"I Am Here": Investigating the Relationship Between Sense of Direction and Communication of Spatial Information

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Navigation is critical for everyday tasks but is especially important for urban search and rescue (USAR) contexts. Aside from successful navigation, individuals must also be able to effectively communicate spatial information. This study investigates how differences in spatial ability affected overall performance in a USAR task in a simulated Minecraft environment and the effectiveness of an individual's ability to communicate their location verbally. Randomly selected participants were asked to rescue as many victims as possible in three 10-minute missions. Results showed that sense of direction may not predict the ability to communicate spatial information, and that the skill of processing spatial information may be distinct from the ability to communicate spatial information to others. We discuss the implications of these findings for teaming contexts that involve both processes.

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INTRODUCTION

People perform navigational tasks every day, whether it is driving a car to the grocery store or walking to the kitchen for a snack. Navigation can be decomposed into two separate components: locomotion and wayfinding (Montello, 2001, 2005). Although locomotion is the physical sensory-motor actions that takes place during navigation, wayfinding is the process of making decisions or plans based on the individual's mental representation of the environment.

To successfully perform wayfinding, humans need to process spatial cues in the environment. Spatial cues can be considered egocentric (observer to object relationships) or allocentric (object to object relationships; Mou, McNamara, Valiquette, & Rump, 2004). People tend to prioritize egocentric spatial cues during navigation because external reference points or axes are not always available (i.e., walls of a room). The egocentric spatial representation is developed by continually perceiving, processing, and updating spatial cues in the environment (Mou et al., 2004; Wang & Spelke, 2000). Though there is a significant body of work on the mechanisms behind navigation and wayfinding, little is known about how a person's navigation ability translates to their ability to communicate spatial information verbally.

The measurement of spatial abilities can be used to predict how effective an individual is at navigational tasks. Sense of direction is an environmental subset of spatial ability, and has been measured using several methods, including recognition of scenes from a familiar environment, or pointing to obscured landmarks (Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002). Individuals can vary greatly in terms of spatial ability, so it is important to understand how differences in spatial ability translate to the ability to communicate spatial information (Hegarty et al., 2002). One such method is to use self-report measures to predict environmental spatial ability (Kozlowski & Bryant, 1977). Though these methods have been used to predict performance on general spatial cognition tasks such as pointing (Hegarty et al., 2002), they have not been used to predict the ability of an individual to communicate spatial information.

Current Study

This study investigated how individual differences in spatial ability—specifically, sense of direction—affect one's ability to communicate spatial information, and whether task training can improve communication of spatial information. It is hypothesized that: (1) participants who score higher on the sense of direction scale will communicate better than participants who score lower; (2) individual sense of direction and task training will interact such that individuals who score high in sense of direction and receive complete task training will perform better than those who score lower in sense of direction and receive less training by scoring higher; (3) participants who score higher on the sense of direction scale will provide higher quality descriptions of their location in the environment than participants who score lower in sense of direction, and; (4) sense of direction and task training will interact such that participants who score higher on the sense of direction ability and receive additional training will provide higher quality descriptions of their location in the environment; Conversely, we hypothesize that participants who score lower in the sense of direction scale and receive minimal task training will perform the worst and provide the lowest quality location descriptions.

METHOD

Participants

A total of 54 Minecraft players (40 males, 13 females, 1 declined to identify, age range 18-39, M_{age} = 21.30, SD_{age}: 3.68) were recruited from Minecraft forums, listservs, and a large southwestern university community. Participants were compensated $35 for 2.5 hours of participation. This research complied with the American Psychology Association code of ethics and was approved by the Institutional Review Board.

Design

Participants performed three simulated USAR missions in Minecraft that each took 10 minutes, at varying levels of difficulty (easy, medium, and hard; within-subjects) in a randomized order. Two types of victims for rescue were present in each mission: high-risk victims (HRVs) worth 30 points each and took 15 seconds to rescue, and low-risk victims (LRVs) worth 10 points each and took 7.5 seconds to rescue. Participants were equipped with an in-game signaling device that would display the word "beep" in the chat if there was a victim for rescue within a room: twice for HRVs, and once for LRVs.

