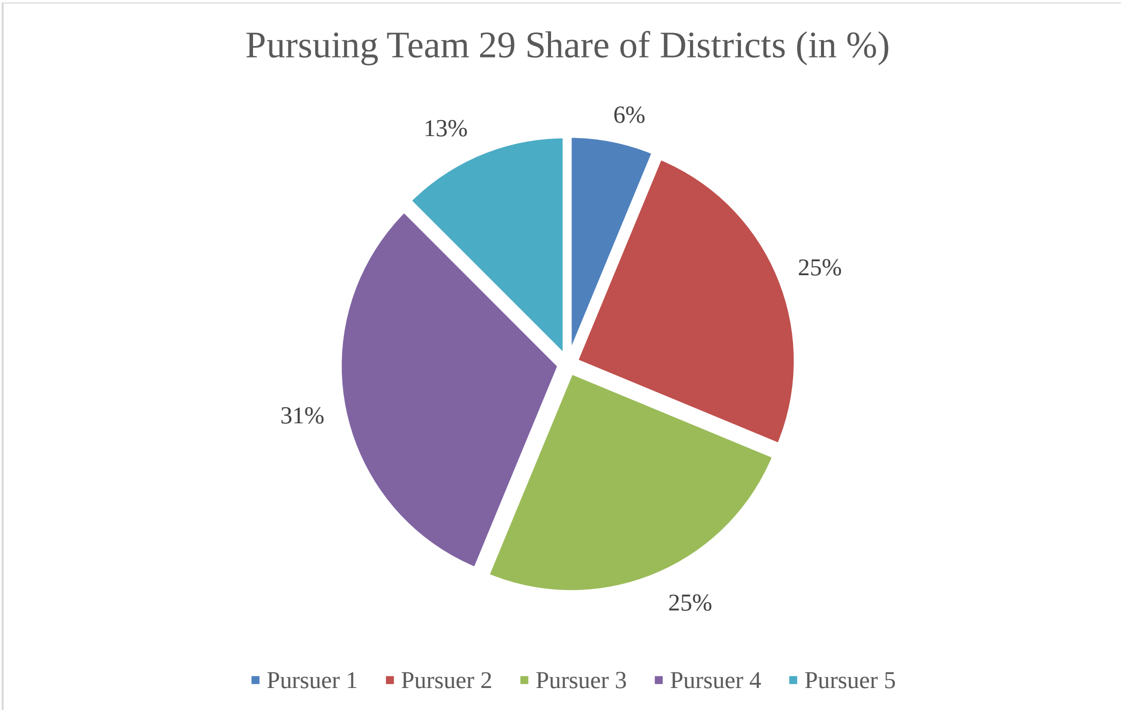

Figure 10. Shared district uses for a single pursuing team.

The second aspect of team spatial cognition is a relationship between the way a leader communicates spatial information and the way his/her team communicates spatial information. The leader's use of districts was compared to the team with the leader removed. Figures 12 and 13 show, for each team, how the leader and the team differed in the percent of communications featuring districts. The red line represents spatial reference use by the leader while the blue line represents spatial reference use by the team with the leader removed. There are two reasons teams are missing from the graphs. The first reason was that there were teams with no tags for leadership. This was true for 9 teams. In these cases, the teams operated mostly autonomously and there was no player functioning as a leader. The other 7 teams that were removed were when two or more players had the same amount of tags for leadership. Thus, only teams with a single player having more tags for leadership than any other player were analyzed.

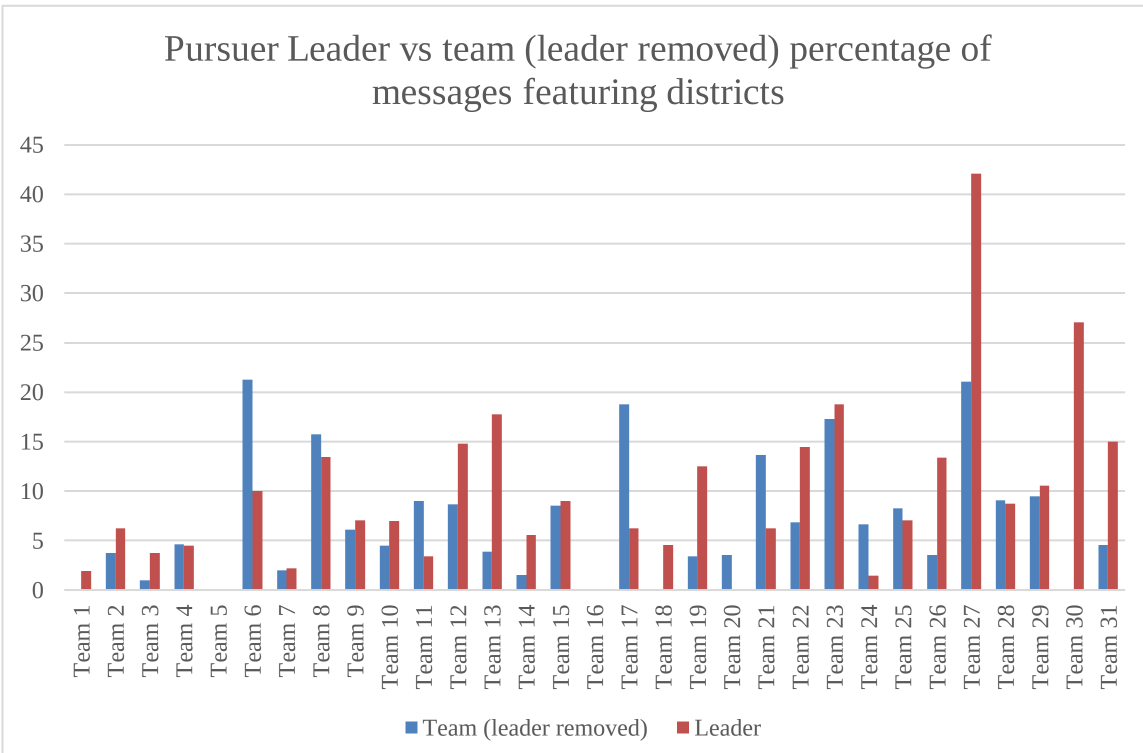

Figure 11. Pursuer leader and pursuing team's percentage of communications featuring districts

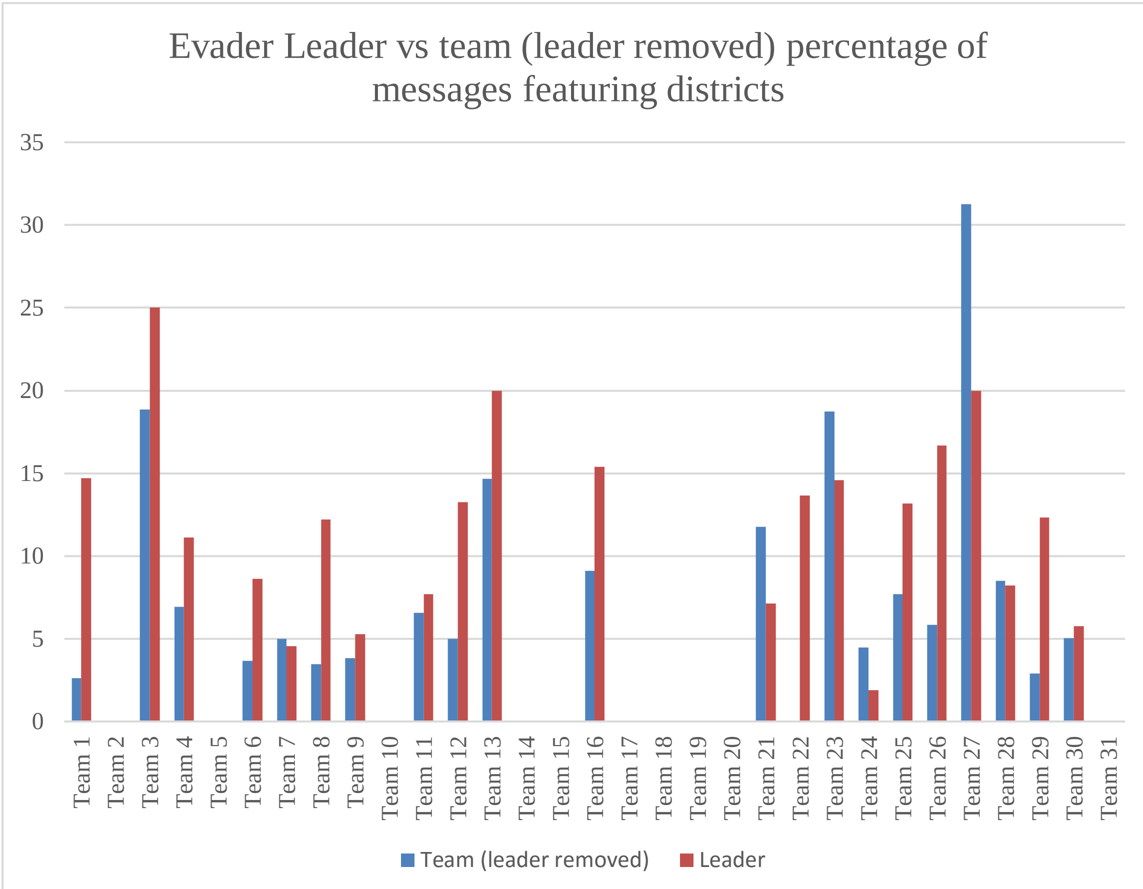

Figure 12. Evader leader and evading team's percentage of communications featuring districts.

