IAC-19-A1,1,6,x51272

Deciding on Mars: The Effects of Isolation on Autonomous Team Decision-Making

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Abstract

Long distance missions, like Mars, hinge on the ability of autonomous crews comprised of diverse experts to make high quality decisions throughout the mission. How well do analog crews perform on decision tasks involving distributed expertise? Are there mission phases where performance is particularly problematic? Does dissent within the crew improve information sharing? Five parallel space-relevant decision making tasks requiring crews to leverage distinct information to make a team decision were developed. Tasks were designed using the hidden profile paradigm. Each task presented the crew with a problem and 3 decision options. Each crewmember received some unique information and some information known by all crewmembers. In total, the crew received 29 or 30 pieces of information about each decision option. In keeping with hidden profile tasks, information was distributed to crewmembers so that a majority, if not all, of the individuals prefer the worst option. Only if the crew combined unique information can they reach the optimal decision. The preference structure of the task was validated on a crowdsourcing website participant pool (N = 3,184). The set of tasks was administered during NASA's Human Exploration Research Analog (HERA) in Campaigns 4 and 5. Six 4-person crews lived and worked in an 80-m^3 habitat for 45-day missions. Unique information sharing and decision quality were assessed on mission day (MD) -4, 6, 14, 20, and 34. Findings show crew decision making suffered in isolation and confinement. The best performing crew correctly solved 60% (3 out of 5) of the tasks, whereas the worst performing crew correctly solved only 20% (1 out of 5) of the task. The decision-making performance of the crews peaked in the second quarter of the mission with a 71% success rate and had a low of 17% on MD 34. Crew information sharing also peaked on MD 14. A manipulation to create dissent within the crew improved the amount of unique negative information shared by the crew (ruling out inferior options), but did not affect the amount of unique positive information they shared (needed to rule in superior options). These findings suggest space crews will benefit from team decision training and protocols for making team decisions that mitigate these performance decrements. The tasks developed here provide a useful way for future analog studies to evaluate the efficacy of training and protocols.
Keywords: Team performance, Team decision making, Information sharing, Isolation, Confinement, Space analog

Acronyms/Abbreviations
Human Exploration Research Analog (HERA)
Isolated and Confined Environment (ICE)
Campaign 4 (C4)
Campaign 5 (C5)
Mission Day (MD)
National Aeronautics and Space Agency (NASA)

1. Introduction

Long distance space missions, like the journey to Mars, will present future space teams with a combination of challenges not yet encountered in spaceflight. These challenges include autonomy, crew composition, and extended isolation and confinement. The distance involved in a Mars mission means the crew will have to make decisions autonomously that were previously made by large expert mission control groups on Earth. On a mission to Mars, a communication delay will slowly increase between the crew and mission control as the crew gets further from Earth. Current space crews benefit from near immediate support from Earth (live communication). However, long distance missions will present 3 to 22-minute communication delays each way. Thus future teams must be prepared to make important decisions without external support, especially in addressing unexpected events that mission control could not plan for before the start of the mission.

The second challenge is crew composition. The crew will be comprised of highly specialized crewmembers, with minimal redundancy. This ensures all requisite expertise is on board, but can make decision making more challenging. Crews may include 4-6 members, allowing little room for redundancy. Thus future crews will need to be skilled at leveraging unique perspectives to maximize the pool of information available to them in making decisions. For example, a biologist could have very different insights on how adjustments to a mission plan may impact mission success compared to that of an engineer, and an effective team decision needs to make sure to include both considerations in identifying an optimal solution.

The third challenge is the extended period of isolation and confinement. This may stifle the complex information processing required to make team decisions, and therefore, poses a barrier to decision making in space crews venturing to Mars.

The goal of this paper is to understand the quality of team decision making over time in isolated and confined teams. We studied crews of 4 spending extended time together isolated from the outside world, confined to a small space analog. Our goal was to see how decision making quality and information sharing changed over time as the crews got further in their missions. The following sections lay out the methods we used to study team decision making in terms of the task and the setting for the research. Following the methods, we go into more depth on the theory behind team decision making. We present the results from our research over the course of 6 different missions. We wrap up with a discussion of the results as well as the key conclusions drawn from the study.

2. Method

2.1 Decision Making Tasks

To assess team decision making, we developed 5 parallel space-relevant tasks based on the principles of the hidden profile paradigm [1], where crews must leverage distinct information available to individual members to uncover the best solution of 3 available options. The tasks are structured such that each individual receives a distinct information set that contains informational items both available to other team members and information unique only to that individual, without knowing which informational items are known to fellow team members. Additionally tasks include 3 types of informational items: negative, positive, and neutral. Negative items are ones that provide support why an option should not be selected, positive items provide support for selecting an option, and neutral items do not shape decision making. The informational items are distributed across members such that information sets bias individuals to preferring a suboptimal option and the best option can only be identified if teams consider each individual's unique information.

