Dyadic Route Planning and Navigation in Collaborative Wayfinding

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Abstract

The great majority of work in spatial cognition has taken an individual approach to the study of wayfinding, isolating the planning and decision-making process of a single navigating entity. The study we present here expands our understanding of human navigation as it unfolds in a social context, common to real-world scenarios. We investigate pedestrian navigation by pairs of people (dyads) in an unfamiliar, real-world environment. Participants collaborated on a task to plan and enact a route between a given origin and destination. Each dyad had to devise and agree upon a route to take using a paper map of the environment, and was then taken to the environment and asked to navigate to the destination from memory alone. We video-recorded and tracked the dyad as they interacted during both planning and navigation. Our results examine explanations for successful route planning and sources of uncertainty in navigation. This includes differences between situated and prospective planning—participants often modify their route-following on the fly based on unexpected challenges. We also investigate strategies of social role-taking (leading and following) within dyads.

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1 Introduction

Wayfinding as a cognitive process is necessarily situated in a social world, whether someone is explicitly traveling with other people, following route directions, using socially-created signs or maps, or following the physical traces of others to direct their travel [5]. Wayfinding consists of all the acts associated with planning the way between an origin and a destination, including remembering routes, recognizing landmarks, and orienting oneself within the environment [8]. People often need to find their way through an environment while co-present with other people, making decisions jointly.

The majority of prior work in spatial cognition has taken an individual approach to the study of wayfinding, isolating the planning and decision-making process of a single person, animal, or robot as the unit of study. We know for instance how a single person looks at a map and plans a route [21], and we know about choice behaviors at decision points along a route [23, 34]. But limited prior research supports how navigation may work for pairs or groups of people, such as strategies that contribute to success in these interactions or the unique challenges and behavioral effects facing multiple people wayfinding together. Our

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project has implications for the design of both physical and digital navigation aids, expanding what we know about the information needs of multiple people working in conjunction on a wayfinding task.

2 Prior Work

Wayfinding is a complex act that depends on our mental representations of physical environmental spaces that we experience directly or indirectly [24]; in many cases, we learn environments both directly, by traveling through the environment, and indirectly, via symbolic media such as maps or language. Both the planning and enactment of a route through navigation are important wayfinding processes that are often social. Analyzing navigation behavior "in the wild" [15] within a more realistic social setting, versus in a controlled laboratory or virtual setting, is important for the construct and ecological validity of our work. While a wealth of information informs our understanding of wayfinding, a small but growing body of work forms the basis for our knowledge about social interaction in human wayfinding and navigation.

2.1 Route Planning

People commonly give route directions by providing a sequentially-structured set of instructions used to identify a route from an origin to a destination [35]. Investigations into direction-giving allow us to define the structure of a complete set of route instructions, what is at the core of a route plan, and what makes for more or less effective route directions [1,6,22]. The establishment of common ground discussed in the route directions literature is also important to people working together in planning and in active navigation.

Studies by Hölscher et al. [14] show a profound difference between situated and prospective planning, wherein participants often modify their route-following *in situ*. The authors also highlight differences between the construction of routes for oneself and for others: Effective routes planned for others are simple (with few direction changes) and contain distinctive landmarks; those planned for oneself are attractive, fast, direct, and not too busy. Additionally, route plans intended for others include more detailed descriptions to establish common ground between planner and addressee. This suggests that verbalized plans of intended behavior often differ from real-world behavior, highlighting a need for more situated studies. Our work looks at these behaviors in planning and during real-time navigation with a partner.

2.2 Navigation

Navigation along a route, as opposed to only planning a route, presents contextual challenges of remembering the route plan, understanding correspondence of the plan to the experienced physical environment, self-localizing and maintaining one's orientation, judging distances, and (often) coordinating one's spatial knowledge with others. Spatial disorientation and misorientation are common problems threatening any navigation activity. According to Montello [25], geographic *disorientation* occurs when people believe they are unsure of their location or heading or which way to go to reach a destination (what people mean by explicitly expressing they "are lost"). When people are geographically *misoriented*, in contrast, they are objectively not where they think they are or are not going the correct way towards the destination, regardless of their awareness.

Environmental factors like low visibility, poor signage, and outdated maps often present real-world challenges to orientation and wayfinding. Fortunately, people have many available strategies to overcome being lost, such as moving in a specific direction, sampling routes from a location, and backtracking [13]. However, the way individuals employ these strategies may only partially inform strategies at the group level. For groups, social factors could either cause problems like disagreement between navigational partners, or could provide valuable aid in dealing with unexpected problems. We look at wayfinding challenges as well as strategies enacted by people at the dyad level.

2.3 Group Navigation

There is recent enthusiasm around the social dimensions of wayfinding [5], though not traditionally explored by spatial cognition researchers. One distinctive example was Hutchins' work on "cognition in the wild," [15] which studied the navigation of a U.S. Naval crew as socially-distributed cognition, situated in the real world, rather than as an independent mental act. Hutchins proposed that group cognition in humans may have qualitatively different properties than individual cognition. This provides support for the ecological validity of conducting such a study in the real-world versus in a lab or virtual environment.

One important finding from He et al. [11] is that better navigators appear to adjust their route directions to the navigational ability of their partner. In their study on route direction-giving and -receiving by pairs using mobile phones for communication, they found that participants with a better sense of direction were better equipped to adjust how they provided navigational instructions. They were able to do so both because they stored more information about the environment they had traversed, and because they were more attuned to their partner's informational needs. Their study shows that flexibility in social coordination between members of a dyad may help overcome the disadvantages of being a poor individual navigator. Pairs perform differently than individuals not only due to differences in their spatial abilities but also because of their interpersonal route communication. Our work builds on this using pairs of people working synchronously in a wayfinding task to explore how people communicate when navigating together.