The following table shows for each team, the percentage of communications featuring districts for the leader of the team as well as the team with the leader removed.

Table 4. Percentage of communications featuring districts for the leader and the team

Team Number	Team Type	Leader districts	Team (leader removed) districts
1	Evader	2.63	14.71
2	Evader	18.87	25.00
3	Evader	6.92	11.11
4	Evader	3.68	8.62
5	Evader	5.00	4.55
6	Evader	3.45	12.20
7	Evader	3.81	5.26
8	Evader	6.57	7.69
9	Evader	4.98	13.24
10	Evader	14.66	20.00
11	Evader	9.09	15.38
12	Evader	11.76	7.14
13	Evader	0.00	13.64
14	Evader	18.75	14.58
15	Evader	4.46	1.89
16	Evader	7.69	13.16
17	Evader	5.85	16.67
18	Evader	31.25	20.00
19	Evader	8.51	8.20
20	Evader	2.88	12.31
21	Evader	5.05	5.77
1	Pursuer	0.00	1.92
2	Pursuer	3.77	6.25
3	Pursuer	0.97	3.74
4	Pursuer	4.62	4.48
5	Pursuer	21.24	10.00
6	Pursuer	1.96	2.22
7	Pursuer	15.73	13.46
8	Pursuer	6.10	7.02
9	Pursuer	4.50	6.98
10	Pursuer	9.03	3.40
11	Pursuer	8.64	14.81
12	Pursuer	3.90	17.78
13	Pursuer	1.55	5.56

14	Pursuer	8.55	8.97
15	Pursuer	18.75	6.25
16	Pursuer	0.00	4.55
17	Pursuer	3.38	12.50
18	Pursuer	3.54	0.00
19	Pursuer	13.64	6.25
20	Pursuer	6.83	14.47
21	Pursuer	17.31	18.75
22	Pursuer	6.67	1.42
23	Pursuer	8.26	7.04
24	Pursuer	3.57	13.41
25	Pursuer	21.05	42.11
26	Pursuer	9.09	8.73
27	Pursuer	9.49	10.53
28	Pursuer	0	27.08
29	Pursuer	4.55	15

The correlation between leader district use and the team's district use with the leader removed was assessed using the correl() function in excel. The following table shows that the percentage of communications featuring districts for the leader was slightly correlated with the percentage of communications featuring districts for the team with the leader removed. This correlation was slightly higher for evading teams (0.57) than for pursuing teams (0.38).

Table 5. Correlations between leader and team district use.

Variable	Correlation
Pursuer leader and team (leader removed)	0.38
Evader leader and team (leader removed)	0.57

There is also evidence that team members who demonstrate leadership qualities tend to correlate with the way other members communicate spatial information. When these influential players had a higher percentage of their communications featuring spatial reference systems, their teammates' communications also tended to contain a higher percentage of spatial reference frames. Figures 14 and 15 show pursuer and evader spatial reference use as a percentage of all communications.

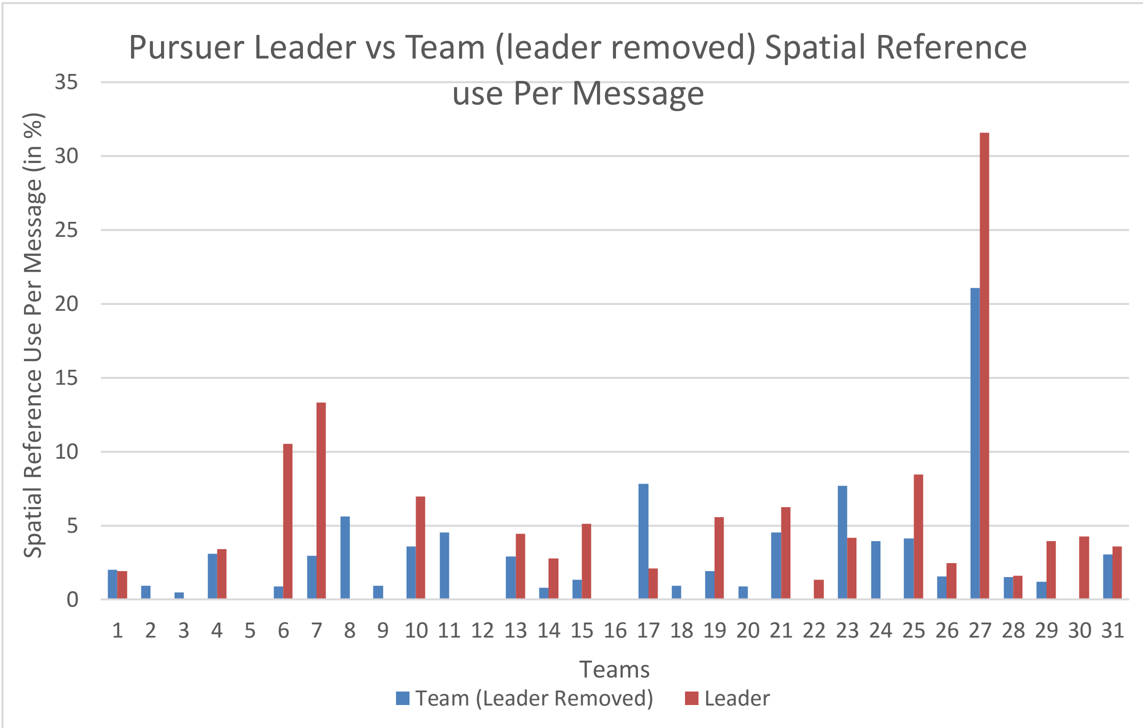

Figure 13. Pursuer spatial reference frame use versus team (leader removed) spatial reference frame use.

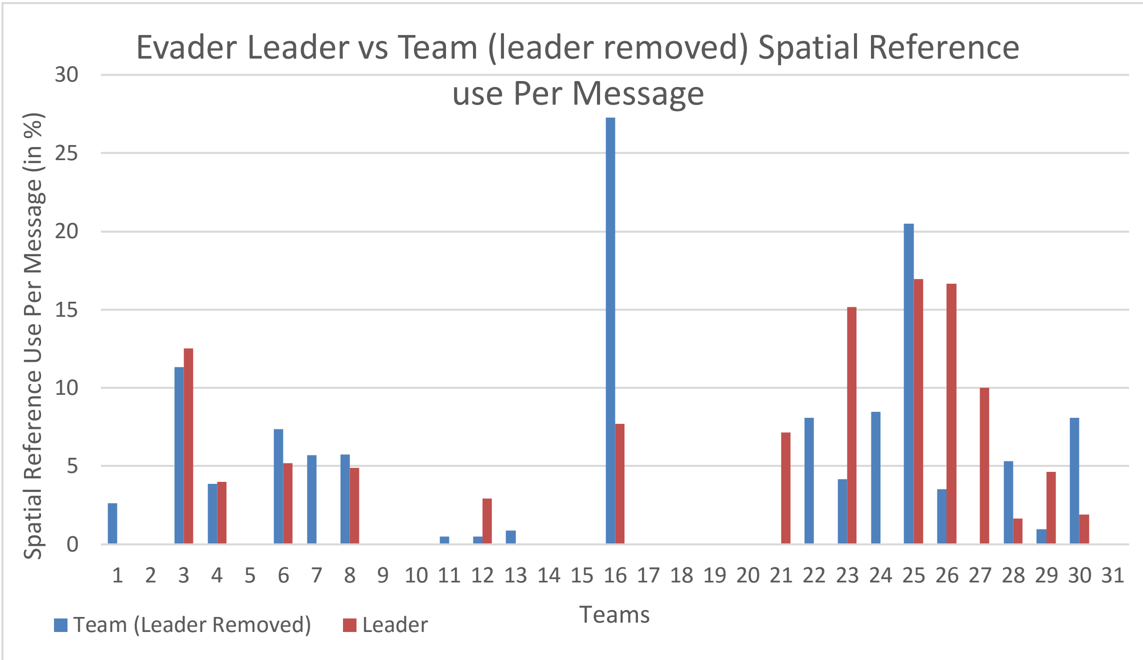

Figure 14. Evader spatial reference frame use versus team (leader removed) spatial reference frame use.

