

Analog Astronaut Self-Scheduling in NASA's HERA Campaign 7

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Future deep space missions necessitate greater crew autonomy, including self-scheduling, a capability not available in current spaceflight operations. Within NASA's Human Exploration Research Analog (HERA), we researched self-scheduling as a novel concept of operations. Prior HERA Campaign 6 results showed a trend suggesting software visualization countermeasures might improve self-scheduling performance. Therefore, this study aimed to evaluate the impact of "No-Go Zones" countermeasures within Playbook (an interactive scheduling tool) on analog astronaut crews' self-scheduling performance and perceived workload during HERA Campaign 7. Performance was assessed via time on task, number of activity movements, and number of violations, while workload was measured using the NASA-TLX. Unexpectedly, the results indicated that the presence of countermeasures was associated with significantly poorer performance: increased time on task, more activity movements, and more violations. No significant impact on workload was observed. A learning effect was evident between scheduling sessions, and Mission Day significantly influenced all outcome measures. Our findings indicate that other operational factors more heavily influence self-scheduling performance than scheduling software and countermeasure aids.

INTRODUCTION

Motivation

Future long-duration spaceflight exploration missions will send crews beyond low-Earth orbit to distances where real-time support from Earth-based mission control centers (MCC) is no longer viable (Parisi et al., 2023). To maintain crew and mission safety and meet mission objectives, these crews will need to act more autonomously and take on some aspects of mission operations traditionally completed by mission control. These tasks, including monitoring environmental control data, commanding vehicles, and maintaining mission plans and timelines, are currently completed by experts in MCC who have trained for years in their specific role to become system/task experts. While crews cannot be expected to perform these tasks with the same level of expertise as the more than 80 personnel in MCC, they must perform many of them adequately and in a timely manner when needed.

NASA researchers have advocated for a new operations paradigm that supports future crew autonomy, providing astronauts the capability to manage their schedule (Jaap & Maxwell, 2005; Zheng et al., 2023). This new paradigm prioritizes crew autonomy, enabling crew to schedule, reschedule, and reassign spaceflight activities, a task traditionally handled by MCC. To support this aim, this paper presents our research efforts focusing on enabling analog astronaut crews to self-schedule their own timelines by developing scheduling countermeasures (i.e., user interface aids that automate some aspects of the scheduling process). In contrast to current operations where timelines are managed on the ground, self-scheduling enables astronauts to autonomously schedule their own activities independently of mission control. We evaluated crews' ability to self-schedule their own operational timeline in NASA's Human Exploration Research Analog (HERA) Campaign 7 (C7).

Background

Current mission operations onboard the International Space Station do not give astronauts the capability to self-schedule. While astronauts have some flexibility to perform a limited number of activities when preferred, they do not have any software or technology that allows them to rearrange activities in spaceflight. Our team has been studying how novice schedulers, like astronauts, conduct scheduling and rescheduling. Additionally, we have developed technologies that support self-scheduling of complex, highly-constrained timelines like those in human spaceflight.

Playbook is an interactive, web-based platform designed to facilitate crew members' visualization of their schedules and constraints, enabling effective collaboration among themselves and remote MCC personnel (Marquez et al., 2013). Playbook is the operational timeline tool deployed during HERA campaigns at NASA's Johnson Space Center (JSC). HERA is a unique habitat designed to serve as an analog for isolation, confinement, and remote conditions in space exploration scenarios. Using Playbook, analog astronauts can schedule and manage their activities directly, accommodating individual preferences and constraints.

Over the last several years, we have been evaluating self-scheduling performance in the HERA analog setting, mimicking a new operations paradigm for crew autonomy. A HERA campaign has four missions, and each mission has four unique analog crew members participating. HERA Campaign 6 (C6) was completed in 2023. In that campaign, analog crewmembers were asked to schedule one mission day using Playbook. As part of this research, we wanted to assess the impact of a visualization countermeasure that supported self-scheduling. Our analysis showed only a trend – that the presence of the countermeasure may improve self-scheduling performance (Karasinski et al., 2025). Given the limited number of participants and the promising trend, we proposed

extending our research to include a second campaign (Campaign 7).