Our study uses the *dyad* as the unit of analysis, a pair of individuals who work together toward a shared goal. The dyad is considered the simplest-sized social group. Simmel's work on social geometry states that as each individual person is added to a group, different social behavioral dynamics emerge, such as a triad's tendency to act more as a dyad plus an individual, and a four-person group to divide into two dyads [33]. Specific to dyads, Reilly et al. [28] characterized the social roles adopted within pairs during navigation. These roles include, but are not limited to, roles such as leader and follower, or independent versus collaborative participants. We use this as a starting point to look at differences in how dyads act more or less collaboratively during both planning and navigation.

2.4 Social Interaction Analysis

The close investigation of social interaction that we employ in this project is *Conversation Analysis* (CA). A key feature of this approach [9, 31, 32] is its concern with conversational talk as it unfolds within a socially-shared context. CA as applied to situated navigation gives us methods of understanding how the project of wayfinding is constructed and maintained in real time (e.g. [10]). When multiple people navigate together, they must orient themselves with regards to the physical environment as well as coordinate their spatial knowledge to establish a shared reality within which they can work [27].

Many behavioral studies are predesigned to record certain expected behaviors, wherein the topics of observation are determined beforehand (i.e., they are top-down). On the other hand, CA gives us a bottom-up opportunity to learn the strategies people employ to form common ground, for example using place labels to establish shared understanding [30]. By examining the talk immediately following an action, we observe how participants jointly understand and respond to what is being done. In the case of navigation, a person may see their partner pause at a juncture and use that opening to provide instruction. We see that they read the pause as an expression of uncertainty and as a point of potential intervention. People clearly orient themselves not only to the spatial task of navigation but also to the social task of shared understanding.

We demonstrate the value of incorporating the methods of CA to understand social actions and strategies relevant to wayfinding. By observing both route planning and in-person navigation, we compare how navigational plans are proposed ahead of time (prospectively) to how they are enacted in the physical environment (situatively). Close analysis of navigational performance by different dyads helps us explain how social interaction contributes to success or failure in solving wayfinding problems such as recovering from being lost. We focus on the issues of leadership, knowledge alignment, and personal characteristics.

3 Method

This work investigates route planning and navigation by dyads in a novel environment. Participants making up the dyads did not previously know each other and had little or no prior knowledge of the study site. To investigate both prospective co-planning of routes and situated co-navigation, the study consisted of two phases: (1) the planning of a route between an origin and destination in a nearby neighborhood, done in a separate lab room, and (2) the subsequent navigation of the route within the environment. We integrate the conceptual and methodological research traditions of geography and sociology, which generally apply group-level analyses, and psychology, which conventionally examines the individual.

3.1 Research Questions

The research questions we address are:

1. How do differences in sense of direction and personality among individual navigators relate to dyadic route planning and travel, examined both as overall characteristics of dyads and as differences between dyad members?
2. Do dyads' prospective planned routes through a novel environment differ from their routes as enacted *in situ*, and if so, how?
3. How do dyads coordinate their knowledge and behavior in a real-world environment to navigate efficiently, such as by adopting social roles within the dyad?

3.2 Participants

A total of 30 pairs of people (60 individuals) were recruited from a subject pool of university students enrolled in introductory Geography classes. However, as these courses fulfill several general requirements, very few students in the subject pool were Geography majors. The average age of participants was 19.5 years old ($SD = 2.1$), which is representative of our subject pool. So that our results would not involve any effects of prior social role-taking, we tested pairs who did not previously know each other. We assessed prior familiarity by asking participants about it at the start of the study session. In 27 of the dyads, participants first met as part of participating in this study; in 3 dyads, members had briefly met in a classroom context, but none considered themselves more than acquaintances. Each dyad was tested at a separate time (i.e. not concurrently).

3.3 Individual Difference Measures

We summarize the wide differences in peoples' individual abilities [16] in terms of three factors important to our research agenda: sense of direction, personality, and gender. We examine whether patterns of social interaction and wayfinding differ as a function of the dyads' overall levels of the factors, or as a function of the relative match or mismatch of these factors between members of the dyads.

Sense of Direction (SOD). Directly relevant to real-world navigational ability is "sense of direction" (SOD), the ability to locate and orient oneself with respect to an environmental space. We assessed SOD with the Santa Barbara Sense of Direction Scale (SBSOD [12]), which asks people to rate their agreement with a variety of navigation-related statements, such as "I can usually remember a new route after I have traveled it only once" and "I have trouble understanding directions." Agreement is expressed on a Likert scale from 1 (strongly agree) to 7 (strongly disagree), with positively worded statements reverse-coded so that a higher score indicates a better reported sense of direction. A summary of our participants' scores on the SBSOD scale are presented in Table 1.

Table 1 Means on SBSOD and Big Five Inventory for Individual Dyad Members ($N = 60$).

Measures	All Members [Range]	Females ($N = 43$)	Males ($N = 17$)
SBSOD	3.9 [1.6–6.6]	3.8	4.2
Extraversion	3.3 [1.5–5.0]	3.3	3.4
Agreeableness	4.0 [2.3–5.0]	4.2	3.8
Conscientiousness	3.6 [1.2–4.8]	3.6	3.4
Neuroticism	2.8 [1.4–4.6]	2.9	2.6
Openness	3.5 [2.1–5.0]	3.5	3.6

Personality. Personality may account for some of the differences in social interaction style, engagement with novel environments, and leadership. Prior work has attempted to delineate the complex relationship between personality factors and spatially-relevant measures such as SOD, starting with Bryant's seminal work [2, 4]. We assessed personality using the "Big Five" Inventory (BFI), a widely-used measure for a modern framework of personality factors [17, 18]. The Big Five factors are widely used and accepted, based on decades of research [7], and include the dimensions of *Extraversion*, *Agreeableness*, *Conscientiousness*, *Neuroticism*, and *Openness to Experience*. Of these, Extraversion has been most consistently shown to correlate with leadership behavior, followed by Conscientiousness and Openness [19]. Respondents express their level of agreement with 44 statements on a 5-point Likert scale. For a given dimension, scores range from the lowest score of 1.0 to the highest of 5.0. A summary of our participants' scores on each dimension is presented in Table 1.