The following table shows pursuing and evading teams and the percentage of messages featuring a spatial reference frame. The numbers represent, for each team, the percentage of a team's communications that used a spatial reference frame and the percentage for the leader. This percentage was calculated by taking the total amount of spatial reference frame tags used by the team divided by the total number of messages for the team.

$$\frac{Team\ frequency\ spatial\ referemce\ Frame}{Total\ team\ messages} \times 100 \qquad \frac{Leader\ frequency\ spatial\ referemce\ Frame}{Total\ leader\ messages} \times 100$$

Table 6. Evader and pursuer percentage of spatial reference use. Leader vs team (leader removed)

Team	Team Type	Team (leader removed) percentage of messages with spatial reference frame	Leader Percentage of messages with spatial reference frame
1	Evader	**2.63**	0.00
2	Evader	**11.32**	12.50
3	Evader	**3.85**	4.00
4	Evader	**7.35**	5.17
5	Evader	**5.71**	0.00
6	Evader	**5.75**	4.88
7	Evader	**0.00**	0.00
8	Evader	**0.51**	0.00
9	Evader	**0.50**	2.94
10	Evader	**0.86**	0.00
11	Evader	**27.27**	7.69
12	Evader	**0.00**	7.14
13	Evader	**8.11**	0.00
14	Evader	**4.17**	15.18
15	Evader	**8.48**	0.00
16	Evader	**20.51**	16.94
17	Evader	**3.51**	16.67
18	Evader	**0.00**	10.00
19	Evader	**5.32**	1.64
20	Evader	**0.96**	4.62
21	Evader	**8.08**	1.92
1	Pursuer	**2.00**	1.92
2	Pursuer	**0.94**	0.00
3	Pursuer	**0.48**	0.00
4	Pursuer	**3.08**	3.38
5	Pursuer	**0.88**	10.54
6	Pursuer	**2.94**	13.33
7	Pursuer	**5.62**	0.00
8	Pursuer	**0.94**	0.00
9	Pursuer	**3.60**	6.98
10	Pursuer	**4.52**	0.00
11	Pursuer	**0.00**	0.00
12	Pursuer	**2.93**	4.44
13	Pursuer	**0.78**	2.78
14	Pursuer	**1.32**	5.13
15	Pursuer	**7.81**	2.08
16	Pursuer	**0.90**	0.00
17	Pursuer	**1.93**	5.56
18	Pursuer	**0.88**	0.00

19	Pursuer	**4.55**	6.25
20	Pursuer	**0.00**	1.32
21	Pursuer	**7.69**	4.17
22	Pursuer	**3.92**	0.00
23	Pursuer	**4.13**	8.45
24	Pursuer	**1.53**	2.44
25	Pursuer	**21.05**	31.58
26	Pursuer	**1.52**	1.59
27	Pursuer	**1.19**	3.95
28	Pursuer	**0.00**	4.26
29	Pursuer	**3.03**	3.57

A correlation was run on these two groups using the =correl() function in excel. For pursuing teams, the correlation between the percentage of spatial reference frame was 0.30 and the correlation for evading teams was 0.42.

Table 7. Correlations between leader spatial reference use and the team's.

Variable	Correlation
Pursuer leader and team (leader removed)	0.75
Evader leader and team (leader removed)	0.34

A t-test was also performed on the percentage leaders used a spatial reference frame compared to the percent of communications the team without the leader used one. The following tables show the t-test results comparing the percentage of communications of the leader compared to the percentage of the team’s communications with the leader removed. The first test performed was an f-test to determine how much variance there was between the percentage of communications featuring a spatial reference frame for the leaders compared to the team with the leader removed (tables 8 and 9).

Table 8. F-Test Two-Sample for Variances, Evading teams

	Team (leader removed) percent messages with spatial reference frame	Leader percent messages with spatial reference frame
Mean	5.95	5.30
Variance	47.73	33.73
Observations	21.00	21.00
df	20.00	20.00
F	1.42	
P(F<=f) one-tail	0.22	
F Critical one-tail	2.12	

Table 9. T-Test: Two-Sample Assuming Unequal Variances, Evading teams

	Team (leader removed) percent messages with spatial reference frame	Leader percent messages with spatial reference frame
Mean	5.95	5.30
Variance	47.73	33.73
Observations	21.00	21.00
Hypothesized Mean Difference	0.00	
df	39.00	
t Stat	0.33	
P(T<=t) one-tail	0.37	
t Critical one-tail	1.68	
P(T<=t) two-tail	0.74	
t Critical two-tail	2.02	

The same tests were performed on the pursuing teams and are shown in the tables below:

Table 10. F-Test Two-Sample for Variances, Pursuing teams

	Team (leader removed) percent messages with spatial reference frame	Leader percent messages with spatial reference frame
Mean	**3.11**	4.27
Variance	**16.34**	39.13
Observations	**29.00**	29.00
df	**28.00**	28.00
F	**0.42**	
P(F<=f) one-tail	**0.01**	
F Critical one-tail	**0.53**	

Table 11. T-Test: Two-Sample Assuming Unequal Variances, Pursuing teams

	Team (leader removed) percent messages with spatial reference frame	Leader percent messages with spatial reference frame
Mean	**3.11**	4.27
Variance	**16.34**	39.13
Observations	**29.00**	29.00
Hypothesized Mean Difference	**0.00**	
df	**48.00**	
t Stat	**-0.84**	
P(T<=t) one-tail	**0.20**	
t Critical one-tail	**1.68**	
P(T<=t) two-tail	**0.41**	
t Critical two-tail	**2.01**	

There was not a significant difference between the two groups. Both for the evading and pursuing teams, neither test had a p value less than 0.05.

It was also found that distance and direction cues were positively correlated with backup behavior. The following graphs show, for each experiment, the percentage of communications featuring backup behavior, and distance/direction cues.

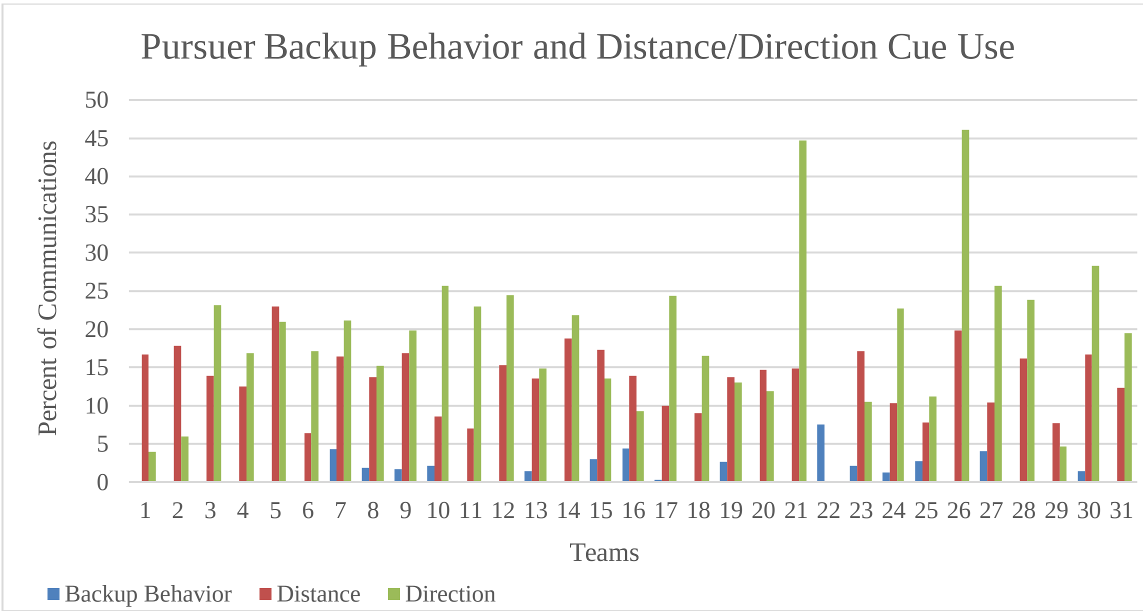

Figure 15. Pursuer backup behavior and distance/direction cue use per experiment.