Each task includes 3 decision options, each with 29 or 30 pieces of available information. Eighteen pieces of information were given to all crewmembers, and the remaining information was distributed evenly among the crew. Negative unique information provides teams with details on why they should not select the worst overall option but the option they are most likely to prefer individually. Positive unique information provides support for the best overall option but not the most preferred individual option.

The information was distributed so that individually, each crewmember would prefer the worst option, but that if the crew put all of the information together, they would choose the best option. As a manipulation, we modified 2 of the tasks to create dissent and administered them to 4 of the 6 teams. These tasks distributed information such that each team had competing preferences, with 2 individuals preferring the worst option, 1 individual preferring the middle option, and 1 individual preferring the best option.

The preference structure was validated using Amazon's Mechanical Turk (N = 3,184), an online crowdsourcing platform. We collected this data to verify that when given a crewmember's individual information, more than 67% of individuals would choose a suboptimal option, but that when given all the crew's information, the best option was chosen more than 67% of the time.

The 5 task scenarios consist of 1) deciding which component to repair on the International Space Station, 2) identifying which of 3 approaching asteroids poses the greatest risk Earth, 3) selecting a planet to explore as potential human colony, 4) determining the most viable landing option on Mars, and 5) selecting the best candidate to include as an additional crewmember for a space team.

2.2 HERA 45-day Study

Tasks were administered to 6, 4-person crews living in the Human Exploration Research Analog (HERA) for 45 days. HERA is an 80-m^3 habitat that simulates some of the conditions expected for long-distance space exploration such as restricted access to the internet and communication with outside parties, and variable workload. Data were collected during 2 different HERA campaigns, and collected as part of a larger protocol. Crews completed 14 days of training, 45-day mission, and a 7-day post-mission period. There was a 30-second communication delay between mission control and the crew on MD 16 and 28; 1-minute delay on MD 17 and 27; 2-minute delay on MD 18 and 26, 3-minute on MD 19 and 25, and 5-minute delay on MD 20-24.

Decision making tasks were administered on MD -4, 6, 14, 20, and 34. After individuals reviewed their information sets, teams came together to discuss the task and were asked to unanimously select their preferred option. Subsequently, each individual received a list of all of the unique informational items (in addition to some distractor items as attention checks) and asked to indicate which items were included in their team's discussion. Team selections were compared to each task's correct answer to determine team decision quality. Responses to unique information items were used to capture team unique information sharing. A sharing score was computed for each unique informational item based on how many of the 4 team members correctly identified that the information had been discussed, and the items scores were aggregated for each task.

3. Theory and calculation

Study of team decision making using the hidden profile paradigm makes up a rich literature spanning more than 30 years and 100 articles [2]. Fundamental findings from this research demonstrate that a) teams fail to leverage their members unique information in making team decisions and b) teams are (8 times) less likely to identify an optimal solution when individuals possess unique information [3,4]. However, these studies are problematic in a number of ways in relation to understanding the performance of space teams. First, almost exclusively, these studies were conducted in a one-off setting. One-off evaluations of decision making fail to consider changes in team dynamics as teams work together over time, such as fluctuations in team cohesion or motivation.

A second limitation of existing work informing understanding of space teams is that almost all of this work has been studied in traditional laboratory or field settings. Environments like that of spaceflight (and corresponding simulations) present unique team challenges pertaining to isolation, confinement, and severity of performance outcomes, thus it should not be assumed that results pertaining to information sharing and decision quality found in traditional settings generalize to teams operating in extreme environments [5].

This research provides novel insights on how well autonomous analog space teams leverage distributed information to make team decisions. Additionally, this study captures how the decision making of these spaced teams evolve as they work together over multiple decision making episodes.

4. Results

Figure **1** shows that crew decision making in isolation and confinement presents a difficult challenge. Two crews tied for best performance, but were only able to correctly solve 60% of the tasks. The remaining crews were able to select the correct option at a rate between 20% (1 team) and 40% (3 teams). These findings show that on average, analogous space teams identify the best option to a decision making task less than 45% of the time.