Gender. Gender has been shown to have a reliable relationship with aspects of spatial ability and style, including survey-based over route-based navigation [3, 20, 26]. Comparison across gender pairings therefore has the potential to capture considerable variation in spatial performance and strategy and in social interaction and role-taking. Scores on the SBSOD measure and the BFI measures of personality, grouped by gender, are shown above in Table 1. Dyads were fairly evenly distributed between female-female ($N = 15$), and female-male (N

= 13) pairs. Unfortunately, we had very few male-male ($N = 2$) pairs, typical for the gender breakdown in our subject pool.

3.4 Materials

Test Neighborhood. The study site is a residential suburban neighborhood approximately 2.5 km from campus (see Figure 1). Although there is public access, the neighborhood has only two entrances (to the north and west) and a number of traffic control measures (lower speeds and speed bumps), so it is not conducive to through-traffic. The layout is complex enough to pose a moderate level of wayfinding challenge, with a mostly circular street structure, smaller streets and cul-de-sacs branching off of the main access, and a central open space with interior footpaths. There is little elevation change throughout, so no locations provide visual access to the entire layout. This suburban neighborhood differs from a typical urban environment in that it has minimal visual differentiation in the form of landmarks and no regular street grid pattern. It differs from a more rural environment in that there are no long-distance vistas available within the neighborhood. We recognize that our results may be limited to this type of environment, leaving room to expand this line of research to a variety of environmental forms.

We selected a neighborhood that our pool of participants would likely be unfamiliar with, to ensure no advantage on the task based on prior knowledge. At the beginning of the study session, participants rated their prior familiarity with this neighborhood while looking at an overview map of the larger region. All participants included in the study rated their prior familiarity with the test neighborhood as either "very unfamiliar" or "unfamiliar," which meant that most had never previously been inside the neighborhood; those that had were further questioned to ensure this knowledge was minimal.

Map for Route Task. The planning phase involved a paper map of the study area, which is shown scaled-down in Figure 1. We created this map by selecting a custom area using the InkAtlas tool[1] from OpenStreetMap[2] base map data, including street, footpath, bike path, and building features, and editing it in Adobe Illustrator to include task instructions, a map key, and origin and destination locations for the task.

3.5 Procedure

The individual spatial ability and personality measures described above were administered using an online or pen-and-paper based questionnaire at sign-up. The main data on route planning and navigation were collected in-person as follows:

Prospective Planning. The two members of a dyad met independently at the lab. They were told they would work together to plan a shortest-path pedestrian route between a given origin and destination in a neighborhood near campus, and that afterwards, they would be taken to the neighborhood to walk their route. They were given the paper map shown in Figure 1 with the start and destination locations clearly marked. Participants were instructed to remember their planned route, as they would not have use of the map itself during their walk. Each dyad was given 10′ (10 minutes) to complete the task, including both deciding upon their route and committing it to memory. We video-recorded dyads' interaction during the planning process.

[1] https://inkatlas.com
[2] Map data copyrighted OpenStreetMap contributors and available from https://www.openstreetmap.org

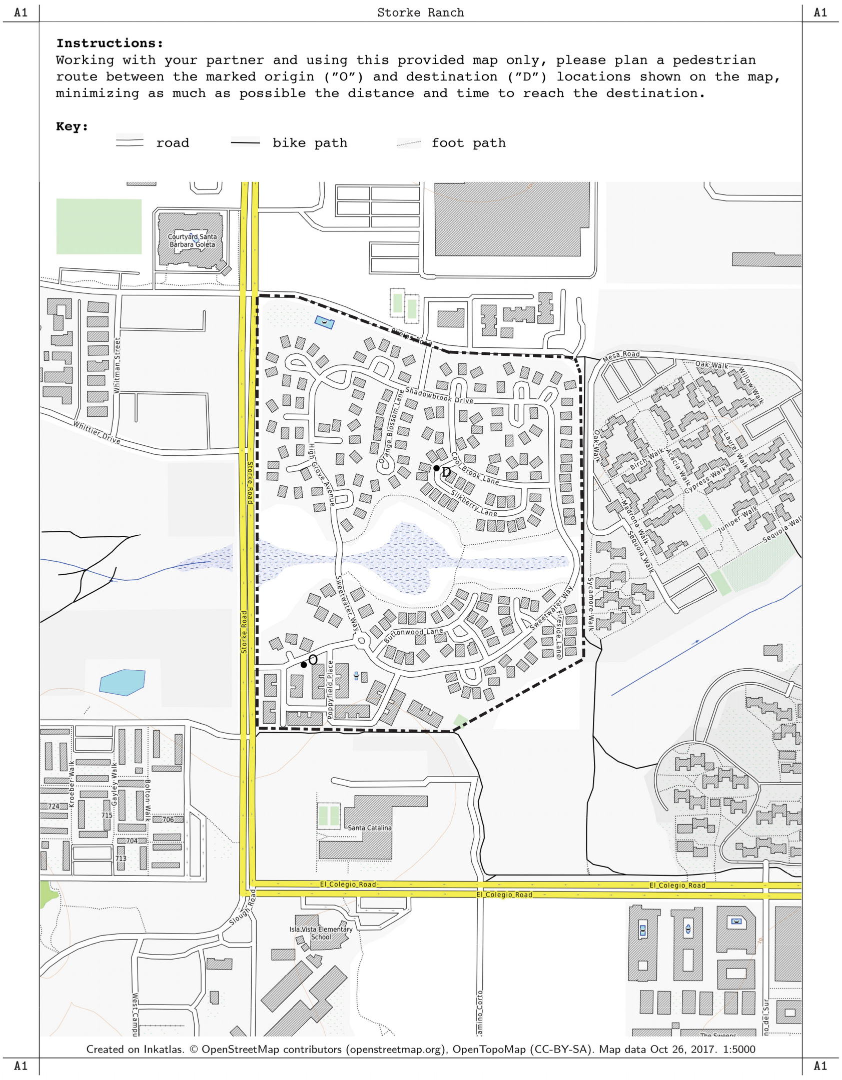

Figure 1 Map for planning with task instructions, marked origin and destination points, and key. The dashed line (not present on maps shown to dyads) shows the extent of the test neighborhood.