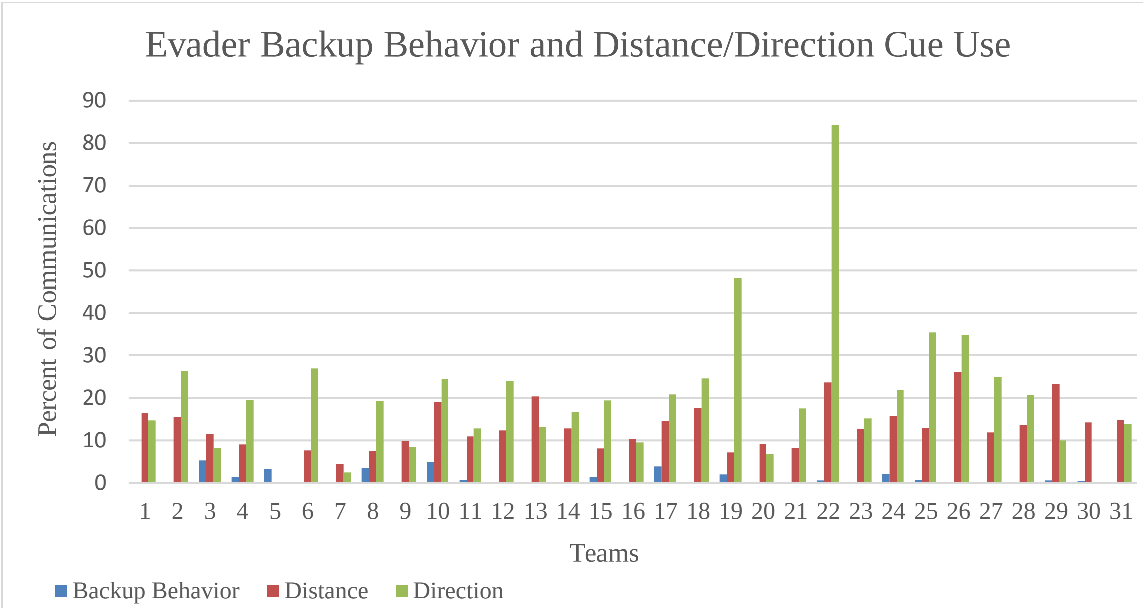

Figure 16. Evader backup behavior and distance/direction cue use per experiment.

Table 12. Pursuing teams percent of communications featuring backup behavior along with percentage of distance/direction cues.

Team Number	Team Type	Percent of communications with backup behavior	Percent of communications with distance	Percent of communications with direction
1	Pursuer	0.00	16.67	3.95
2	Pursuer	0.00	17.86	5.95
3	Pursuer	0.00	13.89	23.15
4	Pursuer	0.00	12.50	16.85
5	Pursuer	0.00	23.00	21.00
6	Pursuer	0.00	6.41	17.09
7	Pursuer	4.32	16.41	21.09
8	Pursuer	1.85	13.72	15.16
9	Pursuer	1.67	16.89	19.87
10	Pursuer	2.13	8.57	25.71
11	Pursuer	0.00	6.98	22.94
12	Pursuer	0.00	15.27	24.43

13	Pursuer	1.46	13.55	14.84
14	Pursuer	0.00	18.75	21.88
15	Pursuer	2.98	17.28	13.58
16	Pursuer	4.35	13.91	9.27
17	Pursuer	0.28	10.00	24.40
18	Pursuer	0.00	8.99	16.55
19	Pursuer	2.68	13.69	13.06
20	Pursuer	0.00	14.69	11.86
21	Pursuer	0.00	14.89	44.68
22	Pursuer	7.48	0.00	0.00
23	Pursuer	2.13	17.11	10.53
24	Pursuer	1.27	10.31	22.68
25	Pursuer	2.74	7.81	11.15
26	Pursuer	0.00	19.86	46.10
27	Pursuer	4.00	10.43	25.65
28	Pursuer	0.00	16.13	23.87
29	Pursuer	0.00	7.69	4.62
30	Pursuer	1.44	16.67	28.33
31	Pursuer	0.00	12.34	19.48
32	Evader	0.00	16.37	14.62
33	Evader	0.00	15.50	26.36
34	Evader	5.20	11.59	8.21
35	Evader	1.30	8.99	19.58
36	Evader	3.29	0.00	0.00
37	Evader	0.00	7.69	26.92
38	Evader	0.00	4.51	2.46
39	Evader	3.51	7.41	19.26
40	Evader	0.00	9.79	8.39
41	Evader	5.02	19.05	24.49
42	Evader	0.78	10.91	12.73
43	Evader	0.00	12.32	23.91
44	Evader	0.00	20.29	13.04
45	Evader	0.00	12.77	16.72
46	Evader	1.29	8.08	19.44
47	Evader	0.00	10.26	9.52
48	Evader	3.88	14.58	20.83
49	Evader	0.00	17.65	24.51
50	Evader	2.02	7.14	48.21
51	Evader	0.00	9.20	6.90

52	Evader	0.00	8.25	17.48
53	Evader	0.61	23.68	84.21
54	Evader	0.00	12.68	15.22
55	Evader	2.08	15.77	21.86
56	Evader	0.72	12.90	35.48
57	Evader	0.00	26.09	34.78
58	Evader	0.00	11.89	24.86
59	Evader	0.00	13.59	20.65
60	Evader	0.56	23.33	10.00
61	Evader	0.37	14.29	0.00
62	Evader	0.00	14.89	13.83

Similar to previous sections, a correlation was run on (1) the percentage of backup behavior in communications and distance cues, (2) percentage of backup behavior and direction cues, and (3) percentage of distance and direction cues.

Table 13. Correlation between percentage of communications featuring backup behavior and percentage of distance/direction cues in communications.

Variable	Correlation
Backup Behavior and distance	-0.35
Backup Behavior and Direction	-0.33
Distance and Direction	0.30

Similar, to district use, distance and direction cues were also well split in certain games. Figures 18 and 19 show how occurrences of these variables is distributed across the team. For example, figures 18, 19, and 20 shows that for backup behavior and distance/direction cues in pursuing team 17, all players shared a large percentage of the team's use.

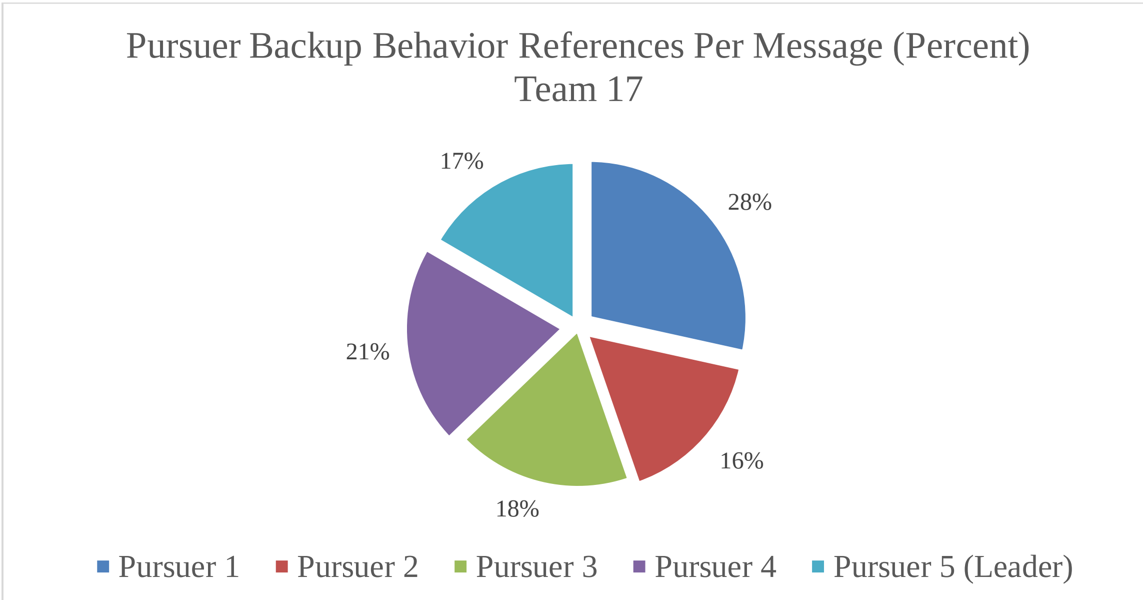

Figure 17. Share of backup behavior across a single pursing team.

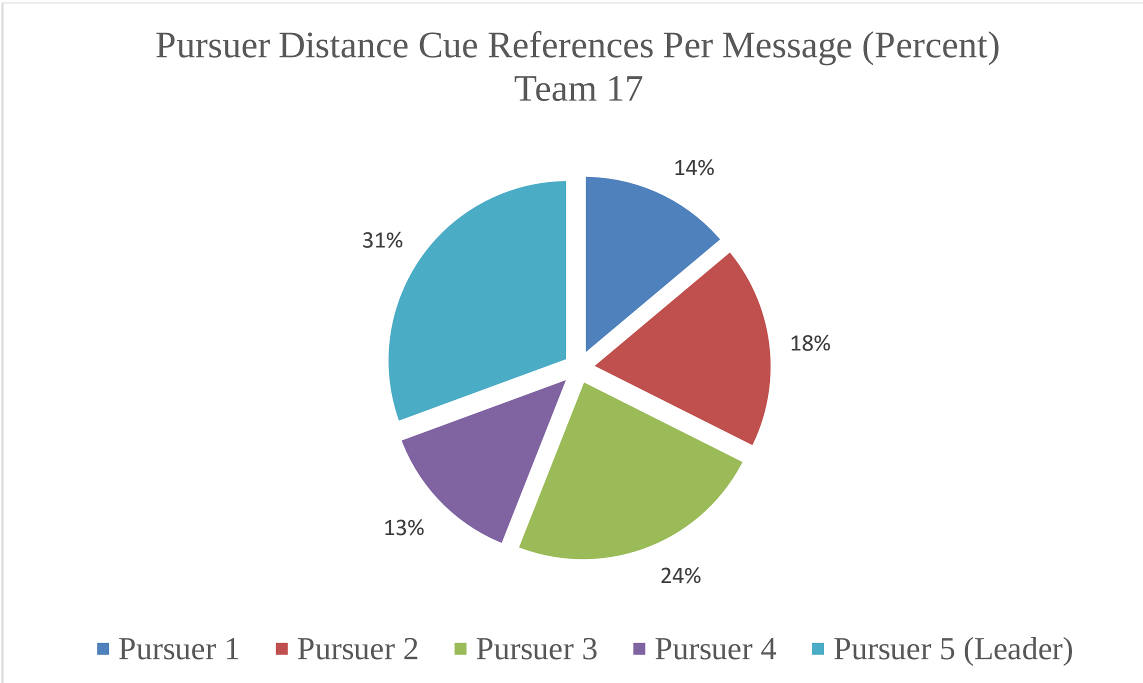

Figure 18. Share of backup behavior across a single pursing team.