Each participant was randomly assigned to one of the following three conditions on training knowledge: *Tradeoff and Signal, Tradeoff Only, and Neither* (between-subjects; see Table 1). Participants in the Tradeoff and Signal condition were informed of each victim's rescue times and point breakdown and were also informed about the function of the victim detection signal device. In the Tradeoff Only condition, they were informed of the point breakdown between HRVs and LRVs in addition to the rescue times. Finally, participants in the Neither condition were only told rescuing each victim could take up to 15 seconds.

Table 1. Experimental Manipulations

Training Condition	Knowledge of Rescue Times	Knowledge of Points	Knowledge of Signal
Tradeoff and Signal	Yes	Yes	Yes
Tradeoff Only	Yes	Yes	No
Neither	No	No	No

Materials

This was a virtual experiment, and the participants joined the session through video conferencing software, Zoom™ (*Zoom*, 2021) and remote video platform, Parsec™ (*Parsec*, 2021) on their personal computer. Zoom was primarily used to communicate with the participants. This included sharing links to surveys, calibrating the gaze tracking software (Baltrusaitis, Zadeh, Lim, & Morency, 2018), annotating a map of the mission building prior to the collapse, and training slides. The Minecraft (*Minecraft Java Edition*, 2020) environment was modified to implement the simulated design and record participant actions. The Minecraft environment was hosted on an experimenter's computer, which participants remotely controlled through Parsec. Events on the experimenter's computer were recorded using Zoom recordings.

The surveys given to the participants included the Satisficing portion of the Maximization Inventory (Turner, Rim, Betz, & Nygren, 2012) and the Santa Barbara Sense of Direction scale (SBSOD; Hegarty et al., 2002). Post-mission surveys also included workload, a knowledge survey to test their task knowledge, a strategy survey to identify their mission strategies, and a demographics survey. For the purposes of this study and also due to page limitations, we only considered the SBSOD measure to address the research questions and hypotheses.

The voiceover training slides instructed participants on a modified Minecraft environment and relayed the knowledge manipulations in the USAR scenario. A training trial and an in-game competency test were also developed to measure participants' basic Minecraft skills related to the task context (e.g., pressing buttons, turning on lights, moving forward, etc.)

After the voiced-over training slides, participants completed two training trials to practice mechanics and answered the incident commander's inquires (e.g., "Without searching for any information, would you describe where you are in the building?").

Mission difficulty was manipulated by altering the distribution of victims and the number and distribution of blockages (created by a roof collapse) for each map. Table 2 shows the breakdown of mission difficulty levels. Additionally, prior to each mission, participants were able to plan their route through the mission space by using the Zoom annotation tool on a static version of the building's layout. The annotated map was visible throughout the mission.

Table 2. Differences between levels of mission difficulty

	Mission Difficulty		
	Easy	Medium	Hard
Blockages	2	4	6
Wall openings	4	8	12
Victim layout by rooms	More high ROI rooms	In between	More low yield rooms, max >1 HRV per room
Victim layout by floor	HRVs close to the start point	Victims spread out	HRVs are away and behind path blockages
Occluded victims	None	2 HRVs, 1 LRV	3 LRVs, 3 HRVs

Note: HRVs = High Risk Victims, LRVs = Low Risk Victims

Measures

Santa Barbara Sense of Direction Scale (SBSOD). Individual spatial ability was measured using the SBSDO, a validated scale that measures environmental level spatial ability, or their "sense of direction" (Hegarty et al., 2002). The measure involves 15 questions about how well individuals believe they can orient themselves within their environment. It is specifically related to tasks that involve an individual having to update their location in an environment due to motion. Therefore, it is an appropriate measure for the USAR task in which the individual is moving through the virtual environment. The SBSOD was scored by reverse scoring positively worded questions and then calculating the mean across all 15 items.

Incident Commander Inquiries. To measure the communication of spatial information, responses to the incident commander inquiry to describe their current locationwere analyzed for the purposes of this study. The responses were coded by (how two raters) on a scale of one (poor) to five (good) in terms of quality, defined as the specificity level of descriptions. For example, a good quality response would mean that the participant can identify the current room and describe the specific map region they are in (i.e., the participant states that they are in the top right corner of the map). Table 3 shows examples of poor and good responses. Raters had a Cohen's Kappa of .75, indicating 75% agreement. To obtain an outcome measure, the average of the two ratings for each response was calculated.