After planning, each member was separately asked to produce a drawing of the route ("route sketch") on a copy of the same base map and verbally describe the route they had planned with their partner. This was video-recorded for comparison within each pair (level of agreement within the dyad) and with the route as enacted by the dyad in the next phase (prospective versus situated navigation). Once the pair completed these route sketch and verbal description tasks, they were driven by the researcher to the start location for the situated navigation.

Situated Navigation. The navigation phase took place immediately following the planning phase, at the route origin in the study neighborhood. Dyads were instructed to work with their partner to walk to the destination, minimizing the time and distance to reach the destination as best they could. Importantly, they were told they did not have to take the same route as planned in the first phase. Each participant wore a chest-mounted video camera (GoPro Hero 3+, a lightweight camera typically used for action sports) that recorded their speech, some of their hand gestures, and their approximate views. The researcher additionally observed, GPS-tracked, and video-recorded dyads using a handheld camcorder, but did not assist the dyads in any way to wayfind (i.e., gave no advice).

This phase of the study stopped either when the dyad reached and identified the destination successfully, unsuccessfully identified the destination point on three attempts (went to the wrong destination), or exceeded the maximum time allotted (30′). We counted as an attempt when both members of the dyad identified to the researcher that they believed they were standing at the destination. The researcher then reported whether they had correctly identified the destination, and if not, how many attempts they had remaining. After this phase, the researcher walked the participants to a nearby location within the study neighborhood to individually complete a follow-up questionnaire noting their leadership, following, or collaboration during the task; any deviations from the planned route; and any other unexpected occurrences during navigation.

4 Results and Discussion

We present overall task success for the dyads in the navigation task, relating navigational performance to difference measures for personality and spatial ability. Next, we summarize the effects of route selection and dyads' correspondence between their planned and enacted routes. We then look more closely at the enactment of leadership within dyads, and examine a specific case of dealing with uncertainty during decision-making.

4.1 Navigational Performance

We use both time and distance as a measure of navigational performance on this task, as dyads were asked to minimize both when navigating to the destination location. Time was highly correlated with distance traveled, $r = .94$, $p < .001$, for all dyads. Generally, those dyads who took more time in navigation were those who walked further, but this is not a perfect correlation due to slight differences in time spent pausing and in walking speed. Our initial measure of success was whether dyads navigated correctly to the destination location within three attempts and 30 minutes (30′). However, only one dyad failed to reach the destination within three attempts, and even they made all 3 attempts within 30′. This means 29 of 30 dyads reached the destination within three attempts. Of those who eventually found the destination, 26 dyads (87%) correctly reached and identified the destination on their *first* attempt.

Given the high eventual success rate, we distinguish the dyads who correctly reached the destination on the first attempt as "successful" and those who did not (including the dyad that never succeeded) as "failed." All 4 failed dyads were female-female pairs. The average navigation time by the successful dyads ($N = 26$) was 9′ 48″ ($SD = 4'\ 05''$), the shortest lasting 5′ 10″ and the longest 22′ 55″. In contrast, the failed dyads ($N = 4$) took on average 22′ 28″ total, but averaged 14′ 06″ to their first (incorrect) attempt.[3] Successful dyads also traveled a shorter distance during navigation, averaging only 0.93 km, as compared to failed dyads, who averaged 1.28 km to their first attempt.

Though each dyad was allowed 10 minutes for planning prior to navigation, none required the entire time. The average planning time across all dyads was only 3′ 25″, and time for

[3] Subsequent comparisons involving time or distance traveled are based on time or distance to the first attempted destination, whether it was correct or incorrect.

planning ranged from 1′ 15″ to 7′ 40″. Successful dyads planned for longer (average of 3′ 32″) than did dyads who failed (2′ 41″). Of course, a sample size of 4 is too small for meaningful significance tests, but it is still suggestive to note that failed dyads took 4′ 18″ longer and walked 0.35 km further to reach their first attempted destination than did successful dyads, though successful dyads spent 51″ longer to plan.

4.2 Individual Differences

To assess sense of direction and personality for each dyad, we compared SBSOD scores and BFI scores on each dimension with navigational success using both the averages of members' individual scores and the differences between them (see Table 2 below). Again, for distance and time measures we use the distance and time to dyads' first attempt during navigation. We also report personality factors averaged from BFI scores for each dyad and their relation to distance and time to the first attempted destination. We found no reliable correlations between navigational time or distance and mean SBSOD or BFI personality factors.

The direction of correlation appeared to be positive for SBSOD, meaning higher SBSOD scores (suggesting better average sense of direction) may have related to travelling longer distances and taking more time to navigate (poorer performance). Comparing successful dyads to failed dyads, we find that mean SBSOD scores for successful dyads were actually 0.6 points poorer than for failed dyads. However, we would require a larger sample to verify these interpretations. This suggests the navigational advantage of better individual sense of direction scores may not apply at the dyad level due to the influence of social interaction. For instance, differences in personality may cause a dyad to have issues reaching consensus in their navigational decisions even where each individual may have a generally good sense of direction.

Table 2 Means on SBSOD and Big Five compared with Navigational Performance.