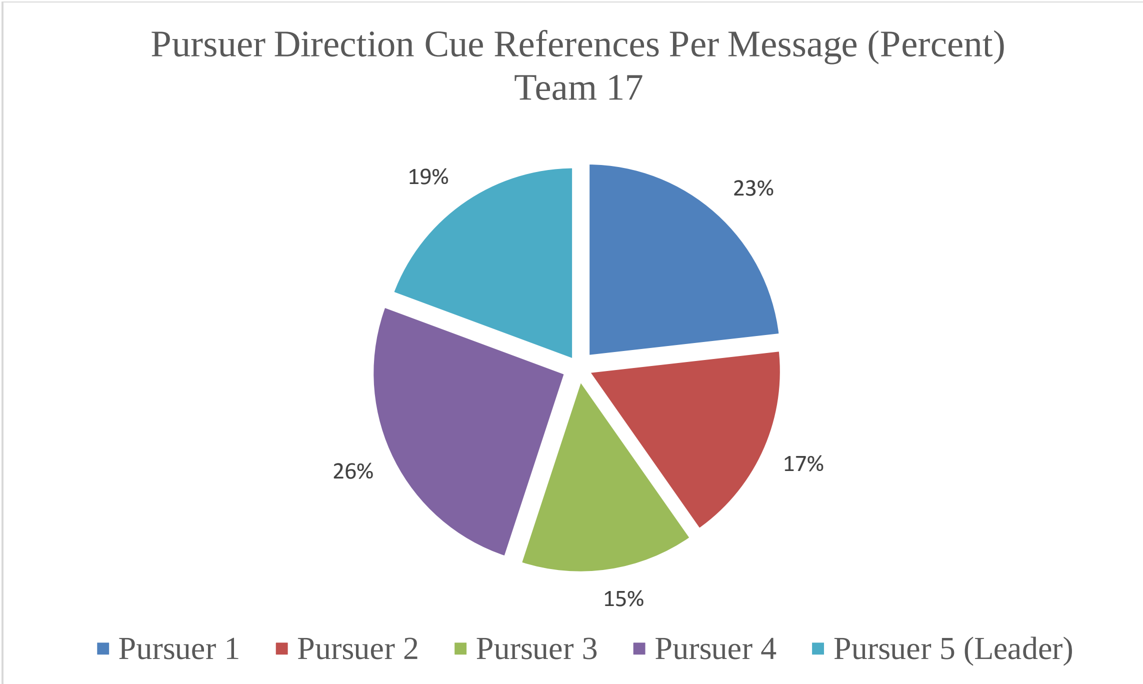

Figure 19. Pursuing team share of direction cues

A large percentage of participants used districts (71%) and spatial reference frames (52%) in their communications to fellow teammates. Additionally, it was shown that leader's use of spatial language was correlated with the team using a spatial reference frame. Unfortunately, there was not evidence for spatial backup behavior. Compared to more frequent tags, backup behavior was never found in more than 10% of a team's communications. There was also no correlation between leader use of spatial reference frames and the team's use. Still, there was strong evidence for the first two characteristics of team spatial cognition, shared districts and leader spatial reference frame.

CHAPTER SEVEN: CONCLUSIONS

Teams used a wealth of spatial language in order to accomplish the goals of the experiment. The use of districts, spatial reference frame, and distance/direction cues were used across all members in their respective teams. Additionally, team leader use of these spatial terms was correlated with team use of these same concepts. Unfortunately, backup behavior as defined by (Salas et al., 2005) was not correlated with communicating distance information (-0.35) and even higher with directional information (-0.33). Despite there being no clear evidence for spatial backup behavior, there was evidence for the first two characteristics of team spatial cognition, shared districts and a correlation between leader spatial reference frame use and the team's. It has been known for several decades that individuals individually process and use spatial information. Now, there is evidence that the team itself also processes and uses spatial information differently than an individual.

The impact of these findings is that it provides evidence that teams are entities that can be studied separate from the individuals which comprise them. As technology evolves, the need for efficient teams will become more important. The results of this research show that there are team level dynamics that can be measured such as shared districts, leadership driven spatial reference frame. These discoveries of team level spatial information are important for science and research. Team spatial cognition is an early attempt to conceptualize team-level processing of spatial information. The three facets of team spatial cognition analyzed are just the tip of the iceberg in regards to studying team-level cognitive processes.

CHAPTER EIGHT: FUTURE RESEARCH

There are many avenues for future research to expand on these findings. The experiments conducted in this study utilized computer based team interactions. It is unknown if these findings also apply to teams navigating in real world environments. The Center for Location Science at George Mason University is currently conducting outdoor pursuit and evasion experiments with players communicating through cellphones to test this notion.

If team spatial cognition research expands, there would be great opportunities to advance science. Kail & Park (1990) showed that changing spatial reference frame is a resource demanding algorithm for individuals, but more research is needed to understand how these tasks are processed at the team level. The following appendix contains the dictionary through which the QDA process was carried out. Should another researcher repeat this study, the appendix contains authoritative definitions for many team and spatial cognition variables as well as real-life examples from player communications.

Team research and spatial cognition research are two very different disciplines. One deals with how teams interact, the other with how humans process spatial information. It is time that the two fields are brought together so that science might better understand how teams process, use, and communicate spatial information. The aspects of team spatial cognition studied in this paper are just a sample of the possibilities team spatial cognition has to offer. As research groups such as the Center for Location Science continue to advance science, the community moves closer to better understanding and characterizing teams and team spatial cognition.

APPENDIX

This appendix is formatted such that each section (1-6) corresponds with a branch of figure 6 which can be found earlier in this document. Bold text indicates the primary part of a communication justifying its corresponding tag.

1. Type: What type of sentence is expressed in the communication?

1.1 Declarative: A declarative sentence states a fact or an argument and ends with a period. Declarative sentences are by far the most common type of sentence.

- "There is an evader near the George Mason statue."

1.2 Interrogative: An interrogative sentence is one which asks a question. A question mark [?] is used to close such a sentence.

"Is there a pursuer near the George Mason statue?"

1.3 Exclamatory: An exclamatory sentence, or exclamation, is a more forceful version of a declarative sentence. In other words, an exclamatory sentence makes a statement (just like a declarative sentence), but it also conveys excitement or emotion. An exclamatory sentence ends with an exclamation mark (!)

- "omg be careful!"

1.4 Imperative: An imperative sentence is a type of sentence that gives advice or instructions or that expresses a request or command.

- "don't come near the engineering building!!!"

2. Location

2.1 Perspective: Using spatial prepositions to locate something in relation to something else. (not the map). Do not label a perspective unless there is an object involved.

- "**I am on the left"** does not get coded.
- **Front, above, behind, back of, right, left, top, bottom, under**

2.1.1 Egocentric: "A central issue for researchers of human spatial knowledge, whether focused on perceptually guided action or cognitive-map acquisition, is knowledge of egocentric directions, directions from the body to objects and places" Montello et al., (1999).

  - "Sandy creek parking deck is to my right"

2.1.2 Intrinsic

  - "The evader is at the main front entrance to the JC"

2.1.3 Extrinsic (Also uses North, South, East, West)

  - "There is one in front of the JC" (using map to determine front)

2.2 Distance

2.2.1 Spatial

2.2.2 Temporal

  - "I am three turns away from the JC"

2.2.3 Relative

  - "I am right by david king hall now"

- “I am going from the JC to the Statue” (also count as a path)
- I am **passing the JC** now”
- I am moving South **from the Starbucks**”
- “I am **in between** Innovation and the School of the Arts”
- **I see** an evader. The game has a sight range, so this is an implicit distance.

2.2.4 Arbitrary

- “I am some distance away.”

2.3 Direction (used with actions and locations)

2.3.1 Cardinal (used when describing location as well)

- “I am standing north of mason pond dr”

2.3.2 Relative

- I am above the student apartments
- Also used when moving a relative direction like, ” I am going towards sub1.”
- I am **just east** of Innovation
- He is **getting closer to me**! – implied that pursuer is moving in his direction.