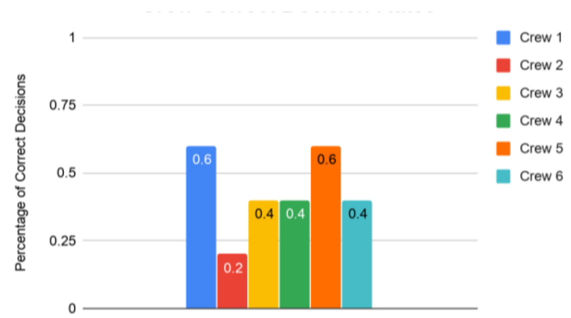

Figure 1. Decision accuracy by crew.

Figure **2** shows that team decision making quality changes over time. Crew decision making peaked on MD 14 with 83% (5 out of 6) of crews selecting the best option. However, after this peak there was a decrease over time. Decision making accuracy decreased after MD 14 and then on MD 34 had only a 17% (1 out of 6 crews) success rate, which was lower than MD -4 pre-isolation baseline scores.

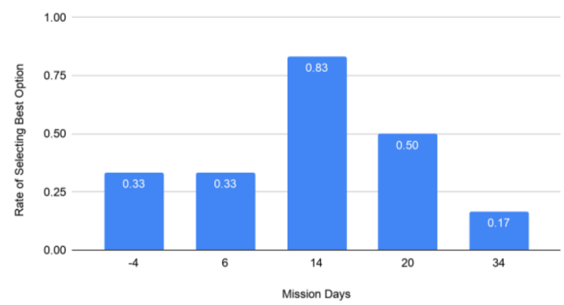

Figure 2. Decision accuracy by mission day.

Figures **3** shows that total unique information sharing followed a similar trend to decision making quality. Total information sharing peaked on MD 14, with 4 of 6 teams reaching their highest information sharing rate at this time point. 5 out of the 6 teams that completed a task on MD 34 showed a decrease in information sharing relative to the preceding time point.

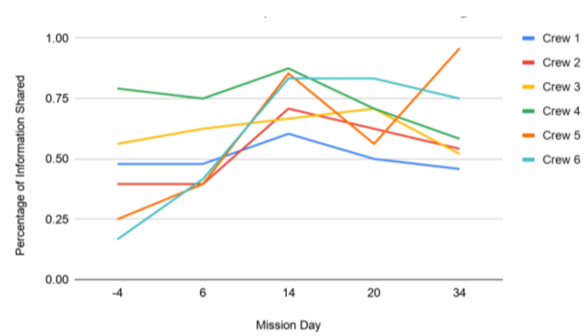

Figure 3. Percentage of total unique information shared by mission day.

Figures **4** and **5** display negative and positive unique information sharing by crews over time, respectively. These figures show that both positive and negative unique information sharing peaked on MD 14. Comparing Figures 4 and 5 suggests that crews share more negative than positive information, with 3 instances of teams sharing all negative information while one such instance of good information. Further, examination of negative to positive unique information sharing across all crews and tasks found that negative information is shared at nearly a 10% higher rate than that of positive information (64% to 56%, respectively).

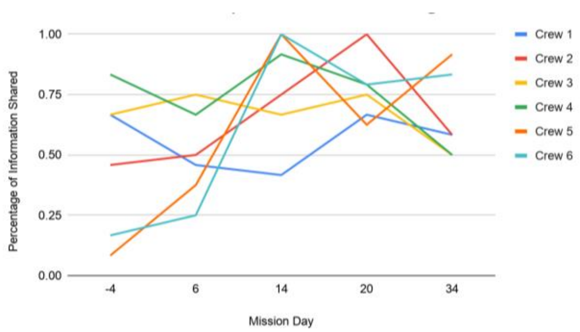

Figure **4.** Percentage of negative unique information shared by mission day.

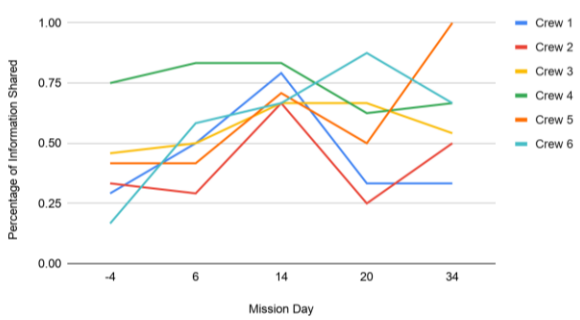

Figure **5**. Percentage of positive unique information shared by mission day.

A manipulation to create dissent within the crew improved the amount of unique negative information shared by the crew (ruling out inferior options), but did not affect the amount of unique positive information they shared (needed to rule in superior options). See Figure **6**. This manipulation also found that teams are 40% less likely to reach the correct decision when team members have differing initial preferences. See Figure **7**.