Measures	All Members [Range]	Corr. with Distance	Corr. with Time
SBSOD	3.9 [1.6–6.6]	0.14	0.20
Extraversion	3.3 [1.5–5.0]	0.11	0.04
Agreeableness	4.0 [2.3–5.0]	-0.15	-0.13
Conscientiousness	3.6 [1.2–4.8]	0.15	0.15
Neuroticism	2.8 [1.4–4.6]	0.13	0.18
Openness	3.5 [2.1–5.0]	-0.12	-0.14

For further comparison, we assessed individual difference scores in terms of their mismatch between dyad members. We did this by calculating the absolute differences between members' scores on each measure (shown in Table 3 above). Although not quite reaching significance, dyads with greater differences in the members' SBSOD scores appeared to travel a shorter distance (r = -0.24, p = 0.19) and take less time (r = -0.29, p = 0.12) to their first attempt. This is consistent with the notion that having a member with better sense of direction helps the dyad navigate more effectively, but especially when the other member is content to accede decisions to the member with better sense of direction (suggested by work such as He et al. [11]).

For personality, we found marginally significant correlations between difference in Extraversion and navigational performance (r = 0.33, p = 0.07 for distance and r = 0.32, p = 0.09

Table 3 Difference Scores on SBSOD and Big Five compared with Navigational Performance.

Measures	All Members [Range]	Corr. with Distance	Corr. with Time
SBSOD	1.3 [0.2–3.7]	-0.24	-0.29
Extraversion	1.0 [0.1–3.5]	0.33	0.32
Agreeableness	0.6 [0.0–2.0]	0.10	0.09
Conscientiousness	0.8 [0.0–2.4]	-0.24	-0.20
Neuroticism	0.9 [0.0–2.0]	-0.06	-0.13
Openness	0.7 [0.1–1.9]	-0.14	-0.11

for time). That is, dyads with greater difference in members' Extraversion tended to travel longer and take more time navigating. We speculate that this could relate to leadership conflicts in groups with differing Extraversion; we examine leadership below. Differences in dyad members' personality scores on the other dimensions did not appear to correlate with performance. This points to our need to further investigate strategies used by dyads in planning and navigation that could contribute to success.

4.3 Adherence to Route Plans

We analyzed route plans as drawn and described by dyads and found high agreement within pairs. Most dyads ($N = 23$) agreed completely on their route plan, with each person reporting the same route as their partner in the individual descriptions of the route via the route sketches and verbal descriptions. In the 7 cases where they drew or described different routes, those routes had only a slight divergence (such as taking the first turn rather than the second onto the same street). In 3 cases, dyads prospectively planned a main route and an alternate route, and both members reported the two routes.

Figure 2 Five most popular route plans.

Figure 3 Overlay of all enacted routes.

A map displaying the five most commonly-planned routes by the dyads in this study is presented in Figure 2. These plans were compiled from the route sketches and checked against the video-recorded descriptions. Route plans not shown were minor variations on those shown, and were described by only 1 or 2 dyads in the study. Labels given to the planned routes are Route A ($N = 12$, shown in blue) which goes all the way around on the main road, Route B ($N = 7$, in green) which takes the footpath, Route C ($N = 7$, in yellow)[4] which takes the footpath and anticipates the shortcut, Route D ($N = 5$, in orange) which takes the footpath and passes by the shortcutting opportunity, and Route E ($N = 4$, in red) which plans a shortcut through a place where it is not possible.[5]

Dyads were instructed to take the best possible route to reach the destination location and not bound to follow their originally planned route. They therefore had the option of taking alternate routes or shortcuts but were not primed by the researcher to look for them. To measure the match between planned and enacted routes, we compare dyads' descriptions of routes during the planning phase with their recorded tracks of routes walked in the navigation phase. We processed minor noise in the GPS tracks by snapping the tracks to the road and path network using ArcGIS Desktop 10.6, while retaining any backtracking or significant divergence by comparing the tracks with the video recordings. In cases where the tracks were of poor quality or failed to record properly, routes were traced by hand based on the video recording only.

An overlay of all traveled paths by dyads during the navigation phase is shown in Figure 3 above. Darker colored lines represent segments that more dyads walked on; lighter colored lines are less-traveled paths. The most popular routes included the northern segment of the footpath and the main road running counter-clockwise through the neighborhood. Therefore, spatial strategies in this study appeared to sort into two main groups, those dyads taking the footpath and those following the main road.

To compare actual traveled distance to distance of the planned route, we computed a ratio of the distance of the route taken divided by the distance of the planned route:[6]

$$\textit{Distance Ratio} = \textit{Distance of Enacted Route} \;/\; \textit{Distance of Planned Route}$$

With this ratio, 0.5 represents a dyad who walked only half as far as they had planned, such as by taking a shortcut; 1.0 represents a perfect match, where the dyad walked the same distance as the planned route (though not necessarily following the same route); 2.0 represents a dyad who walked twice as far as planned; and so on. The resulting ratios ranged from 0.67 to 4.33, with an average of 1.34 ($SD = .75$); this mean is significantly longer than 1.0, $t(29) = 2.49$, $p < .01$. Dyads thus walked longer overall on the enacted route than they had planned to walk, with one walking a distance over four times as long.

From participant responses to the follow-up questionnaire, we find that many were conscious of deviation from their original plan. In half the dyads ($N = 15$), one or both members mentioned taking a different path. Their explanations attribute these deviations to a variety of causes, which we categorized as "lost", "alternate", or "shortcut". In order of declining frequency, dyads explained deviations as due to: unexpected problems (such as disorientation, turning the wrong way, or overshooting), taking a planned alternate route based on decisions during active navigation, or recognizing and taking a shortcut to the destination. Table 4 gives examples of these explanations.

Overlap between Planned and Enacted Routes. To further compare prospectively-planned routes to routes enacted during navigation, we defined route overlap using the

[4] This is the shortest possible (legal) route.
[5] Numbers do not sum to 30, as some dyads reported two alternate plans.
[6] In cases where the dyad decided on and reported more than one route option, the distances of those planned routes were averaged.

Table 4 Question was posed as "Did you and/or your partner take a path that was different from your planned route in any way? Describe if so."