2.3.3 Arbitrary

- “I am going to move in a random direction”

3. Description or Evaluation

3.1 Object Type

3.1.1 Landmark

"Landmarks. Landmarks are another type of point-reference, but in this case the observer does not enter within them, they are external. They are usually a rather simply defined physical object: building, sign, store, or mountain. Their use involves the singling out of one element from a host of possibilities. Some landmarks are distant ones, typically seen from many angles and distances, over the tops of smaller elements, and used as radial references. They may be within the city or at such a distance that for all practical purposes they symbolize a constant direction. Such are isolated towers, golden domes, great hills. Even a mobile point, like the sun, whose motion is sufficiently slow and regular, may be employed. Other landmarks are primarily local, being visible only in restricted localities and from certain approaches. These are the innumerable signs, store fronts, trees, doorknobs, and other urban detail, which fill in the image of most observers. They are frequently used clues of identity and even of structure, and seem to be increasingly relied upon as a journey becomes more and more familiar" Lynch, (1960).

- JC, Mason Statue, The Clock, Mason pond

3.1.2 Paths

"Paths are the channels along which the observer customarily, occasionally, or potentially moves. They may be streets, walkways, transit lines,canals, railroads. For many people, these are the predominant elements in their image. People observe the city while moving through it, and along these paths the other environmental elements are arranged and related" Lynch, (1960).

- Patriot circle, Rivanna River way
- Also included descriptions of movement pattern such as…"Making **my way around the JC**" I am making **a loop**. I am **circling around the JC.** I am **cutting through the commons.**

3.1.3 District

Districts are the medium-to-large sections of the city, conceived of as having two-dimensional extent, which the observer mentally enters "inside of," and which are recognizable as having some common, identifying character. Always identifiable from the inside, they are also used for exterior reference if visible from the outside.

- I am between the JC and Planetary
- The evaders are on the top half of the map
- Quadrant, He is in the student apartment area,
- The pursuer is in the center
- Mentions a side…"I am on the **right side**" Mark as an edge if they say they are on the "**right side of the JC**"
- Any references to map regions like "I am in the **south side of the map**" even references like **I am in the North** were counted.

- References to corners "I am in the **bottom right corner**"
- If someone says "**Very south of map**", treat it as an edge.
- **Check around the HUB**. – references to checking places implies an area. Check **behind the student apartments.**
- If they say "**Move up the left side of the map**" this is both a district (the map) and an edge, "**Left side of the map**"
- "**Check the mason statue**" was treated as a district and a landmark because the player is specifying an area to be checked, not a single point.
- There is an evader **around Fenwick – This is an indication of being in an area.**
- Everyone **Come South** to Help me! – In this case, the player is assuming everyone is north, so the South is being considered an area.

3.1.4 Edges.

"Edges are the linear elements not used or considered as paths by the observer. They are the boundaries between two phases, linear breaks in continuity: shores, railroad cuts, edges of development, walls. They are lateral references rather than coordinate axes. Such edges may be barriers, more or less penetrable, which close one region off from another; or they may be seams, lines along which two regions are related and joined together. These edge elements, although probably not as dominant as paths, are for many people important organizing features, particularly in the role of holding together generalized areas, as in the outline of a city by water or wall" Lynch, (1960).

- I am moving alongside the top of the map
- I am on the southern edge

3.1.5 Node

- The evader is at the intersection of Riviana and patriot circle

3.1.6 Pursuer

- Referring to teammates in the third person on the pursuer team. Or, referring to the other team or other team players (when on the evading team)
- "Is anyone by the JC?"

3.1.7 Evader

Referring to teammates in the third person on the evading team. Or referring to the other team or other team players (when on the pursuing team)

- Where is the pursuer moving??"

3.2 Quantity

Refers to expressions of quantities greater than one.

3.3 Quality

Refers to any description of the identity or value of an object.

3.4 Knowledge Domain

3.4.1 Static/Environment

- "Stay away from Eastern Shore lol"

3.4.2 Dynamic/Task

- 'Our job is to capture the evaders'

4. Action: Doing something. Usually moving or not moving.

4.1 Perspective

4.1.1 1st Person

- "I am moving to the center of the arts"

4.1.2 2nd Person

- "don't come near the engineering building!!!"

4.1.3 3rd Person

- "The evader is heading toward the bottom of the JC"

4.2 Verb

4.2.1 Moving:

- "**looking** by the skyline fitness center now"
- "**Going** towards you"
- "He is **moving** North"
- "I am **headed** to the JC"
- "I am **coming**!"
- "**On my way**"
- "I am **following** an evader"
- "I am being **chased**"

- “He is **running** away”
- “**Checking** around Mason Pond”
- “I am **patrolling** the North half”
- “**Now passing** the Sandy Creek Parking Deck”
- “I am trying to **avoid** being captured.
- “Pursuer **crossing** Patriot Circle
- “I am **walking** down the map”
- “**Making my way** there”
- “**Get out** of there!”
- “He is **after** me”
- “**Spread out**!
- “I will **circle around** Exploratory”
- “I am **looping through** the buildings”
- 4.2.2 Not moving:
- “I am **not moving**”
- “I will **camp** here”
- I will **stick** around here”
- “**Stay** there”
- “I am **hanging out** by Innovation”
- “**Hiding** near mason pond”
- “**Chilling** over there”
- “**Staying** behind engineering building”

- "I am **hiding** here"

3.1.5 Nodes

"Nodes are points, the strategic spots in a city into which an observer can enter, and which are the intensive foci to and from which he is traveling. They may be primarily junctions, places of a break in transportation, a crossing or convergence of paths, moments of shift from one structure to another. Or the nodes may be simply concentrations, which gain their importance from being the condensation of some use or physical character, as a street-comer hangout or an enclosed square. Some of these concentration nodes are the focus and epitome of a district, over which their influence radiates and of which they stand as a symbol. They may be called cores. Many nodes, of course, partake of the nature of both junctions and concentrations. The concept of node is related to the concept of path, since junctions are typically the convergence of paths, events on the journey. It is similarly related to the concept of district, since cores are typically the intensive foci of districts, their polarizing center. In any event, some nodal points are to be found in almost every image, and in certain cases they may be the dominant feature" Lynch, (1960).

- I am at the **end** of Riviana River Lane.
- "Let's Capture the evaders at the **intersection**"

5. Team Variables

5.1 Adaptability

“Ability to adjust strategies based on information gathered from the environment through the use of backup behavior and reallocation of intra-team resources. Altering a course of action or team repertoire in response to changing conditions (internal or external).”

Behavior indicators – “Identify cues that a change has occurred, assign meaning to that change, and develop a new plan to deal with the changes. Identify opportunities for improvement and innovation for habitual or routine practices. Remain vigilant to changes in the internal and external environment of the team” Salas et al., (2005).

- Do you think **they are using the roads as paths**? **maybe avoid them**
- **we are all by mason pond deck. Let's spread more.** Someone go towards jc
- **i'm gonig to head to clock since we got all 3 out near patriot circle.** lets move to the middle or in between E. shore down engineering.

5.2 Backup Behavior

“Ability to anticipate other team members’ needs through accurate knowledge about their responsibilities. This includes the ability to shift workload among members to achieve balance during high periods of workload pressure.”

Behavior Indicators – “Recognition by potential backup providers that there is a workload distribution problem in their team. Shifting of work responsibilities to underutilized team members. Completion of the whole task or parts of tasks by other team members” Salas et al., (2005).

- **I’m going to pond to help catch evader**
- at top of quadrant **2 coming to help with starbuck evader**
- **Coming around commonwealth to help.**

5.3 Leadership

“Ability to direct and coordinate the activities of other team members, assess team performance, assign tasks, develop team knowledge, skills, and abilities, motivate team members, plan and organize, and establish a positive atmosphere.”

Behavior indicators – “Facilitate team problem solving. Provide performance expectations and acceptable interaction patterns. Synchronize and combine individual team member contributions. Seek and evaluate information that affects team functioning. Clarify team member roles. Engage in preparatory meetings and feed-back sessions with the team” Salas et al., (2005)

- everyone try to stay near buildings. It gives them less range of motion since they can't go through them
- Everyone go towards the spots we had set up near the beginning but stay near the edges. If they are staying near the edges it should b easy to find them Wait there do it next round

5.4 Mutual Performance Monitoring

“The ability to develop common understandings of the team environment and apply appropriate task strategies to accurately monitor teammate performance.”

Behavior indicators – “Identifying mistakes and lapses in other team members’ actions. Providing feedback regarding team member actions to facilitate self-correction” Salas et al., (2005).

- theres a persuer close by evader 4 by mason pond so watch out
- is the persuer in sight? you should probably think about moving...
- Guys. Remember we are red!

5.5 Team Orientation

“Propensity to take other’s behavior into account during group interaction and the belief in the importance of team goal’s over individual members’ goals.”