METHOD

HERA Campaign 7

HERA C7, conducted from September 2023 to December 2024, consisted of four missions (C7M1–C7M4). We used this opportunity to assess the impact of “No-Go Zones” countermeasures in the Playbook user interface on crew performance and workload in a simulated operational environment (see Figure 1). This countermeasure grays out parts of the user interface where scheduling the currently selected activity would result in a violation and is aimed to enhance scheduling efficiency and reduce constraint violations in the operational timelines. The number of constraints and the complex set of requirements for activities are what make spaceflight timelines complicated to schedule and reschedule. Since astronauts are not expert schedulers, it was hypothesized that “No-Go Zones” countermeasures would assist in scheduling and help to resolve violations. Violations occur when participants schedule activities at a time that violates an activity’s constraints. Each activity could have one or more constraints (e.g., exercising claims the bicycle; lunch must occur between 1000 and 1400).

Our previous work in HERA C6 counterbalanced the appearance of countermeasures within the campaign (i.e., C6M1 and C6M2 did not have countermeasures, while C6M3 and C6M4 had countermeasures enabled). To counterbalance between campaigns, our HERA C7 experiment counterbalanced the countermeasures in the opposite order (i.e., C7M1 and C7M2 had countermeasures enabled, while C7M3 and C7M4 did not).

Unlike C6, the C7 crew were asked to self-schedule two days within each mission. With four analog crewmembers per mission, each assigned to self-schedule two operational Mission Days (MDs) for their entire crew, this provided 8 data points per mission, 32 data points across the entire campaign. While each operational day shared some attributes (e.g., they were weekdays, had roughly similar numbers of activities, and had the presence of activities with all the constraints listed above), they each constituted a truly unique scheduling challenge which is difficult to quantify. As this was an operational mission, we were thus limited to enabling crew to schedule these days; we were unable to control any characteristics about that day. Though these mission days were unique, they were repeated and held constant across each mission (i.e., crew in each mission self-scheduled the same days).

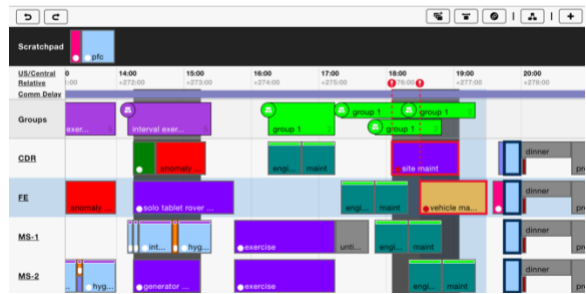


Figure 1 The Playbook interface, showing the gray “No-Go Zones” where the selected activity violates constraints.

Self-Scheduling Task

Each crew member had a list of constrained activities that they had to schedule for a particular MD. This list was found within Playbook under the Task List view; the list also contained descriptions of the constraints. Crew were also familiar with the activities since they had already performed most of them throughout the mission. The activities to be scheduled were to be assigned to all crew and occurred throughout the MD. To self-schedule, the crew selected one or more activities, which moved an activity to Playbook’s scratchpad. From the scratchpad, they could drag and drop an activity into the timeline. The timeline consists of four rows (or bands) for each crew member. Once in the timeline, activities could be rescheduled or reassigned.

Analog crew had up to 75 minutes to conduct their self-scheduling task and were not instructed to minimize their number of activity movements nor their number of violations. Guidance provided was to completely schedule the MD with the given set of activities, ensuring that no violations remained when the task was completed. Once an activity is scheduled, Playbook automatically checks if the activity’s constraints are met. In both conditions (with and without countermeasures), Playbook provided warnings to all users indicating a violation, namely a red outline and marker. For additional task and Playbook descriptions, see our previous work (Karasinski et al., 2025; Marquez et al., 2021).

Self Scheduling Metrics

In this paper, we analyze three primary scheduling performance metrics and crew workload. The three performance metrics were time on task, the number of activity movements, and the number of violations. These performance metrics were established previously (Karasinski et al., 2022; Marquez et al., 2021). Time on task was calculated by summing the scheduling time across each participant’s sessions. Occasionally, participants paused their scheduling task during the session. To account for this, pauses of greater than 5 minutes were removed from participants’ task times. Activity movements were counted by summing the total number of activity interactions (e.g., moving an activity from

the scratchpad to the timeline, moving an activity between two rows of the timeline, moving an activity within a row in the timeline) across the sessions. The number of violations was calculated by summing the number of each constraint violation created within a session. As some activities had more than one constraint, it was possible that participants could generate more than one violation simultaneously. For this analysis, we counted each individual violation of each type and did not attempt to compensate for instances where multiple violations were created simultaneously. We hypothesized that better scheduling performance would be associated with lower task times, fewer movements, and fewer violations.