Coded Explanation	Count of Dyads	Example Explanation
lost	8	"Yes, we weren't sure about a few of the turns and overshot them so we had to backtrack."
alternate	4	"We had 2 paths planned out. We found out that the plan A doesn't work, so we took the plan B."
shortcut	3	"Yes, instead of going all the way up the footpath we discovered a shortcut."

recorded routes and route plans as coded in our GIS. For each dyad, we extracted the overlapping segments between the enacted and planned routes using the ArcGIS Intersect tool. We then calculated route overlap by dividing the total distance of the overlapping segments by the distance of the route as actually walked by the dyad:[7]

$$\textit{Route Overlap} = \textit{Distance of Overlapping Segments} \,/\, \textit{Distance of Enacted Route}$$

In cases where dyads took the route they planned without any deviations, planned and enacted routes completely overlap (100%); in cases where dyads took completely different routes, overlap is 0%. In our study, percentage route overlap ranged from 100.0% to 11.9%; the average across all dyads was 69.1% (SD = 32.4%). One third of all dyads (N = 10) followed their route exactly as planned and reported with 100.0% overlap. Route overlap correlated negatively with time to first attempt, $r(28) = -0.59$, $p < .001$, and with distance to first attempt, $r(28) = -0.48$, $p < .01$, suggesting that dyads reached their first attempted destination more quickly and directly if they more closely followed their original plan. Navigational performance therefore differed not only in total time and distance of travel, but also in terms of directness (as a result of more or less adherence to route plan).

Route Selection Strategy. The particular route selected during the planning phase appears to be the strongest predictor of whether or not dyads successfully reached the destination without getting lost. The most common route choice, Route A (refer back to Figure 2), involved taking the main road counter-clockwise through the neighborhood and included the fewest number of turns. Correspondingly, the dyads who planned this route were more likely to closely follow it (N = 12, average 89.0% overlap) than were dyads who planned other routes (N = 18, average 55.8% overlap); they were also more likely to follow the route exactly without going off course (9 of 12 dyads). There were no gender differences between those who took this route versus other routes.

Review of the video recordings made during planning show that some, but not all, dyads explicitly decided to take a route with fewer turns because it was easier to remember and held less risk of getting lost. We think this points to the influence of route simplicity on navigational success. More complex routes have more turns to remember (or misremember), making them inherently more difficult to follow in a task that did not allow much opportunity to rehearse the planned route. Additionally, with more decision points to recognize, there is greater chance of travelers missing a cue in the environment while navigating *in situ*. We are

[7] Where two different routes were described by dyads after planning (such as the case above where the dyad "had 2 paths planned out"), the planned route more closely matching the enacted route was used to derive the overlapping segment.

performing more in-depth coding to characterize the nature of how different types of route plans were assessed relative to one another by dyads during planning.

4.4 Social Leadership and Decision-Making

In their follow-up questionnaire, individuals were asked (separately) to state who acted more as the navigational leader during the task. Of the 30 dyads, 18 agreed that "neither was clearly leading more," 5 agreed that "one was leading more," and in the remaining 7, the two members disagreed about leadership. In the 5 dyads where one member claimed they were leading more, the partner agreed. Interestingly, in all 7 of the 'mismatch' cases, one person claimed "neither was clearly leading more" while their partner claimed that the first person was leading more. Perhaps people are hesitant to claim that they are leading more—that it is more socially acceptable to claim equal collaboration in the dyad rather than assert leadership (at least in the context of dyads whose members did not formerly know one another). This highlights a shortcoming of self-assessment; we follow this up below by coding conversational behaviors to assess leadership and following versus collaboration in navigation.

Individual and Dyad-Level Differences. At the dyad level, Conscientiousness significantly differed between the 12 groups with a stated leader and those 18 without ($t(17) = 2.17$, $p < .05$). Those dyads with a self-reported leader/follower dynamic had an overall lower score (0.4 less) on Conscientiousness than those who reported a collaborative dynamic, and tended to have a larger mismatch (1.0 difference) between dyad members' Conscientiousness scores. No other individual difference measure appeared significant. We also looked at individual-level leadership scores[8] in relation to SOD and personality, and found no significant relationships.

Although Conscientiousness was significantly related to leadership at the dyad level, individual scores on Conscientiousness did not correlate with a tendency for an individual to lead. To not see effects of Extraversion and possibly SOD seems surprising, since we expect these differences to relate to the emergence of a leader within a group; for instance, Judge et al. [19] showed Extraversion to significantly relate to leadership. The adoption of leadership roles is likely to be context-specific: navigational leadership may be more likely to express itself in a larger group, where there is more potential advantage to having a strong leader and potentially cumulative inefficiency in considering each members' suggestions.

Talk During Navigation. As another measure of leadership versus collaboration in navigation, we examined talk during navigation and calculated a ratio of navigationally-relevant talk between the two members of each dyad. In our exploratory assessment of the collected video-recordings, we noted that if one person made most of the wayfinding decisions, that person generally spoke more about the navigation than their partner, who affirmed or accepted their partner's suggestions. In dyads that looked to be more collaborative in their decision-making, we observed that this was more of an equal exchange, with both partners discussing their available options and neither "dominating" the conversation. To quantify these observations with the transcribed video recordings of the navigation task, we summarized the total time each member contributed navigationally-relevant talk to the conversation. This provides a high-level view of comparative participation in the wayfinding, as another indicator of leadership.

[8] Scores were assigned wherein stronger reports suggesting a given member was leading corresponded with a higher score: "0" for those who reported their partner led, "1" for each if both agreed neither was leading more, and "2" for those who claimed to lead or were identified by their partner as leading.