Behavior indicators – “Taking into account alternative solutions provided by teammates and appraising that input to determine what is most correct. Increased task involvement, information sharing, strategizing, and participatory goal setting” Salas et al., (2005).

- should i go down to mason pond?
- Lol, I know but lets hope **we both win!!!**
- Pursuer right by me for some reason, gonna try avoiding him, i won't lead him/her towards you lol’
- Also used this as a tag for things like “**Good job everyone. We can do it!”** because this is a form putting the team’s goals over the individual’s.
- Any kind of sacrificial behavior like offering to be a decoy.

5.6 Coordination Mechanisms

5.6.1 Closed Loop communication

“The exchange of information between a sender and a receiver irrespective of the medium.”

Behavior indicator – “Following up with team members to ensure message was received. Acknowledging that a message was received. Clarifying with the sender of the message that the message received is the same as the intended message” Salas et al., (2005).

- Yeah, that's what I'm doing.
- yes the evader is going towards engineering building
- yea theres a persuer following me in the top right corner of the map

5.6.2 Shared Mental Models

“An organizing knowledge structure of the relationships among the task the team is engaged in and how the team members will interact. Anticipating and predicting each other’s needs. Identify changes in the team, task, or teammates and implicitly adjusting strategies as needed” Salas et al., (2005).

5.6.3 Mutual Trust

“The shared belief that team members will perform their roles and protect the interests of their teammates.

Behavior indicators – “Information sharing. Willingness to admit mistakes and accept feedback” Salas et al., (2005).

- Sorry I saw someone from our team. I got the colors confused.

- Also I think I messed up their direction, theyre on the edge down from the corner
- I want to come to where you are so we can lose together if i lose, but i'm scared”

6. Special

- Anything that does not fit into the above categories.

REFERENCES

Artman, H., & Garbis, C. (1998). Team communication and coordination as distributed cognition. In *Proceedings of 9th Conference of Cognitive Ergonomics : Cognition and cooperation* (pp. 151–156). Dept. of Communication studies, Linköping University.

Baptiste, I. (2001). Qualitative Data Analysis: Common Phases, Strategic Differences. *Forum Qualitative Sozialforschung / Forum: Qualitative Social Research; Vol 2, No 3 (2001): Qualitative Methods in Various Disciplines II: Cultural Sciences*. Retrieved from http://www.qualitative-research.net/index.php/fqs/article/view/917/2003

Barker, A. D. (2015). *Understanding the Geographic Dynamics of Goal-Directed Social Behaviors*. George Mason University.

Campion, M. A., Medsker, G. J., & Higgs, A. C. (1993). Relations Between Work Group Characteristics and Effectiveness: Implications for Designing Effective Work Groups. *Personnel Psychology*, *46*(4), 823–847. https://doi.org/10.1111/j.1744-6570.1993.tb01571.x

Cañas, A., Novak, J., González, F., & O'connor, D. L. (2004). Measuring team cognition: Concept mapping elicitation as a means of constructing team shared mental models in an applied setting.

Chang, H.-H. (2013). Wayfinding Strategies and Tourist Anxiety in Unfamiliar Destinations. *Tourism Geographies*, *15*(3), 529–550. https://doi.org/10.1080/14616688.2012.726270

Chase, W. G. (1983). Spatial Representations of Taxi Drivers. In D. Rogers & J. A. Sloboda (Eds.), *The Acquisition of Symbolic Skills* (pp. 391–405). Boston, MA: Springer US. Retrieved from http://dx.doi.org/10.1007/978-1-4613-3724-9_43

Chowdhury, M. F. (2015). Coding, sorting and sifting of qualitative data analysis: debates and discussion. *Quality & Quantity*, *49*(3), 1135–1143. https://doi.org/10.1007/s11135-014-0039-2

Chraibi, M., & Haensel, D. (2017). A Knowledge-based Way-Finding Framework for Pedestrian Dynamic. *ArXiv E-Prints*.

Chrastil, E. R., & Warren, W. H. (2013). Active and passive spatial learning in human navigation: Acquisition of survey knowledge. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *39*(5), 1520–1537. https://doi.org/10.1037/a0032382

Committeri, G., Galati, G., Paradis, A.-L., Pizzamiglio, L., Berthoz, A., & LeBihan, D. (2004). Reference frames for spatial cognition: different brain areas are involved in viewer-, object-, and landmark-centered judgments about object location. *Cognitive Neuroscience, Journal of*, *16*(9), 1517–1535.

Cooke, N. J., Gorman, J. C., Kiekel, P. A., Foltz, P., & Martin, M. (2005). *Using team communication to understand team cognition in distributed vs. co-located mission environments*. ARIZONA STATE UNIV EAST MESA AZ.

Cooke, N. J., Salas, E., Kiekel, P. A., & Bell, B. (2004). Advances in measuring team cognition. *Team Cognition: Understanding the Factors That Drive Process and Performance*, 83–106.

Couclelis, H., Golledge, R. G., Gale, N., & Tobler, W. (1987). Exploring the anchor-point hypothesis of spatial cognition. *Journal of Environmental Psychology*, *7*(2), 99–122. https://doi.org/10.1016/S0272-4944(87)80020-8

Daniel, M.-P., & Denis, M. (2004). The production of route directions: investigating conditions that favour conciseness in spatial discourse. *Applied Cognitive Psychology*, *18*(1), 57–75. https://doi.org/10.1002/acp.941

de Jong, J. P., Curşeu, P. L., & Leenders, R. T. A. J. (2014). When do bad apples not spoil the barrel? Negative relationships in teams, team performance, and buffering mechanisms. *Journal of Applied Psychology*, *99*(3), 514–522. https://doi.org/10.1037/a0036284

Downs, R., & Stea, D. (2011). Cognitive Maps and Spatial Behaviour: Process and Products. In M. Dodge, R. Kitchin, & C. R. Perkins (Eds.), *The map reader: theories of mapping practice and cartographic representation*. Chichester, West Sussex [England] ; Hoboken, NJ: Wiley-Blackwell.

Edmondson, A. (1999). Psychological safety and learning behavior in work teams. *Administrative Science Quarterly*, *44*(2), 350–383.

Fleştea, A. M., Fodor, O. C., Curşeu, P. L., & Miclea, M. (2016). “We didn”t know anything, it was a mess!’ Emergent structures and the effectiveness of a rescue operation multi-team system. *Ergonomics*, 1–15. https://doi.org/10.1080/00140139.2016.1162852

Galea, L. A., & Kimura, D. (1993). Sex differences in route-learning. *Personality and Individual Differences*, *14*(1), 53–65.

Gibbs, R. W. (1984). Literal meaning and psychological theory. *Cognitive Science*, *8*(3), 275–304.

Goldiez, B. F., Ahmad, A. M., & Hancock, P. A. (2007). Effects of Augmented Reality Display Settings on Human Wayfinding Performance. *IEEE Transactions on Systems, Man and Cybernetics, Part C (Applications and Reviews)*, *37*(5), 839–845. https://doi.org/10.1109/TSMCC.2007.900665

Golledge, R. G., & Dougherty, V. (1995). Acquiring spatial knowledge: Survey versus route-based knowledge in unfamiliar environments. *Annals of the Association of American Geographers*, *85*(1), 134.

Huang, M. (n.d.). What Influences Trust Building in Cross-cultural Semi-virtual Work Teams: A Multilevel Analysis Based on Social Contagion, Reciprocity, Affect, and Cultural Norms François Lambotte, PhD Facultés Universitaires Catholiques de Mons Chaussée de Binche 151, 7000 Mons, Belgium.

Hund, A. M., & Padgitt, A. J. (2010). Direction giving and following in the service of wayfinding in a complex indoor environment. *Journal of Environmental Psychology*, *30*(4), 553–564. https://doi.org/10.1016/j.jenvp.2010.01.002

Ishikawa, T., & Montello, D. R. (2006). Spatial knowledge acquisition from direct experience in the environment: Individual differences in the development of metric knowledge and the integration of separately learned places. *Cognitive Psychology*, *52*(2), 93–129. https://doi.org/10.1016/j.cogpsych.2005.08.003

Jeanne Sholl, M., Acacio, J. C., Makar, R. O., & Leon, C. (2000). The Relation of Sex And Sense of Direction to Spatial Orientation in an Unfamiliar Environment. *Journal of Environmental Psychology*, *20*(1), 17–28. https://doi.org/10.1006/jevp.1999.0146

Kail, R., & Park, Y. (1990). Impact of practice on speed of mental rotation. *Journal of Experimental Child Psychology*, *49*(2), 227–244.

Kiekel, P. A. (2002). Developing automatic measures of team cognition using communication data.