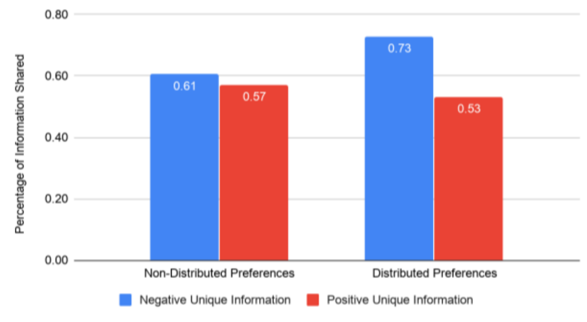

Figure **6**. Percentage of unique information shared by dissent condition.

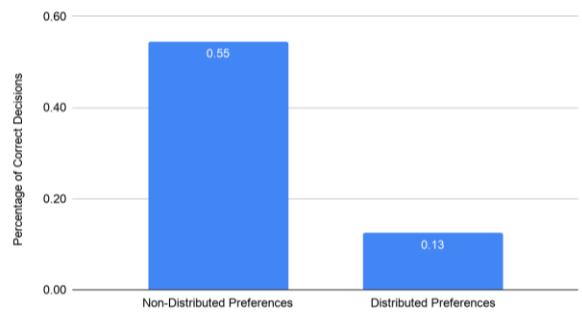

Figure **7**. Decision accuracy by dissent condition.

5. Discussion

The findings of this study suggest that crews may have difficulty making high quality decisions over time, particularly when the decision requires integration of unique perspectives. Crews in our study identified the best answer on less than 45% on their tasks. The trajectory of team decision making from the first task to the third suggests that there may be a practice effect with the team improving as they have the opportunity to make more decisions. However, the results also suggest that performance ultimately declines over time in isolation. Given the initial practice effect, training is likely a means for accelerating effective decision-making in isolation.

This study suggests that information sharing may be an effective focus for decision making. Our results indicated that the highest levels of information sharing corresponded with the highest rates of correct decisions (i.e., MD 14), which is in line with existing research on the importance of information sharing in making quality decisions [3]. Further, decision making training for space crews could emphasize that teams are likely to be biased in the type of information they share. Existing meta-analyses have found that teams share more common (information known to all team members) than unique information (information known by only 1 team member) [3,4]. This study found that teams share more negative than positive information, when sharing unique information. The tasks in the study contain only positive unique information about an option that majority of team members do not prefer individually (i.e., a fact that supports a preference that most, if not all, individuals did not prefer) and only negative unique information about the option most preferred by individuals (i.e., a negative fact about a preference most or all individuals initially prefer). This means that team members are sharing their unique information, but more so when that information helps eliminate a choice. Teams are not as likely to share unique information when that information helps support choosing an option. Therefore, any training aimed at improving information sharing needs to address this bias.

Findings in the differences between distributed and nondistributed conditions are intriguing in that the results were mixed. Teams who enter the team decision making phase with dissenting opinions share more unique negative information than teams in agreement. This suggests that individuals are more likely to dismiss their teammates' suggestions when they have different opinions, perhaps suggesting a more competitive discussion dynamic. However, dissenting teams show no difference from teams in agreement in the amount of unique positive information shared, which suggests that teams may be pointing out the faults of the options of others without much consideration of the merits for each option. Finally, in the end, dissenting teams were less likely than other teams to identify the best option. Perhaps coming in with opposing opinions fostered a more competitive conversation leading to less objective consideration of the facts. However, these findings merit further examination of decision making in space teams that may explain these findings

Lastly, this study found evidence of a decrease in performance during the third quarter of the mission, with teams showing declines in both decision quality and information sharing on MD 34 (see Figures 2 and 3, respectively). The affective, cognitive, and social toll (e.g., third quarter effect) of prolonged isolation and confinement may shape decision making; countermeasures should be put in place to address this decrements in decision making.

6. Conclusions

Long distance spaceflight will push future space teams to a new frontier of autonomy and high stakes decision making. This study contributes novel insights about what happens to team decision making over time in isolated and confined environments, with evidence of teams struggling to identify optimal solutions, focusing on the sharing of negative information, and experiencing decreases in performance in the third quarter of their missions. These findings provide direction into the type of training and interventions future space teams should receive to ensure mission success. Additionally, this study introduces 5 space themed decision making tasks that can be used to both train and evaluate future space teams.

Acknowledgements

This research is based upon work supported by NASA under awards NNX16AQ48G (PI = Bell), NNX15AM32G (PI = Contractor), and 80NSSC18K0221 (PI = DeChurch). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Aeronautics and Space Administration, or any other organization associated with the project.

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