Using all transcribed talk for each pair during navigation, we filtered out only the navigationally-relevant talk. Navigationally-relevant talk included all talk relevant to decision-making, identifying landmarks, remembering the route plan, or commentary on the current physical environment or the route. We excluded "getting to know you" talk, casual chat about interests, classwork, or weather, and anything that did not appear to contribute to wayfinding. We calculated a "talk ratio" equal to the duration of relevant talk by the partner who contributed less to the wayfinding divided by the duration of relevant talk by the partner who contributed more. This gave us values between 0 and 1 for each dyad, where values closer to 1 would describe more equal durations of relevant talk between the members, a value of 0.5 would represent a case in which one member talked twice as much as their partner, and values closer to 0 would describe situations where one member dominated most of the relevant conversation. For our 30 dyads, these values averaged 0.71 and ranged from a pair in which one person talked almost four times as much about the navigation as their partner (0.28) to a pair which was virtually equal (0.97).

Talk ratios corresponded with self-reported leadership, where dyads with a clear leader averaged a talk ratio of 0.65 and those who did not report a clear leader averaged 0.76. These means were significantly different, $t(21) = 2.1$, $p < .05$, meaning those who did not report leadership within the dyad did indeed have more equal durations of relevant talk than those with a reported leader. Especially in dyads with less collaborative talk ratios, the reported leader was consistently the one who talked at greater length over the entire task, with most navigation talk consisting of directives by the leader and often simple clarifications or affirmations by the follower. See Appendix A, Examples 1 and 2, for two short excerpts from dyads with a low talk ratio that demonstrate this. This suggests either that navigational leadership in a dyad is indeed associated with a less equal ratio of relevant talk, or that a less collaborative talk ratio gives the impression of leadership even where there is none.

Uncertainty in Decision-Making. As an example of the detailed analysis of interaction we are undertaking, we share the case of one "failed" dyad who took three attempts to reach the correct destination point. This pair (Dyad 2) was made up of two female participants with similar SOD and personality scores. They planned to take Route B (0.9 km long), but ended up walking more than twice what they had planned (1.9 km). The dyad traveled for 19′ 35″ to reach what they first thought was their destination, and traveled a total of 23′ 45″ to finally reach the correct destination.

Dyad 2 encountered trouble throughout the task, not only with remembering the route plan but also in managing their en-route decision-making. Though one member (A) reported afterward that her partner was leading, neither displayed strong leadership during navigation. The ratio of relevant talk between the two members was close to equal over the entire navigation (0.84), and from the coded video recordings it appears that neither person was predominantly leading. The decision-making in the dyad was mostly collaborative, where each attempted to establish consensus with her partner before proceeding. The following excerpt portion demonstrates, however, that this was often difficult (see explanations of coding symbols and the entire excerpt in Appendix A, Example 3):

```
01 B: we were supposed to make a le-
02 A: LEFT, huh? a LE^FT? [wait (.) THA^T way?]
03 B:                      [that's why I said through the-] through the-
04    that's why I SAID I was like, through the THI^NG (0.1)
05 A: HH.h are you SU^RE?
06 B: NO I dunno^ ((shields eyes, looks in same direction as partner))
07 A: NO we go... ((turns, brings hands together)) kay on the map it was...
```

Only three minutes in, the dyad is already off course and disoriented. Revisiting what went wrong (line 1), B suggests they should have gone left instead of right to find the footpath. When A questions B further (line 5) with "Are you sure?" her partner backs down with "No, I don't know," and they proceed to review their ongoing navigation from the beginning (line 7, continued in Appendix A, Example 3). After further review of their plan using the available communicative resources of speech, gesture, and body positioning, B shows impatience with their inability to figure out what went wrong. B interrupts with "All right, let's just see, whatever. We'll just go through the streets," (lines 51–52) and begins to walk away. This prompts A to follow along even while asking, "Well, what are the pathways supposed to look like?", something B would have no reason to know any better than her. Much later (not included in the excerpt), B attempts to use a stick to draw their plan in the soil; however, this is quickly abandoned as it does not appear to aid in mutual understanding.

This dyad's attempt to work collaboratively during navigation was handicapped by a 'divide and conquer' strategy for memorizing their route and by studying only the streets relevant to their plan. During planning, they focused exclusively on two street names that cued important turns on their route. When they encountered trouble committing both names to memory, they decided each person would focus on only one of the street names. Once in the actual environment, the dyad struggled with correspondence between their plan and those unstudied options. The dyad demonstrated uncertainty throughout the entire task and explicitly stated this in the follow-up questionnaire. One stated, "Most of the navigation I felt lost, at one point I knew for sure we were on the right path, but then [became] confused when I didn't see the way we planned to take." They also acknowledged disagreement at several points during the task, which is corroborated in the analysis of their decision-making. Our detailed example suggests that disagreement and miscommunication between dyad members presents a source of uncertainty and suboptimal navigational performance.

5 Summary and Conclusions

Our study makes a contribution to the empirical evaluation of wayfinding by explicitly considering social interaction. We present a comprehensive account of dyads working together to plan a navigational route through a new environment, then working together within a situated context to enact the planned (and sometimes misremembered) route. This scenario exemplifies *strong synchronous* social wayfinding in the framework by Dalton et al. [5], as dyad members directly interact with one another to make wayfinding decisions and accompany one another during the task in real time. This is one of the few empirical studies to date that has done so; others that have looked at strong synchronous wayfinding have generally used remote methods of communication [11, 28]. As stated above, there exists a body of work that looks at situations of asynchronous wayfinding (such as providing route directions [6]), but we also believe complementary work that would support this research agenda would focus on weak wayfinding scenarios, in which people follow social cues indirectly provided by others.

In our results, navigational performance did not seem to relate to gender pairings within dyads, though we recognize that the small number of male-male pairs in this study is a shortcoming. We do believe that future studies focused on comparing different gender pairings would make a valuable addition to the literature. Performance also did not relate much to the average sense of direction or personality scores of the dyads, suggesting more in-depth interactional analysis is necessary to determine the social contributions to successfully wayfinding in pairs. Difference scores on sense of direction and personality measures between the dyad members showed modest and marginal relationships with performance: Dyads with greater difference in members' SBSOD navigated more quickly and for less distance, while dyads with greater difference in Extraversion navigated more slowly and for more distance.