Kiekel, P. A., Cooke, N. J., Foltz, P. W., Gorman, J. C., & Martin, M. J. (2002). Some Promising Results of Communication-Based Automatic Measures of Team Cognition. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *46*(3), 298–302. https://doi.org/10.1177/154193120204600318

Kozlowski, S. W. J., & Chao, G. T. (2012). The Dynamics of Emergence: Cognition and Cohesion in Work Teams: THE DYNAMICS OF EMERGENCE. *Managerial and Decision Economics*, *33*(5-6), 335–354. https://doi.org/10.1002/mde.2552

Landauer, T. K., Foltz, P. W., & Laham, D. (1998). An introduction to latent semantic analysis. *Discourse Processes*, *25*(2-3), 259–284. https://doi.org/10.1080/01638539809545028

Lawton, C. A. (1996). Strategies for indoor wayfinding: The role of orientation. *Journal of Environmental Psychology*, *16*(2), 137–145.

Le Bon, G. (1897). Review of The Crowd: A Study of the Popular Mind. *Psychological Review*, *4*(3), 313–316. https://doi.org/10.1037/h0069323

Leinonen, P., Järvelä, S., & Häkkinen, P. (2005). Conceptualizing the Awareness of Collaboration: A Qualitative Study of a Global Virtual Team. *Computer Supported Cooperative Work (CSCW)*, *14*(4), 301–322. https://doi.org/10.1007/s10606-005-9002-z

Lynch, K. (1960). *The image of the city* (Vol. 11). MIT press. Retrieved from http://books.google.com/books?hl=en&lr=&id=_phRPWsSpAgC&oi=fnd&pg=PA1&dq=%22and+all%22+%22associations+with+some+part+of+his+city,+and+his+image%22+%22operation,+and+the+image+is+the+composite+of+them%22+%22phases.+No+wonder,+then,+that+the+art+of+shaping+cities%22+&ots=jGGa3h3Dhe&sig=jgbRSYM3DPqVDXWaIdr5KTvxy2g

MacMillan, J., Entin, E. E., & Serfaty, D. (2004). Communication overhead: The hidden cost of team cognition. *Team Cognition: Process and Performance at the Interand Intra-Individual Level. American Psychological Association, Washington, DC. Available at Http://www. Aptima. com/publications/2004_MacMillan_EntinEE_Serfaty. Pdf*. Retrieved from https://www.researchgate.net/profile/Linda_Elliott2/publication/265435896_COMMUNICATION_OVERHEAD_THE_HIDDEN_COST_OF_TEAM_COGNITION/links/54b6b8fa0cf24eb34f6d89dd.pdf

Mathieu, J. E., Cobb, M., Marks, M. A., Zaccaro, S. J., & Marsh, S. (2004). Multi-team ACES: A research platform for studying multi-team systems. *Scaled Worlds: Development, Validation and Applications*, 297–315.

Ma, Y., Hu, X., & Wilson, F. A. (2012). The egocentric spatial reference frame used in dorsal–lateral prefrontal working memory in primates. *Neuroscience & Biobehavioral Reviews*, *36*(1), 26–33. https://doi.org/10.1016/j.neubiorev.2011.03.011

Millikin, J. P., Hom, P. W., & Manz, C. C. (2010). Self-management competencies in self-managing teams: Their impact on multi-team system productivity. *The Leadership Quarterly*, *21*(5), 687–702. https://doi.org/10.1016/j.leaqua.2010.07.001

Montello, D. R., Richardson, A. E., Hegarty, M., & Provenza, M. (1999). A comparison of methods for estimating directions in egocentric space. *Perception*, *28*(8), 981–1000.

Nonose, K., Kanno, T., & Furuta, K. (2012). A team cognition model derived from an analysis of reflection on cooperation. *Cognition, Technology & Work*, *14*(1), 83–92. https://doi.org/10.1007/s10111-011-0179-2

Nonose, K., Kanno, T., & Furuta, K. (2013). A Method of Team Communication Analysis Based on a Team Cognition Model and Task Analysis. In C. Stephanidis (Ed.), *HCI International 2013 - Posters' Extended Abstracts: International Conference, HCI International 2013, Las Vegas, NV, USA, July 21-26, 2013,* *Proceedings, Part II* (pp. 519–523). Berlin, Heidelberg: Springer Berlin Heidelberg. Retrieved from http://dx.doi.org/10.1007/978-3-642-39476-8_105

NVivo qualitative data analysis Software. (2017). (Version 11.4.0.1062). QSR International.

Pearsall, M. J., Ellis, A. P. J., & Bell, B. S. (2010). Building the infrastructure: The effects of role identification behaviors on team cognition development and performance. *Journal of Applied Psychology*, *95*(1), 192–200. https://doi.org/10.1037/a0017781

Prestopnik, J. L., & Roskos–Ewoldsen, B. (2000). THE RELATIONS AMONG WAYFINDING STRATEGY USE, SENSE OF DIRECTION, SEX, FAMILIARITY, AND WAYFINDING ABILITY. *Journal of Environmental Psychology*, *20*(2), 177–191. https://doi.org/10.1006/jevp.1999.0160

Proshansky, H. M. (1974). Theoretical Issues in Environmental Psychology. *The School Review*, *82*(4), 541–555.

Retz-Schmidt, G. (1988). Various views on spatial prepositions. *AI Magazine*, *9*(2), 95.

Richards L. (2002). Rigorous, rapid, reliable and qualitative? Computing in qualitative method...Proceedings of the 2nd Scientific Meeting of the American Academy of Health Behavior, March 24-27, 2002, Napa Valley, CA. *American Journal of Health Behavior*, *26*(6), 425–430.

Salas, E., & Fiore, S. M. (2004). Why team cognition? An overview. In E. Salas & S. M. Fiore (Eds.), *Team cognition: Understanding the factors that drive process and* *performance.* (pp. 3–8). Washington: American Psychological Association. Retrieved from http://content.apa.org/books/10690-001

Salas, Fiore, S., Warner, N., & Letsky, M. (2010). Emerging multi-disciplinary theoretical perspectives in team cognition: an overview. *Theoretical Issues in Ergonomics Science*, *11*(4), 245–249. https://doi.org/10.1080/14639221003729110

Salas, Sims, D. E., & Burke, C. S. (2005). Is there a “Big Five” in Teamwork? *Small Group Research*, *36*(5), 555–599. https://doi.org/10.1177/1046496405277134

Silverman, I., Choi, J., Mackewn, A., Fisher, M., Moro, J., & Olshansky, E. (2000). Evolved mechanisms underlying wayfinding: further studies on the hunter-gatherer theory of spatial sex differences. *Evolution and Human Behavior*, *21*(3), 201–213. https://doi.org/10.1016/S1090-5138(00)00036-2

Smelser, N. J., Baltes, P. B., & others. (2001). *International encyclopedia of the social & behavioral sciences* (Vol. 11). Elsevier Amsterdam.

Soós, J. K., & Juhász, M. (2010). Capturing team performance differences through communication based analyses of team cognition. *Periodica Polytechnica. Social and Management Sciences*, *18*(2), 75–85. https://doi.org/10.3311/pp.so.2010-2.03

Tenbrink, T., & Winter, S. (2009). Variable Granularity in Route Directions. *Spatial Cognition & Computation*, *9*(1), 64–93. https://doi.org/10.1080/13875860902718172

Thorndyke, P. W., & Hayes-Roth, B. (1982). Differences in spatial knowledge acquired from maps and navigation. *Cognitive Psychology*, *14*(4), 560–589. https://doi.org/10.1016/0010-0285(82)90019-6

Tolman, E. C. (1948). Cognitive maps in rats and men. *Psychological Review*, *55*(4), 189–208. https://doi.org/10.1037/h0061626

Twyman, A. D., Newcombe, N. S., & Gould, T. J. (2009). Of mice (Mus musculus) and toddlers (Homo sapiens): Evidence for species-general spatial reorientation. *Journal of Comparative Psychology*, *123*(3), 342–345. https://doi.org/10.1037/a0015400

Van Den Berg, W., L. Curseu, P., & T.H. Meeus, M. (2014). Emotion regulation and conflict transformation in multi-team systems. *International Journal of Conflict Management*, *25*(2), 171–188. https://doi.org/10.1108/IJCMA-05-2012-0038

Werner, S., & Schindler, L. E. (2004). The Role of Spatial Reference Frames in Architecture: Misalignment Impairs Way-Finding Performance. *Environment & Behavior*, *36*(4), 461–482. https://doi.org/10.1177/0013916503254829

Wiener, J. M., Schnee, A., & Mallot, H. A. (2004). Use and interaction of navigation strategies in regionalized environments. *Journal of Environmental Psychology*, *24*(4), 475–493. https://doi.org/10.1016/j.jenvp.2004.09.006

Zimmermann, S. (1994). Social cognition and evaluations of health care team communication effectiveness. *Western Journal of Communication*, *58*(2), 116–140. https://doi.org/10.1080/10570319409374491

BIOGRAPHY

In 2013, John Paul Solly graduated from Ghidotti Early College High School in Grass Valley, California. He received his Bachelor of Arts in Geography with a GIS emphasis from University of California, Santa Barbara in 2015. He now pursues a Master of Science in Geoinformatics and Geospatial Intelligence at George Mason University in Fairfax, Virginia.