Table 3. Example incident commander responses.

Response Quality	Examples
5 (Good)	"I'm in the men's room, which is on the right-hand side of that first horizontal hallway."
3 (Neither Poor nor Good)	"Still in the south side of the building towards the middle now."
1 (Poor)	"I don't know where I'm at."

Procedure

After joining the video call and consenting, participants filled out the pre-trial surveys on Qualtrics (SBSOD and other surveys that are not analyzed in this paper). Next, the participant's gaze vector was mapped to the screen using a 17-point calibration procedure using PsychoPy (Peirce et al., 2019). Participants were then presented with the voiced-over training slides, which covered the basics of moving, triaging victims, and interacting with doors and light switches.

Next, participants connected to the experimenter's computer and completed the Minecraft training mission. The training mission asked participants to practice rescuing victims and moving through the environment. After completing the hands-on training, participants transitioned to a competency test to check their basic Minecraft skills without any assistance. If participants were unable to finish the competency test twice, they would have been removed from the study. After the competency test, participants watched the condition-specific training video and engaged in another hands-on training that is specific to the experimental tasks.

After completing the hands-on training, participants started each mission with a 3-minute pre-mission planning, followed by the 10-minute USAR mission, and then a post-mission questionnaire on workload, task-specific knowledge, strategy, and demographics surveys. After completing the three missions and surveys, they were thanked for their time and compensated with $35.

RESULTS

Trial Score

A mixed-effects model was conducted to investigate the main effects of SBSOD score, knowledge training, and map difficulty on the overall score that participants achieved at the end of each trial. Training condition and map difficulty were both dummy coded because they are categorical variables. The overall score was calculated based on the number of low-risk victims (LRVs, 10 points each) and high-risk victims (HRVs, 50 points each) rescued during the trial. The results of the main effects model showed no significant effect of SBSOD score on overall score ($\beta = 2.82$, $p = .74$).

There was a significant main effect of training condition ($F(2,48) = 4.82$, $p = .01$) such that participants in the *Tradeoff and Signal* condition performed significantly better ($\beta = 57.00$, $p < .05$) than those in the *Neither* condition. There were no significant differences between the *Tradeoff Only* and *Neither* conditions ($\beta = 21.50$, $p = .25$).

There was also a significant main effect for map difficulty ($F(2,103) = 9.42$, $p < .001$) such that the medium difficulty map ($\beta = -34.29$, $p < .001$) and the hard difficulty map ($\beta = -27.12$, $p < .001$) both resulted in significantly lower overall scores than the easy map. Figure 1 shows the main effects of training condition. Overall, the main effects model had a marginal R^2 of .16 and a conditional R^2 value of .61. The findings of the main effects model show that participants who were given more training on key information about the mission score tended to have better higher mission scores.

The interactions between the within-(map difficulty) and between-(training condition) subject factors were also investigated using a two-level mixed-effects model, with SBSOD as a covariate. The results showed a significant two-way interaction between SBSOD score and training condition on the overall score ($F(2,31) = 5.05$, $p = .01$). Figure 2 shows that for participants who scored lower in SBSOD, those in the *Neither* condition scored significantly less points than participants who scored high SBSOD score. However, participants who scored lower SBSOD outperformed high SBSOD participants when both received the *Tradeoff Only* training. Interestingly, there were no significant differences between high and low SDSOD groups that received the tradeoff and signal training. This suggests that the knowledge training that participants received was sufficient to overcome any differences in sense of direction.