Finally, crew workload was measured using the NASA-TLX (Hart & Staveland, 1988), which crew completed immediately following each self-scheduling session. Crew rated their workload on each of the six workload subscales, then completed the fifteen pairwise comparisons. The resulting, weighted NASA-TLX was used for this analysis.

Statistical Modeling

Our primary analysis focused on evaluating the effects of the countermeasures and session on our scheduling metrics. Linear mixed-effects models were employed to examine the effects of countermeasures and session order on task time and NASA-TLX. The model included fixed effects for countermeasures (with vs. without), session order (first vs. second), and their interaction, with a random intercept for participants.

To analyze the count data of activity movements and violations, Generalized Linear Mixed Models (GLMM) with a negative binomial distribution and log link functions were employed, as our count data exhibited overdispersion. These models included fixed effects for countermeasures, session order, and their interaction. Their random effects structure included a random intercept for participants and a random slope for session order within participants, allowing the effect of session order on our count data to vary across participants.

Our secondary analysis repeated these primary analyses, instead focusing on the impact of mission day on each of our metrics. For these, task time and NASA-TLX again used linear mixed-effects models with random intercepts for participants, but this time the only fixed effects modeled were mission day (8 unique days). Similarly, the same types of GLMMs were again used, with the same random effects structure, but only including fixed effects of mission day.

RESULTS

Primary Analyses

Time on task served as our primary measure of performance (see Figure 2). An analysis of fixed effects, using

Satterthwaite's method for degrees of freedom, indicated a marginally significant main effect of countermeasures ($F(1, 14.0) = 4.003, p = .065$). There was no statistically significant main effect of session order ($F(1, 14.0) = 1.326, p = .269$), nor was the interaction significant ($F(1, 14.0) = 0.246, p = .628$). Given the non-significant interaction, subsequent comparisons focused on the main effects. These comparisons confirmed that participants spent notably more time on task when countermeasures were present (Mean Difference = 12.0 minutes, $SE = 5.99, t(14.0) = 2.00, p = .065$) compared to when they were absent. No significant difference in time on task was observed between the first and second sessions (Mean Difference = -4.81 for the second session, $SE = 4.17, t(14.0) = -1.15, p = .269$).

The number of activity movements, which tracked the participants' interactions with Playbook, was also analyzed. Likelihood ratio tests for fixed effects revealed a highly significant main effect of countermeasures ($\chi^2(1) = 25.726, p < .001$). There was also a significant main effect for session order ($\chi^2(1) = 7.209, p = .007$). The interaction effect was not statistically significant ($\chi^2(1) = 0.870, p = .351$). Post hoc comparisons, reported on the exp(B) scale, supported the main effect findings: the presence of countermeasures was associated with an approximate 27.6% increase in activity movements compared to their absence ($p < .001$). Additionally, the number of movements in the second session was approximately 10.7% lower than in the first session ($p = .007$).

The number of violations tracked the number of constraints violated by participants during the planning process (see Figure 3). Likelihood ratio tests for fixed effects indicated a significant main effect of countermeasures ($\chi^2(1) = 6.29, p = .012$). However, neither the main effect of session order ($\chi^2(1) = 5.47 \times 10^{-4}, p = .981$) nor the interaction ($\chi^2(1) = 1.79, p = .181$) was statistically significant. A post hoc comparison for the significant main effect of countermeasures confirmed that providing countermeasures was associated with an approximate 75.4% increase in the number of violations compared to when they were not provided ($p = .012$).

Finally, the NASA-TLX was used to measure the participants' overall workload. Analysis of fixed effects for these scores indicated no statistically significant main effect for countermeasures ($F(1, 14.0) = 0.275, p = .608$) or session order ($F(1, 14.0) = 2.484, p = .137$), nor the was interaction effect significant ($F(1, 14.0) = 2.462, p = .139$). Given these non-significant omnibus test results, further post hoc comparisons (with Bonferroni correction) also revealed no significant differences for any main effects or interaction.

Secondary Analyses

Following the examination of countermeasures and session order, further analyses were conducted to investigate

the influence of MD on the same outcome measures, employing similar mixed-effects modeling approaches. In these subsequent models, MD was introduced as a fixed categorical factor, with its various levels compared against a common reference day, while individual subject variability continued to be accounted for using random intercepts.