Most dyads walked further than planned, demonstrating challenges of accurately enacting a route plan *in situ*. The specific overlap between planned and enacted routes was nearly 70% and correlated strongly with time and distance walked to first attempt. In general, dyads who chose the simplest possible route to the destination were most likely to accurately walk the planned route. The cost associated with getting off-track when taking a complicated route reduced the advantage of planning a shorter route. Although selecting the simplest route to walk appeared to play a role in navigational success, dyads had various spatial and social strategies at their disposal to deal with uncertainties.

Self-reported leadership within dyads did not relate to individual Extraversion, but dyads with higher Conscientiousness did tend to work more collaboratively during navigation. However, as self-report falls short of assessing actual leadership verbalizations and other behaviors, we looked at individual members' contributions to navigation during the task as a "talk ratio" and found that navigation-related conversation was indeed more one-sided in dyads with a reported leader-follower dynamic.

However, detailed Conversation Analytic (CA) investigations into dyadic decision-making processes during navigation will help us illuminate the strategies employed in successful versus unsuccessful navigation. We plan to follow up with this in a future paper. As justification for this, we presented a detailed transcript of the interactions between the members of one dyad, suggesting that disagreements and miscommunications are an important source of uncertainty and contribute to poor navigational performance. Studying social navigation elucidates how people share knowledge in a task-oriented setting specific to wayfinding, establish social roles like leadership within groups, and deal with common challenges.

Our study focuses on dyads without prior familiarity with one another, but we acknowledge that social interactive aspects relevant to navigation may be more pronounced in familiar dyads. Ongoing work will present a similar navigational scenario but recruit dyads with existing social relationships. Whether accurate or not, existing notions about others' relevant navigational abilities should plainly influence group interaction. Established dyads are likely to have established patterns of interaction relevant to the domain of navigation and are likely to feel comfortable enacting those roles, so leadership may be more clearly expressed in such a comparison. We also plan to make a direct comparison between dyadic and individual navigators, to help elucidate differences in planning and dealing with uncertainty when one is working alone versus with others. Additionally, we will use the video-recorded interactions to produce a large collection of specific conversational actions relating to navigational leadership across dyads to form a generalizable account of how this type of leadership is enacted socially.

Our interest in studying navigation from a social interaction perspective is related to how people use and communicate spatial knowledge in a task-oriented setting, establish social roles within groups, and interact with one another to deal with common challenges such as uncertainty at decision points. The sources of potential uncertainty in wayfinding are many, and further study applying these methods will allow us to investigate how people deal with these uncertainties in direct, situated interaction. Real-world navigation is a phenomenon that occurs within social contexts, often explicitly in conjunction with other people. Our work highlights the rich nature of observing people working together towards a navigational goal.

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A Navigational Transcript Excerpts

We follow basic conventions in Conversation Analysis, adapted from the guide by Sacks et al. [29]. This guide directs coders to spell transcribed utterances in a way that attempts to directly capture speech as produced rather than as properly spelled, aligns overlapping speech between two speakers [within brackets], uses colons to indicate the prolonging of a syllable, capitalizes louder speech, surrounds softer speech with °degree symbols°, and represents upward inflections with ˆ. Gestures are described within ((double brackets)). Pauses lasting less than a tenth of a second are represented as (.); longer pauses are shown with the duration in tenths of a second in parentheses.

A.1 Dyad 24 Excerpt [03′13″-03′21″]

Example from Dyad 24, whose member A spoke 3.6 times as long about navigation than partner B (talk ratio = 0.28):

```
01 B: thi^s is...
02 A: or do you want me to che^ck like-
03 B: yeah, we can... check
04 A: yeah, we can check and then come back if we're not certain about it
```

A.2 Dyad 9 Excerpt [00′14″-00′23″]

Example from Dyad 9, whose member A spoke 2.4 times as long about navigation than partner B (talk ratio = 0.41):

```
01 B: what was the first street, Sweetwater?
02 A: ye::s:: I'm pretty sure it's this one
03 B: okay
04 A: this is the roundabout and we just go that way
05 B: okay
```

A.3 Dyad 2 Excerpt [03′06″-04′24″]

```
01 B: we were supposed to make a le-
02 A: LEFT, huh? a LE^FT? [wait (.) THA^T way?]
03 B:                     [that's why I said through the-] through the-
04    that's why I SAID I was like, through the THI^NG (0.1)
05 A: HH.h are you SU^RE?
06 B: NO I dunno^ ((shields eyes, looks in same direction as partner))
07 A: NO we go... ((turns, brings hands together)) kay on the map it was...
08 B: ((turns around to face same direction as partner)) (0.4)
09    ah.hh (0.1)
10 A: °out of° Sweetwater...
11 B: yeah Sweetwater ((turns to face same way as partner))
12    and then there was a LOOP ((draws circle with finger, points forward))
13 A: and then you go
14    [you go around the loop] ((extends left arm with right arm to elbow))
15 B: [then after you barely ] wa^lk
16    yea^h we go arou^nd the LOOP
... 28 lines removed for space considerations ...
45 A: cuz we were supposed to go a- (0.6)
46 B: NO cuz if you go through tha-
47 A: it's either we go-
48    it's either we go tha^t way ((points straight out with left arm))
49    or we come this way and we wait for the... ((holds out right arm)) (0.3)
50    no cuz we were [supposed t-    ]
51 B:                [all right let's] just g- let's just-
52    let's just see, whatever (0.2) we'll just go through the streets
53 A: well, what- what are the pathways suppo-
54    [°walking pathways supposed to look like°   ]
55 B: [that's what I'm sayin like where are the p-] (0.8) pathway
```

```
   (0.9) I don't know where the pathways were
   (2.1)
A: I think they-
   (0.5)
B: do you wanna go ba^ck?
A: Sweetwater... NO cuz if we woulda went tha^t way it woulda been another stree::t
```