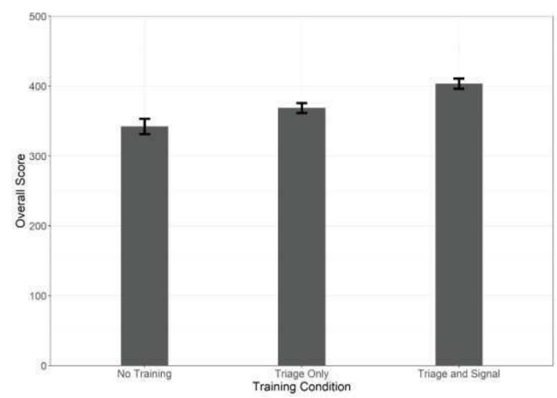

Figure 1. Main effects for training condition on the score (Vertical lines represent Standard Error -SE)

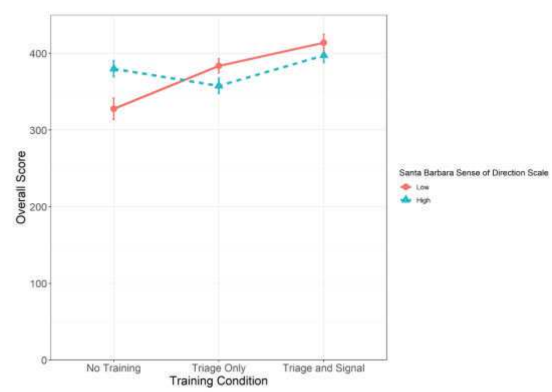

Figure 2. Two-way interaction between sense of direction and training conditions (Vertical lines represent SE).

Incident Commander Inquiry Responses

Incident commander responses were coded by two independent raters on a scale of 1 (poor) to 5 (good) in terms of quality (description specificity). In total, 486 incident commander inquiry responses were analyzed. A repeated measures mixed ANOVA was conducted to analyze the effects of training condition, map difficulty, and sense of direction on the quality of the description of the participants' response when asked to describe their location in the environment. The results showed that there was a significant main effect for knowledge training condition ($F(2, 479) = 8.95$, $p < .001$, $\eta^2 = .04$). Figure 3 shows the breakdown of the main effect. Participants in the *Neither* condition provided significantly higher quality responses ($M = 4.07$, $SD = .88$) than participants in the *Tradeoff Only* ($M = 3.73$, $SD = .95$) or *Tradeoff and Signal* ($M = 3.73$, $SD = .66$) conditions. This suggests that the level of training had a negative impact on the participants ability to describe where they were in the environment. This may be due to the participant focusing more attention on the extra information that was provided respective to their training condition. There were no significant differences between the *Tradeoff Only* and the *Tradeoff and Signal* conditions.

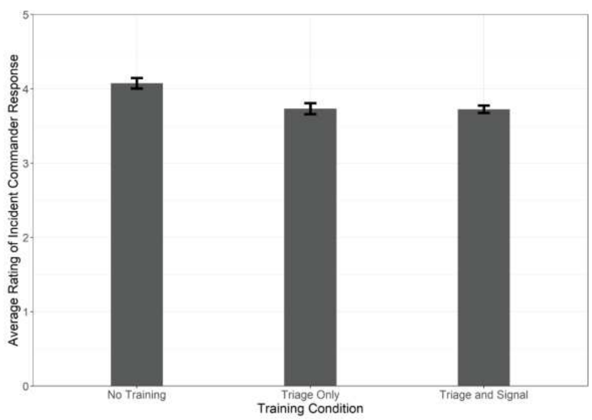

Figure 3. Main effect of training condition on quality of incident commander response (Vertical lines represent SE).

There were also significant main effects for sense of direction ($F(1, 479) = 4.70$, $p = .031$, $\eta^2 = .01$) and video game experience ($F(1, 479) = 4.86$, $p = .028$, $\eta^2 = .01$). Participants who scored lower in sense of direction ($M = 3.75$, $SD = .88$) were able to provide better descriptions of their location within the environment than participants who scored higher ($M = 3.91$, $SD = .82$). This is possibly due to those participants attempting to compensate for their poorer sense of direction by attempting to provide as many details as they could during the response, whereas participants who scored higher in sense of direction may have been more direct in their response than participants who were more experienced in video games ($M = 3.91$, $SD = .79$) tended to provide more detailed responses when asked to describe their location in the environment than less experienced participants ($M = 3.72$, $SD = .92$). This is most likely due to the requirement of video games that participants know where they are in the environment during gameplay. There were no significant interactions found between the variables.