For task time, the analysis of fixed effects for MD, using Satterthwaite's method for degrees of freedom, revealed a significant overall effect ($F(7, 15.7) = 3.80, p = .013$). Regarding activity movements, likelihood ratio tests for the fixed effects of MD also indicated a highly significant overall influence ($\chi^2(7) = 28.3, p < .001$). Similarly, MD was found to have a highly significant main effect on the number of violations ($\chi^2(7) = 29.2, p < .001$). Finally, for the NASA-TLX scores, the analysis of fixed effects for MD showed a significant overall effect ($F(7, 24.0) = 2.83, p = .027$).

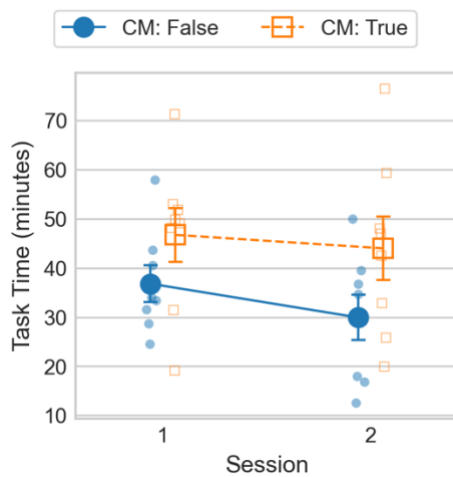


Figure 2 Task time for participants with and without countermeasures (CM).

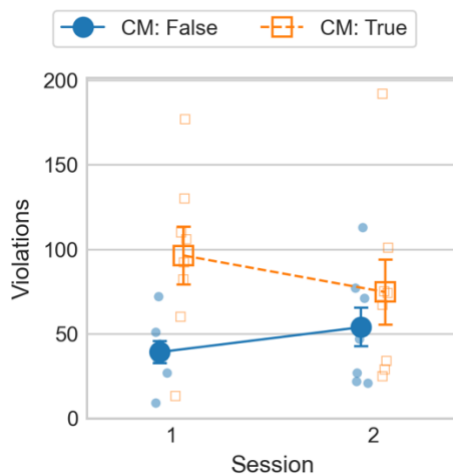


Figure 3 The number of violations for participants with and without countermeasures (CM).

DISCUSSION

We hypothesized the countermeasure visualization would facilitate self-scheduling. Our research in HERA C7 indicates that the presence of a countermeasure aid resulted in a significant reduction in self-scheduling performance, which is counter to what we had expected based on HERA C6 results. We were able to detect a learning effect between sessions, suggesting that the more experience the crew gained with doing self-scheduling, the better they were at it. Interestingly, we could not detect a difference in workload due to the countermeasure, implying that its presence was not necessarily demanding additional mental resources, despite the decrease in performance.

The most direct interpretation of these counterintuitive results is that the “No-Go Zones” countermeasure, contrary to our hypothesis, did not ease the cognitive burden of scheduling and may have instead hindered performance. The visual aid might have encouraged a trial-and-error approach, where crew members relied on the gray zones to check for violations rather than thinking through the complex constraints beforehand. This could lead to more movements and, paradoxically, more violations as they ‘tested’ the boundaries of the system. Beyond this direct interpretation, other factors such as individual differences for self-scheduling may have an overwhelming effect on the results. Participants in C7M3 and C7M4 may have simply been better at self-scheduling. Crew were asked about their planning and scheduling experience before each HERA mission, but given the limited data, this factor is difficult to control in the analysis. Our previous work has shown that there are many factors which profoundly influence the difficulty of scheduling (Lee et al., 2021). When estimating our power analysis, we assumed a large effect due to the presence of the countermeasure. However, the largest effect in this operational setting appears to be the Mission Day. Any subtle differences due to countermeasures may not be detectable under these conditions. Finally, while everyone received the same training, C7M3 and C7M4 may have chosen to practice more in-mission. The HERA mission timeline provided many opportunities for ad hoc (or spontaneous) self-scheduling (which is an aspect of this mission that is out of our control). Since we did detect a learning effect, it may be that some crew independently chose to become better trained and prepared to conduct self-scheduling.

By presenting these analyses, this paper aims to contribute to the ongoing discussion on managing crew schedules in long-duration space missions, ensuring high performance and low workload, and enhancing the overall probability of mission success. Developing countermeasures that improve novice schedulers’ performance can help enable greater crew autonomy in future spaceflight missions and increase the likelihood of mission success.

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