DISCUSSION AND CONCLUSION

The purpose of this study was to investigate how individual differences in sense of direction might affect performance in a simulated search and rescue task and contribute to individuals' ability to communicate spatial information about their location in the environment. The interaction between sense of direction and task knowledge training was also investigated. The first hypothesis stated that participants who scored higher on the sense of direction would also obtain a higher score on the trials. This hypothesis was not supported. There was no significant main effect of SBSOD on the trial score. This indicates that there were other features of the task that may have increased difficulty to the point that sense of direction may not play a role. Additionally, the structure of the map itself may not have been complex enough for the participants to require the need to orient themselves to the environment. Interestingly, a significant main effect for training level supports the notion that the USAR task had other knowledge-related task features that affected performance.

The second hypothesis stated that sense of direction ability and knowledge training would interact such that participants who score higher on sense of direction and receive the most training will score the highest. This hypothesis was partially supported. For participants who received no training, those who scored higher in sense of direction performed better. However, when participants received training about tradeoff only, or tradeoff and signal, participants who scored lower in sense of direction performed better than participants who scored higher. In the tradeoff and signal training condition there were no significant differences between those who scored lower in sense of direction and those who scored higher. This is very interesting, as it suggests that in the absence of training, participants who scored higher on sense of direction may have been able to rely on their spatial abilities more, but as training increased, participants could rely on task knowledge training instead to develop a strategy. In other words, training appears to eliminate a putative baseline level of performance afforded simply by having a better sense of direction.

The third hypothesis stated that participants who score higher on sense of direction ability will also provide higher quality descriptions of their location on the map. This hypothesis was not supported. However, participants who were more experienced with video games provided higher quality responses. This suggests that a separate process is involved other than simply being able to orient oneself in the environment when verbalizing spatial locations. Many video games, especially multiplayer ones, require communication of spatial information to other team members, which means that more experienced players may have more development on this skill than others.

The fourth hypothesis stated that sense of direction ability and training would interact such that participants who scored higher on the sense of direction and had more task training would provide higher quality descriptions of the environment. This hypothesis was also not supported. This finding provides further support that there is a distinction between processing and verbalizing spatial information.

Overall, the findings suggest that the processing and communication of spatial information are most likely separate skills that require training. This has implications for improving teamwork in task contexts that have a spatial component, such as search and rescue or military operations. Interactive Team Cognition (ITC) posits that the two foundational aspects of team interaction are communication and coordination, with communication being the primary form of team cognition (Cooke, Gorman, Myers, & Duran, 2013). Understanding the mechanisms by which humans communicate spatial information may aid in developing team training interventions for tasks that necessitate it.

Limitations

We recognize some limitations of this study. One is that spatial ability was measured using a single self-report measure. Spatial ability has been shown to be a unitary construct that is comprised of multiple components (Malanchini et al., 2020). Using a battery of spatial abilities measures would provide a more granular inspection of what spatial skills may actually be involved. Applying the same nuance to the evaluation of spatial information communication qualities may also help more specifically identify which qualities thereof are affected by training and prior experience. Individual differences in verbal skills are also likely to be related to the qualities of communicated spatial information; stronger conclusions about the ostensibly different processes involved in the processing and communication of spatial information may have been possible had these been accounted for in this study.

Another limitation is that this study uses individuals in isolation instead of a team; thus, further studies are needed to confirm whether our findings hold in team task contexts, particularly those that heavily involve the communication of spatial information among teammates. However, studying individuals allows for the investigation of the specific characteristics that may play a role in this process in isolation from other external factors. Finally, this study was also conducted remotely due to Covid-19. Remote studies create technical limitations that do not exist in the laboratory because of the equipment setup.

Future Directions

Future studies should investigate the communication of spatial information in a team task context, particularly in task contexts that requires updating locations to solve team tasks (Freeman, Huang, Woods, & Cauffman, 2021). Investigating how real-time spatial communication occurs in a team setting would allow for a detailed exploration of how task parameters might affect communication and how teams might adapt to differences in spatial abilities.

Conclusion

This study sought to investigate the role of spatial ability in how effectively humans can communicate spatial information during a search and rescue task. The findings suggest that to facilitate spatial information communication, it is not enough to simply emphasize spatial abilities. The processing of spatial information and the communication of spatial information are separate processes that must be trained together.

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